MSCBOT-607

M. Sc. IV Semester

FOREST ECOLOGY

DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY

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Title	**:**	**Forest Ecology**
ISBN No.	**:**	
Copyright	**:**	**Uttarakhand Open University**
Edition	**:**	**2023**

Published By: Uttarakhand Open University, Haldwani, Nainital-263139

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UNIT-1- GENERAL ASPECTS OF FORESTS

Contents:

1.1 OBJECTIVES

After studying this module, you shall be able to:

- define terrestrial ecosystem
- learn the meaning of forest ecosystem
- describe different types of forest ecosystem
- understand the importance of forest ecosystem
- biodiversity and environmental conservation
- describe climate change due to human activities

1.2 INTRODUCTION

All terrestrial habitats are naturally quite different from aquatic habitat. The amount of water determines the habitability of a particular land mass. Besides water, the sustaining foundation of all terrestrial life is air and/or indirectly soil. Like air, soil is itself a home for vast majority of terrestrial organisms. The soil creates the necessary conditions required for the survival of all terrestrial organisms. The physical conditions such as temperature, wind, humidity and sunlight in terrestrial environments are not as uniform as in the aquatic habitat. Terrestrial ecosystems in their natural state are found in different types as forests, grasslands, semiarid areas and deserts (Figure 1.1).

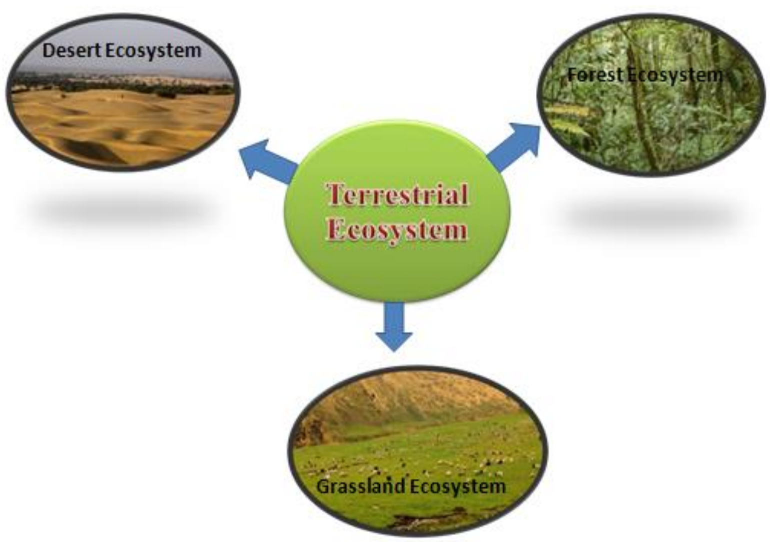

Figure.1.1: Different types of terrestrial ecosystem

Figure 1.2 explains the pattern of terrestrial biomes in relation to moisture and temperature. Where the climate varies, soil can shift the balance between types. The dashed line represents the environments in which grassland or other types dominated by woody plants may dominate.

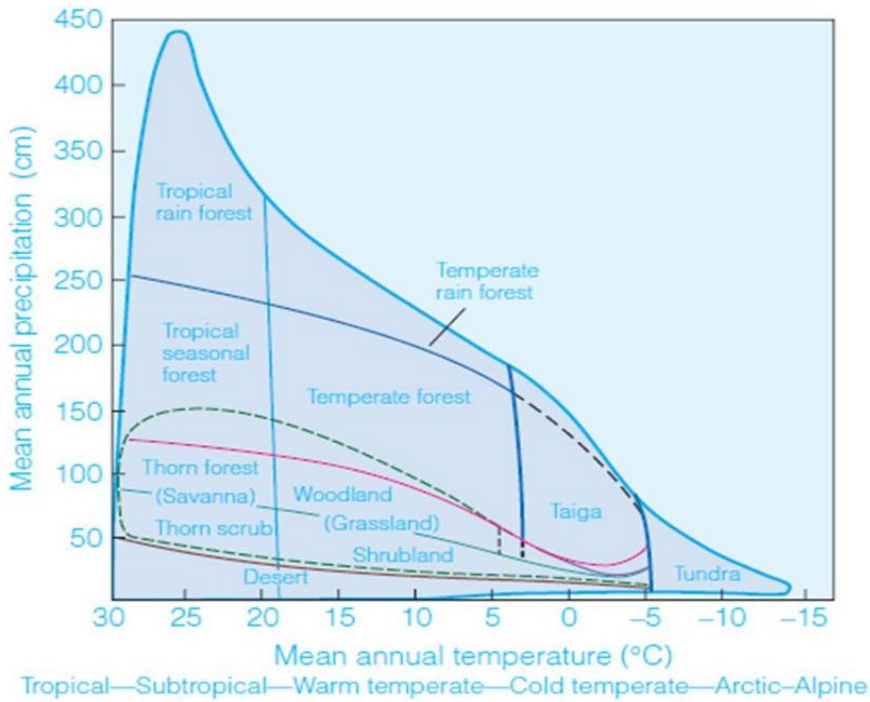

Figure 1.2: Pattern of terrestrial biomes in relation to moisture and temperature.

1.3 FOREST ECOSYSTEM

The word forest is derived from the Latin word 'foris' which means outside. It refers to the village boundary fence and includes those lands which are uncultivated and uninhabitated for humans. The forest ecosystem includes a complex assemblage of different kinds of biotic communities. The nature of soil, climate and local topography determine the distribution of trees and their abundance or sparseness in the forest vegetation. Forests may be evergreen or deciduous. They are distinguished on the basis of leaf into broad-leafed or needle leafed coniferous forests in the case of temperate areas. Characteristics of different types of forests are described below.

Coniferous forest:

These forests are found in cold regions around Northern Hemisphere with long winters and very short summer which restrict the growing season to few months. These forests are characterized by evergreen forests such as Spruce (*Picea glauca*), pine trees (*Pinus resinosal* and *Pinus strobus*) (Figure 1.3), fir (*Abies balsamea*) and having needle shaped leaves which is transcontinental.

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*Figure **1.**3: White pine trees.*

At higher altitude in the Rocky Mountains, Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are dominating species. The largest area of vegetation on Earth is formed by the boreal forest, or taiga (Russian term means "land of little sticks"). It is situated at high latitudes of the Northern Hemisphere where cold edge of the climatic range that can support forest and occupy 11% of Earth‟s land. The forest is present at the point where climatic conditions are unfavourble for deciduous or evergreen temperate forest. Here the temperature is on an average above 10^{o}C. The taiga extends in the northern part of North America and Eurasia to the south at higher elevations of mountains as subalpine forest. The taiga is formed by three zones of vegetation:

1. The forest–tundra ecotone having lichens, stunted spruce and moss
2. Open lichen woodland having lichens and black spruce
3. The boreal forest

The dominant trees are evergreen firs (*Abies balsamea*), spruce (*Picea glauca*) and larches (*Larix* spp.) or pines in most areas. In some area deciduous trees of *Populus* and *Betula* form dominant species. Species richness in these boreal forests is low. The forest is close canopied and tree reaches to an average height of 20 meters and longevity is around 200-300 years. The ground is covered by club mosses (*Lycopodium*), dwarf shrubs, true mosses and lichens. The vegetation is reduced to open pine woodlands in arid mountains and bogs or muskegs in humid community towards the timber line.

The characteristic animals are Caribou (*Rangifer tarandus*), moose (*Alces alces*), called elk in Eurasia, pine martin (*Martes americana*), snowshoe hare (*Lepus americanus*), The arboreal red squirrel (*Sciurus hudsonicus*) quill-bearing porcupine (*Erethizon dorsatum*), lynx (*Lynx canadensis*), and owls. In addition, several ecologically important insect species are also present in the forest including spruce budworm (*Choristoneura fumiferana*). The taiga also forms the nesting ground for migratory neotropical birds and also habitat of several species of birds such as crossbills (*Loxia* spp.), siskins (*Carduelis* spp.) and grosbeaks (*Coccothraustes* spp.).

In general, trees are shallow rooted with predominant ectomycorrhizal associations. Soil largely belongs to the spodosol soil order. Decomposition is very slow, as much as 60% of all carbon in an ecosystem remains locked up in humus due to cooler temperatures and the short growing season. The litter formed from conifer needle is degraded very slowly and is not very rich in nutrients. These soils are acidic and deficient in mineral nutrients due to the movement of large amounts of water through the soil without a counter upward movement of evaporation. As a result some essential soluble nutrients like nitrogen, calcium and potassium are leached beyond the contact of roots. Thus, productivity and community stability of boreal forests are lower as compare to any other biome.

***Temperate deciduous forest**:* The temperate deciduous forests are moderate climate forests characterized by moderately humid condition with a marked short period of cold season and an annual rainfall of 75-150 cm. The plants of these forests bear broad-leaves which are shed in fall season and remain bare over winter. New leaves came up in spring. These forests are characteristic of North America, Eastern Asia, Europe, Chile, some part of Australia and Japan. The temperature may drop to -30^{o}C or so in winter and maximum temperature may reach up to 38^{o}C in summer. There is no clear division of dry and wet seasons and growth period is around 4 to 6 months long. The species richness is high in these forests and shows wide range of species diversity as well.

Tree are quite tall, typically 35 meters with thin and broad leaves, although at some place trees height can be reached up to those of the tropical rain forests around 50 to 65 meters. The abundantly present genera in these forests includes basswood (*Tilia*)**,** beach (*Faqus*), oak (*Quercus*), chestnut (*Castnea*), hickory (*Carya*), and cotton wood (*Populus*). However, at certain locations, coniferous vegetation such as white pines (*Pinus strobus*), and willow (*Salix*) may become predominant. These forests are generally open which permit more light to reach the floor of the forest as compared to temperate conifer forests. The activity in the forest starts when snow melts in March-April and activity ceases in autumn with rapid leaf fall. Geophytes are first to appear when snow melts and may account for 18% of all species, which is three times of the Raunkiaer's world average.

The animal diversity is also high which includes virginia deer, bobcats, bear, gray squirrels, gray fox, and wild turkey of the original forests of North America, Europe and some of the other regions. Common invertebrates in the forest are millipede, earthworm, coleoptera, snails and orthoptera and amphibians such as frog, toad and salamander, reptiles such as snake, turtle and lizard, mammals such as mountain lion, raccoon and opossum and birds includes horned owl and hawks.

Soils of these forests are podozolic and fairly deep. Litter decay is relatively rapid and its half life is in order of one year, resulting in rapid mineral cycling. The net productivity is around 13-15 tons/ha/yr.

Temperate evergreen forest: Many parts of the world have a mediterranian type of climate which is characterized by warm and dry summers as well as cool and moist winters. These parts of the world are commonly occupied by low evergreen trees having broad leaves. In woodland, trees are usually lacking but the shrubs are dominating whose height may range up to 3-4 meters. The fire acts an important factor to adversely affect these forests. Plants are adapted in such a way that they can regenerate themselves quickly after being burnt by fire. The characteristic animals of temperate evergreen woodland chaparral are mule, deer, rabbit, wood rat, chipmunk and lizard.

Temperate rain forests: The temperate rain forests are giant forests occurring in cool climate than other rain forests, with winter rainfall and occur at higher latitudes than tropical rainforest. They exhibit a marked seasonality in temperature and rainfall. The average rainfall is high; however, heavy fog may actually represent a more important water source than rainfall itself. A belt of mixed coniferous rainforest along the Pacific coast of North America from Oregon to Alaska is a typical example. They are called rainforest not because of rainfall throughout year, but due to the fogs which provides water to leaves in dry summer.

The biotic diversity of temperate rain forests is high, however, it is much lower as compared to their warmer counterparts. The redwood (*Sequoia sempervirens*) trees in temperate rain forest of the Pacific Coast attain height of 60-90 meters, with some trees reaches upto 100 meters. The 10 genera of largest trees are found in the Pacific North Coast conifer forests: *Abies, Chamaecyparis, Larix, Calocedrus, Picea, Pinus, Pseudotsuga, Sequoia, Thuja* and *Tsuga*. The sitka spruce (*Picea sitchensis*) forest of Alaska are dwarf. Unlike the tropical rainforest, species richness is low. The aboveground standing crop averages 2000 tons/ha. Longevity is more than 500 years and may exceed 1000 years. Other temperate rain forests such as *Nothofagus* (broad leaf southern beech) of South America and southern hemisphere conifers in northern New Zealand (*Podocarpus*) are not that tall. Australian temperate rain forests of *Eucalypptus regnans* are perhaps the tallest in the world.

Temperate evergreen forests show varied structure in response to varied climates, they occupy.

Species with evergreen sclerophyll leaves (tough, relatively small and broad leaves) dominate in less humid, maritime (summer dry) climates in California, the Mediterranen region, and southern Australia. On the other hand, needle leaved evergreen forest (conifers) occupy large area in continental climates of the Western United States. The mixed forest of Sierra redwood (*Sequoia sempervirens*) with pine, fir and incense cedar (*Libocedrus decurrens*) in the Sierra Nevada, is another representative of ever green forest in the United States. In the eastern Asia, evegreen forest occur where soil conditions or fire frequency or both favour pines. In Chile, Southern Hemisphere conifers dominate temperate evergreen forests, while in Australia *Eucalyptus* prevails. In India, temperate evergreen forests are found at high altitudes in the Himalaya and are dominated by conifers. The oak forests of the Himalaya are also evergreen. The animals of temperate rainforests are similar to those of deciduous forests, but show a somewhat higher diversity.

Tropical rain forests: These forests are evergreen having broad leaf that occupies low altitude zones near the region of equator. These forests are among the highest diverse regions on the earth. These regions have high temperature, rainfall and humidity which favours rich biodiversity. Dry season in these forests are either very short or totally absent. The annual rainfall exceeds 200 cm to 225 cm (80-90 inches) and uniformly distribute throughout the year. These forests are found in South and Central America, Africa, Southeast Asia and North Australia. Largest tropical forest is found in the Western Ghat. Trees are tall which may reaches the height of 50 to 55 meters in height. The flora of the forest is more diversified having 300 different species of trees per square kilometer. The vegetation of the tropical rain forests remains vertically stratified. Trees generally form five layers:

1. Scattered, very tall emergent trees that project 50-60 meters above the general level of canopy.
2. Canopy layer, which forms a continuous evergreen carpet 25 to 35 meters tall
3. A lower tree understory stratum, 15-24 meters high, that becomes dense only where there is a break in the canopy.
4. Poorly developed shrubs and young trees in deep shade
5. A ground layer composed of tall herbs and ferns.

Many of them have buttressed roots which may reach as far as 9 meters up the trunk. Many species are similar with one another in a way that it is difficult to distinguish them. They have generally similar oval, medium sized leaves with drip tip. Three or more strata are distinguishable with large woody climbers or lianas extending from the ground to the canopy, orchids, epiphytes and stranglers are abundant. Stranglers figs are “hemi epiphytes”, which germinates on the branch of the tree, then rapidly grow down the trunk of supporting tree up to the ground and enmesh it. As the strangler fig roots thicken, they weaken the secondary growth of supporting host-tree, which is eventually strangled and killed. The canopy is concentrated with species unlike the temperate forests, where more species are present in the undergrowth. Invertebrate fauna is also very rich, striking in colour, size and adaptations for defense by mimicry and other means. Mammals and reptiles are predominantly arboreal (living in canopy) and nocturnal. Birds are present in great diversity in the upper strata of the rainforest.

Decomposition is rapid and nutrients rapidly mineralized and immediately taken up by surface root mat, having well developed mycorrhizal association. The tropical rainforests are being exploited for subsistence agriculture, timber harvest and extraction of non timber forest produce. Timber harvest is a source of valuable timber like mahogany as well as fire wood.

Elfinwoods is a tropical biome occupying the subalpine belt of mountains of Africa, South America and New Guinea. Because of high elevation, the climate is cold but because of low latitudes, seasons are not sharply distinguishable; rain, fog and clouds are constant features. Because of the latter, they are also called „cloud forest". In elfinwoods, evergreen broadleaf shrubs or small trees show a characteristic thicket like growth with contorted branches and low canopies. Branches are festooned with mosses, lichens and ferns and when dense, the hanging mosses make the stands visually and physically impenetrable. Thus overall impression is of a miniature rain forest.

Soils of tropical rainforests are red latosols and they may be very thick. The high rate of leaching process leads the soils useless for agricultural purposes. If the soil is left undisturbed, the fast cycling of nutrients within the litter layer can compensate for the natural poverty of the soil. The commonly found vertebrates are the arboreal amphibian *Rhacophorus malabaricus,* aquatic reptiles, agamid, chameleons, geckos and several species of snakes and birds and a variety of mammals. Nocturnal and arboreal habits are commonly found in many mammals eg, leopard, jungle cats, insectivores, anteaters, monkey, giant flying squirrels and sloths. Fruit and termites are stable foods for animals in the tropical rain forest. Birds are often abundant in such forests eg, fruit eating parakeets, toucans, hornbills, contingas, trogons and birds of paradise.

Tropical seasonal forests: Tropical seasonal forests are found in regions where total annual rainfall is very high but segregated into pronounced wet and dry periods. These include monsoon forests and several other forest communities, semi-evergreen or deciduous in leaf habits. They occurs in Southeast Asia, India, South of Amazon basin in South America, Africa, on both side of equator, Northern Australia and West Indies. The wet tropical seasonal forests are generally known as monsoon forests. The annual precipitation in these forests may be several times higher than that of the tropical rain forests. Teak is a major large tree in the tropical seasonal forests of India (central India) and south East Asia. Bamboo is also an important climax shrub found in these areas.

The annual rainfall is generally high but majority of it occurs during a short period of the late summer, generally from mid June to mid-September in the monsoon climate eg. India and the dry season is quite long. Depending upon the moisture availability, communities may be semi-evergreen or totally leafless during the dry season. But species which shed leaves with the onset of dry season begin to leaf out and flower well before the end of summer drought. Trees are usually 30-35 m tall, but become shorter in dry climate, where forests are also reduced to open woodlands. The NPP often reaches 15-20 ton/hac/yr and standing crop 200- 500 ton/ha. In India, these forests occupy extensive areas in the Central highlands and Deccan Peninsula.

The tropical dry forests have infertile soil. The major land uses of this biome are timber harvest, grazing and agriculture. Due to overexploitation for long time and population pressure, only a fraction of the tropical dry forests have remained in their original state. Less than 2% of the dry tropical forests remain intact in Central America and are one of the most threatened ecosystems of the biosphere.

Tropical Broadleaf Woodlands and Thornlands: These are composed of small trees which replace tropical seasonal forests in area towards drier climates and towards less favourable soil conditions. Cerrado that occurs extensively in Brazil includes a range of communities from woodlands with canopy typically at 4 to 7 m height to a thicket or scrub less than 3 m tall on arid soils of low fertility. Canopy may range from a closed one to open scrub, with or without scattered trees. Leaves of trees and shrubs are large, rigid, semi-evergreen and branches are markedly twisted. They have thick fire resistant bark. Spinose plants and succulents are generally absent, but palms and leguminous trees with small leaflets are usually present. In broad terms, Cerrado occupies intermediate position between seasonal forest (in more favouable conditions) and thorn woods (less favourable conditions). Miombo, the woodlands which occur extensively in the interior southern Africa and evergreen and semi evergreen woodlands and thickets that occur in northern part of South America, the West Indies and in Southeast Asia are also representative of this ecosystem.

Thornwood occurs in tropics towards more arid climates than those of seasonal forests and broadleaf woodlands. Widespread in South America as the Brazilian „Caatinga", thorn wood also occur in areas of Myanmar, India and Thailand, Africa and Madagascar and on limestone in the West Indies and Middle America. Spiny species of *Acacia* and other genera which become leafless during the dry season are dominant and occur extensively. Succulent plants are also present and increase in proportion towards the dry limit of the biome. The physiognomy ranges from thorn woodlands approaching forest in density and structure, through more typical woodlands of smaller trees with more open canopy to dense scrub of large shrubs or shrub thickets.

1.4 IMPORTANCE OF FORESTS

For man, forests have been a source of recreation and the development of his culture and civilization. In addition to fuel wood, they are the raw materials to various industries such as pulp and paper, rayon, composite wood and other man-made fibers, furniture, matches, shuttles and various sport goods. The forests are also known to provide several other minor products eg, essential oils, resins, medicinal plants, lac and shellac, katha and catechu and tasser silk. Tropical countries have abundant timber and heartwood resources. Timber accounts for *95%* of all photosynthetic materials produced on the earth and about half of the total biomass produced by a forest. Forests have great biological importance as reservoirs of genetic diversity apart from playing an important role-in regulating earth's climate. Forests also provide habitat, food and protection to wildlife species of plants and animals against extremes of climate. It also helps in balancing carbon dioxide and oxygen concentration in the atmosphere. Forests increase the local precipitation and also improve the water holding capacity of soil, regulate water cycle. It maintains soil fertility by returning the nutrients to the soil through litter by decomposition process. Forests also check landslide, soil-erosion and reduces the intensity and frequency of flood and droughts. Forests being home of wildlife are important assets of aesthetic, touristic and cultural value to the society.

1.5 BIODIVERSITY AND ENVIRONMENTAL CONSERVATION

Biodiversity and Environmental conservation are inter allied subjects and can be treated as synonyms as the conservation of biodiversity will eventually have a positive effect on environmental conservation. Biodiversity defines the variation at the genetic, species and ecosystem level. The distribution of biodiversity is not even and is concentrated at the tropical forest and hotspots. The nature has created a balance between the biodiversity and the ecosystem that includes all form of life from aerial to land dwellers and marine life forms. This chapter is dedicated to discuss the environmental conservation aspect of biodiversity in brief and all these are discussed in detail in different modules of this paper.

1. Keystone Species: Zoologist Robert T. Paine, coined the term "keystone species". A keystone species is an organism that defines an entire ecosystem and its absence can cause an ecosystem to change or cease to exist. They have low functional redundancy, which means if a species disappear then no other species could replace them thus leaving a void in the ecological niche. Hence the ecosystem would exert a radical change and allow new invasive species to populate the habitat. Any living organism can be a keystone species and need neither enormous in size nor abundant. Nevertheless, practically most of the examples for this type have enormous influence on the food web and varies from habitat to habitat.

The expulsion of a keystone species from an ecosystem triggers a set of negative changes. One such example is the overpopulation of one species, which leads to disappearance of other species. A well-documented case of such a chain of events was the elimination of wolves from the Yellowstone National Park at the beginning of the last century. The negative effect on the national park’s biodiversity was so profound that authorities have taken steps to introduce this keystone predator back.

2. IUCN Categories of Threatened Species: The IUCN Red List Categories and Criteria is intentionally made as a straightforward system for classification of species who are at high risk of global extinction. The mainstream focus is to provide a direct and unbiased framework where species are broadly classified based on their extinction risk. Even though the red data gives the list of species who are at high risk they still are not the only party to provide priorities for conservational measures.

3. Critically Endangered (Cr): A taxon is considered Critically Endangered when the species is facing extreme danger of becoming extinct in the wild.

4. Endangered (En): A taxon is considered as endangered when the species is facing a very high risk of extinction in the wild.

5. Vulnerable (Vu): A taxon is said to be Vulnerable if it is facing a high risk of extinction in the wild in the near future.

6. Red Book Data: List of Threatened Flora and Fauna in India

- Sumatran Rhinoceros **(*Dicerorhinus sumatrensis*)**
- Hangul deer (***Cervus canadensis hangul***)
- Himalayan Brown or red Bear ***(Ursus arctos isabellinus)***
- Pygmy Hog (***Porcula salvania)***
- Andaman White-toothed Shrew **(*Crocidura andamanensis*)**
- Kondana Soft-furred Rat (***Millardia kondana)***
- Elvira Rat or Large Rock Rat (***Cremnomys Elvir***).
- Namdapha Flying Squirrel (***Biswamoyopterus biswasi***)
- Malabar large-spotted civet(***Viverra civettina)***
- Red panda (***Ailurus fulgens)***
- Asiatic wild dog (***Cuon alpines***).
- Wild ass ***(Equus hemionus)***
- Brow-antlered deer ***(Rucervus eldii)***
- Golden Langur (***Trachypithecus geei)***
- White-bellied Musk Deer (***Moschus leucogaster)***
- Hispid hare/ Assam rabbit (***Caprolagus hispidus)***
- Indian hog deer (***Axis porcinus)***
- Lion tailed macaque (***Macaca Silenus)***
- Tibetan antelope ***Pantholops hodgsonii)***
- Nilgiri langur (***Trachypithecus johnii)***
- Nilgiri tahr (***Nilgiritragus hylocrius)***
- Ganges river dolphin (***Platanista gangetica***) Threatened flora species are:
- Milkwort (***Polygala irregularis***)
- Bird's foot (***Lotus corniculatus***)
- Assam catkin yew (***Amentotaxus assamica)***
- Moa, skeleton, fork fern, and whisk fern (***Psilotum nudum***)
- Umbrella tree, kudai vel (Tamil) (***Acacia planifrons***)

- Indian mallow, thuthi (Tamil) and athibalaa (Sanskrit) (***Abutilon indicum***)
- Ebony tree (***Diospyros celibica***)
- Malabar lily (***Chlorophytum malabaricum***)
- Spider wort (***Belosynapsis vivipara***)
- Malayuram, Malavuram (***Pterospermum reticulatum***)
- Jeemikanda (Gujarat) (***Ceropegia odorata***)
- Musli (*Chlorophytum tuberosum*)

7. Endangered and endemic species of India: Any organism whether it is a plant, animal or an microorganism who is in prompt danger of undergoing biological extinction is called as an endangered species or threatened species. In India, it is estimated that around 450 plant species, 100 mammals and 150 birds are endangered. India's biodiversity is threatened primarily due to:

- Habitat destruction
- Degradation
- Over exploitation of resources

The RED-data book contains a list of endangered species of plants and animals that might become extinct in the near future if not protected. Some of the endangered and endemic species found in India are:

Fish

- Knife tooth sawfish (***Anoxypristis cuspidata***)
- Asian arowana (***Scleropages formosus***)
- Red line torpedo barb (***Sahyadria denisonii***)
- Golden Mahaseer (***Tor putitora***)

Birds

- Steppe Eagle (***Aquila nipalensis***)
- Great Knot (***Calidris tenuirostris***)
- Masked Finfoot (***Heliopais personatus***)
- Greater Adjutant (***Leptoptilos dubius***)
- White-bellied Blue Robin (***Myiomela albiventris***)
- Nilgiri Blue Robin (***Myiomela major***)
- White-headed Duck (***Oxyura leucocephala***)
- Green Peafowl (***Pavo muticus***)
- Narcondam hornbill (***Rhyticero***)
- Spotted Greenshank (***Tringa guttifer***)
- Banasura Laughingthrush (***Trochalopteron jerdoni***)

Reptiles

- Perrotet's Vine Snake (***Ahaetulla perroteti***)
- Three-striped Roofed Turtle (***Batagur dhongoka***)
- Green Turtle (***Chelonia mydas***)
- Indian Narrow-headed Softshell Turtle (***Chitra indica***)
- Goan Day Gecko (***Cnemaspis goaensis***)
- Wyanad Day Gecko (***Cnemaspis wynadensis*)**
- Keeled Box Turtle (***Cuora mouhotii***)
- Boulenger's Dasia (***Dasia subcaerulea***)
- Poona Skink (***Eurylepis poonaensis***)
- Inger's Mabuya (***Eutropis clivicola***)
- Yellow-headed Tortoise (***Indotestudo elongata***)
- Asian forest tortoise (***Manouria emys***)
- Indian Kangaroo Lizard (***Otocryptis beddomii***)
- Assam Roofed Turtle (***Pangshura sylhetensis***)
- Asian Giant Softshell Turtle (***Pelochelys cantorii***)
- Travancore Hills Thorntail Snake (***Platyplectrurus madurensis***)
- Travancore Earth Snake (***Rhinophis travancoricus***)
- Cochin Forest Cane Turtle (***Vijayachelys silvatica***)

Mammals

- Red panda (***Ailurus fulgens***)
- Sei whale (***Balaenoptera borealis***)
- Blue whale (***Balaenoptera musculus***)
- Fin whale (***Balaenoptera physalus***)
- Banteng (***Bos javanicus***)
- Wild water buffalo (***Bubalus arnee***)
- Hispid hare (***Caprolagus hispidus***)
- Dhole (***Cuon alpinus***)
- Indian elephant (***Elephas maximus indicus***)
- Woolly flying squirrel (***Eupetaurus cinereus***)
- Kolar leaf-nosed bat (***Hipposideros hypophyllus***)
- Lion-tailed macaque (***Macaca silenus***)
- White-bellied musk deer (***Moschus leucogaster***)
- Servant mouse (***Mus famulus***)
- Mandelli's mouse-eared bat (***Myotis sicarius***)
- Nilgiri tahr (***Nilgiritragus hylocrius***)
- Asiatic lion (***Panthera leo persica***)
- Bengal tiger (***Panthera tigris tigris***)

- Ganges river dolphin (***Platanista gangetica gangetica***)
- Gee's golden langur (***Trachypithecus geei***)
- Nicobar tree shrew (***Tupaia nicobarica***)

Man and Wildlife Conflicts

Interaction between humans and wildlife that results in negative impacts on human social, Human–wildlife conflict is defined by the World Wide Fund for Nature (WWF) as any economic or cultural life, on the conservation of wildlife populations, or on the environment The ever-growing human population, deforestation, loss of habitat and decline in prey species, injured or old animal are one of the few reasons for this arise in India. Uncontrollable encroachment into wildlife zone thus stopping the movement of wildlife is a reason behind this problem. Every year countless number of humans and animals die due to this very reason. A few cases of this conflict are:

- Leopard attack
- Tiger attack
- Elephant attack
- Bear attack

These attacks lead to animal deaths, loss of crops, loss of human life, livestock depredation and injury to wildlife, destruction of geographic land and reduction in wildlife population. This conflict can be reduced by taking measures like electric fencing agricultural land, not stepping beyond the buffer zone, and use planning and livestock protection, community-based natural resource management (CBNRM), ecotourism, growing crops which are disliked by the wildlife among etc.

A classic example is seen where red pepper is grown along with other crops which keeps elephants at bay due to the fact that elephants don’t like and avoid crops containing capsaicin.

Strategies for Conservation of Biodiversity

- Maintain flawless (viable) landscapes - the aim of this strategy is to provide protection along with priority actions such as repair historic impacts or removal of threats and improve the ecological integrity by maintaining long-term viability of the more intact (core) landscapes of the region.
- Reverse declines – here the strategy involves in bringing back the lost ecological sites so as to reinstate critical ecological processes by improving the habitat of shrubby systems and open woodland and eventually help in bringing back declining species
- Recover threatened species and ecological communities –the aim of this strategy is to fortify the perseverance of species that are on the verge of extinction in the wild thus indirectly protecting ecosystems from failing. The work here is done not at a community level but is based on individual species as each has their own unique requirements for

survival. The actions are based on implementing measures for increasing their distribution and abundance while trying to put a stop to their decline.

- Control emerging threats –the aim is to educate people of the threats that are knocking at the door before the final extinction happens. Some of the threats are climate change and the introduction of invasive species.
- The submissive adaptation to improve the elasticity of natural systems and allowing them to adapt to change can be done by various activities such as by maintaining functional areas and ensuring that there are representatives for the environments and that the associated processes for removing and minimizing existing stressors are done. Active adaptation can be done by influencing ecological processes to moderately direct the nature of adaptation by activities like restoring habitats and system dynamics. Identifying and protecting climate refugees and managing/restoring connectivity by increasing the matrix permeability and functional connectivity. Transformation can be done to fundamentally alter ecological processes in an aim to prevent irreversible changes from happening. The relevant activities would include keystone structuring of revised systems (eco-engineering and transformation) and species translocations or ex situ conservation (genetic preservation).

a). Conservation Prioritization

Spatial conservation prioritization is about identifying priority areas for biodiversity, as well as the allocation and scheduling of alternative conservation actions to inform decision-making. In other words, spatial conservation prioritization tries to answer the question of where, when, and how we act to efficiently meet conservation goals. Efficiency is an important concept, as possible conservation actions are always limited by available resources. Spatial conservation prioritization can be informative for many different types of conservation action, such as selecting locations most suitable for extending protected area network, targeting restoration and management, or designing broad scale green infrastructure.

The term “quantitative” refers to prioritization based on quantitative and spatially explicit data that describes the extent and occurrence of biodiversity features (e.g. species and habitats) and other relevant information (e.g. costs and threats). A prioritization algorithm then does the actual prioritization by ordering the planning units used according to some explicit formulation and the results are usually presented in the form of maps that describe the spatial distribution of priorities over the area of interest. Tools aimed at quantitative spatial conservation prioritization have multiple distinct advantages over non-quantitative approaches. They are able to account for the occurrence of biodiversity over potentially very broad geographical areas. For example, when working with species on local level, it is important to account for the occurrence of that species elsewhere. When designing new protected areas, it is similarly important to know what is already protected. Ecological connectivity is yet another factor that is not easy to account for in conventional planning. Expert-based and quantitative approaches are not, however, mutually exclusive. Expert input is always needed to make use of quantitative spatial conservation planning tools.

b). Biotechnological Approaches for Biodiversity Conservation

Though it is generally believed that biotechnology has adverse effects on biodiversity, but in fact biotechnology offers new means of improving biodiversity. Seed banks are the most efficient and effective method of ex-situ conservation for the majority of endangered species. In seed banks, genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another.

Tissue culture techniques are of great interest for the collection, multiplication and storage of plant germplasm (Bunn et al., 2007). Such techniques allow propagating plant material with high multiplication rates in an aseptic environment. Micro-propagation refers to in vitro mass production of whole plant from any plant part or cell. Through micro-propagation, elite clonal material can be very rapidly multiplied. DNA barcoding is a technique in which species identification is performed by using DNA sequences from a small fragment of the genome, with the aim of contributing to a wide range of ecological and conservation studies in which traditional taxonomic identification is not practical.

***Invitro* Production of Embryos**

Invitro embryo production is another way in biodiversity conservation. Methods used in the production of embryos in vitro include splitting and cloning of embryos, marker-assisted selection, sexing of embryos and transfer of new genes into an embryo. Embryo Culture and Transfer technique is used to introduce fertilized embryos into surrogate mothers. Sometimes closely related species can be used to produce the offspring of an endangered species.

Production of transgenic crops and animals is another application of biotechnology in biodiversity conservation. Transgenic crops are more likely to increase agricultural biodiversity and help maintain native biodiversity rather than to endanger it. Such crops may prove to be very useful to the farmers and can be of commercial value. However, the practical benefits and risks of the crops need to be assayed in the field and their products scrutinized. In case of animals, several lines of transgenic farm animals have been produced, but none have been commercialized. Some lines are made for the pharmaceutical industry to produce drugs in their milk. Others may show improved resistances towards certain infections. Biotechnological methods have many advantages to conventional captive breeding procedures. Since the animals need not to be moved around, less stress is experienced and the problem of space for keeping the animals is also solved since samples can be taken in the wild. Storage of genetic resources will help to preserve biodiversity and counter the effect of genetic drift on small populations. Even if an animal dies, its genes will still be available for future breeding work.

c). Biodiversity Conservation Policies and Programmes: National and International

The IUCN (International Union for Conservation of Nature),helps governments at national level by preparing national biodiversity policies, whereas it provides advice to environmental conventions such as the Convention on Biological Diversity, CITES and the Framework Convention on Climate Change in an international level. It also councils the UNESCO on natural world heritage.

There is a formally accredited permanent observer mission to the United Nations in New York. It's been stated in their website that they are the only international observer organization in the UN General Assembly with proficiency regarding issues concerning the environment, specifically biodiversity, nature conservation and sustainable natural resource use.

It has solemn relations with the Council of Europe, the Food and Agriculture Organization of the United Nations (FAO), the International Maritime Organization (IMO), the Organization of American States (OAS), the United Nations Conference on Trade and Development (UNCTAD), the United Nations Environment Programme (UNEP), the UNEP World Conservation Monitoring Centre (UNEP-WCMC), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Intellectual Property Organization (WIPO) and the World Meteorological Organization (WMO).

d). Habitat Conservation Plan

Habitat Conservation Plan (HCP) is a permit included in the application for an Incidental Take Permit that is issued under the United States Endangered Species Act (ESA) to exclusive establishments that undertake projects that could lead to an outcome of annihilation of an endangered or threatened species. It is a planning document that ensures that the anticipated take of a listed species will be minimized or mitigated by conserving the habitat upon which the species depend, thereby contributing to the recovery of the species as a whole. The environmental community and landowners take different stands on HCPs. Following are the strengths:

- Flexible to accommodate a wide range of projects that vary greatly in size and scope.
- Forces consideration of species by all parties.
- Reduced uncertainty for landowners. The weaknesses are:
- Inflexible with regards to changing knowledge relating to species and habitat.
- The "No Surprises Policy" has been highly controversial with critics arguing that it burdens the agencies, rather than landowners, with additional financial and mitigation responsibilities if unforeseen circumstances arise.
- HCPs are viewed as having weak and insufficient monitoring plans. Additionally, the parties responsible for monitoring HCPs are not regulated in a systematic manner due to private funding.
- Criticism over scientific standards and limited credible scientific data.

Agencies have interpreted the role of HCPs under section 10(a) of the ESA as a means to contribute to survival of species but not as a recovery tool. The Habitat Conservation Planning Handbook is inconsistent with this stand and states that "…contribution to recovery is often an integral product of an HCP…" and in general, conservation plans that are not consistent with recovery plan objectivess should be discourage

e). Convention on Biodiversity

The Convention on Biological Diversity (CBD) is an international agreement adopted at the Earth Summit, in Rio de Janeiro, in 1992. It has three main objectives:

- to conserve biological diversity
- to use its components in a sustainable way
- to share fairly and equitably the benefits arising from the use of genetic resources.

The CBD was negotiated under the guidance of the United Nations and was signed by more than 150 government leaders at the Rio Earth Summit (whose official denomination is the '**United Nations Conference on Environment and Development**'). The Convention is now one of the most widely ratified international treaties on environmental issues, with 194-member countries. Unlike other international agreements that set compulsory targets and obligations,
the CBD takes a flexible approach to implement rules and regulations. It identifies general goals and policies, and countries are free to determine how they want to implement them.

One of the CBD's greatest achievements so far has been to generate an enormous amount of interest in biodiversity which is a critically important environment and developmental issue, both in developed and developing countries.

1.6 CLIMATE CHANGE: VIEWS OF SCIENTIFIC COMMUNITY

In the beginning, people were not in favour of accepting the idea that the climate change is happening due to human activities. It has already been mentioned in the Module 33.However, after about two decades of scientific research conducted all over the world and compiled and produced in the form of Five Assessment Reports by Intergovernmental Panel on Climate Change (IPCC) have been able to create a consensus among scientific community about human induced climate change. These reports presented peer-reviewed, consensus opinions among experts in the scientific community concerning the causes of climate change. Further research areas were identified to study in detail to remove any uncertainties. The latest IPCC Fifth Assessment Report concludes that the primary cause of climate change is human activities in 95%–100% of the cases. The Report has also concluded with 95% certainty that humans are responsible for the temperature increase during the period of 1951- 2010.

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The Report has also concluded that anthropogenic forcings have made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica.

For better understanding of climate change due to anthropogenic activities, we need to understand the trend of GHG emission and its radiative properties. Before discussing about the trend of GHG emission and its radiative properties, let us discuss the anthropogenic sources of GHGs.

Sources of Anthropogenic Greenhouse Gases

Do you know, from where these GHGs are emanating?Practically, these emissions are coming from almost all the sectors of our economy. Let us discuss four major GHGs and their sources of origin due to anthropogenic activities. As mentioned in the module on "Climate Change: Evidences and Causes" the four major GHGs are Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O)and Fluorinated gases (mostly HFCs). Let us now discuss about major sources of emission of these four principal greenhouse gases particularly arising out of human activities.

Carbon Dioxide (CO_2): The major sources of CO_2 are mainly originated from burning coal, oil, and gas (about 75%). About 20% of the total CO_2 emissions come from deforestation and decomposition of peat lands, crop residues, and organic materials in agricultural soils. Smaller amounts are produced from turning oil and gas into plastics and other compounds that eventually are decomposed into CO_2 again (about 3%) as well as from manufacture of cement through decomposition of one of the main ingredients, limestone (about 3%).

Methane (CH_4): It comes from a variety of sources.The largest source is livestock, particularly cattle and sheep (25%). This is followed by leaks from extraction, processing, and distribution of natural gas (15%). Other important sources are rice cultivation (12%), associated gas from coal production (10%), and decomposition of organic waste in waste water treatment (9%) and landfills (7%).

Nitrous Oxide (N_2O): It mainly comes from fertilized grasslands and croplands, where nitrogen fertilizers are decomposed in the soil (35%).This is followed by animal waste (26%). Surface water polluted with nitrogen accounts for about 15%. Small amounts come from chemical factories, such as those for nylon production (5%) and waste water treatment (2%). A small quantity of N_2O (about 1% of the total) comes from Cars with catalytic converters.

Fluorinated Gases (mostly HFCs): These gases are mainly emitted from air conditioners in cars and refrigerators, as well as from the production of industrial chemicals. SF6 is mainly used as an insulator in electrical equipment. Let us discuss in brief about global warming potential

Global Warming Potential of Anthropogenic Greenhouse Gases

Do you know what is the Global Warming Potential (GWP) of anthropogenic GHGs and how do we calculate it? GWP was developed for comparing the global warming impacts of different gases. In other words, it is a measure to calculate how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). Therefore, calculation of GWPtakes into account both the radiative properties of a particular greenhouse gas molecule and its lifetime existence in the atmosphere, once emitted. The larger the GWP value, the more is the warming capacity of that particular given gas incomparison to CO_2 over that particular time period. The time period usually used for GWPs is 100 years. This is the atmospheric life time of CO_2.

GWP of CO_2 is 1 because it is the gas being used as the reference. On the other handmethane is considerably more short-lived in the atmosphere than CO_2, persisting for decades rather than centuries (Table 1). This measurement is helpful for formulation of mitigation policies.If we need to avoid a dangerous short-term climate tipping point, we might focus more effort on reducing methane because it is a particularly potent, if short lived, greenhouse gas. On the other hand, if our goal is to stabilize long-term greenhouse gas concentrations, we would be better served by focusing purely on CO_2 emissions.

***Table 1: Atmospheric Lifetime and GWP of Major Greenhouse Gases (*Gases emitted solely from human* sources)**

Sr. No.	Green House Gases	Atmospheric Lifetime in Years	Global Warming Potential
1	Carbon dioxide (CO_2)	Approx. 100	1
2	Methane (CH_4)	12	23
3	Nitrous oxide (N_2O)	120	310
4	Hydrofluorocarbons (HFCs)	1.5 to 264	140 to 11,700
5	Perfluorocarbons (PFCs)	3,200 to 50,000	6,500 to 9,000
6	Sulphur hexafluoride (SF_6)	3, 200	23900

To have a better understanding about the global warming and climate change due to GHG emission by anthropogenic activities, we have to understand the processes of radiative forcing.

Radiative Forcing

You have already read in other modules on climatology about heat budget. Theoretically, we can say that Earth's energy balance is zero. What does this mean? This means that the amount of energy arriving at Earth's surface is equal to the amount of energy eventually radiated back to space. However, Earth's climate has cycled through periods where this balance is not achieved and Earth systems are either gaining or losing heat. The term radiative forcing is also known as climate forcing. In other words, any change in the radiative balance caused by changes in atmospheric composition. Therefore, it describes the amount by which some perturbation causes Earth's energy balance to deviate from zero. A positive forcing indicates a warming condition whereas a negative forcing indicates cooling.

Scientists at National Oceanic and Atmospheric Administration (NOAA) have measured the radiative forcing caused by major long-lived greenhouse gases for the period 1979-2015.This is quantified in watts of energy affecting Earth's energy budget. Figure 1.4, shows Annual Greenhouse Gas Index, as measured by NOAA. According to the figure the Annual Greenhouse Gas Index value reached 1.32 in 2012. Do you know what does this indicator convey? This indicator converts the total radiative forcing for each gas into an index by using the ratio of the Radiative Forcing (RF) for a particular year compared with the RF in 1990 (the baseline year). The graph shows that RF has increased steadily for all gases, with the proportion attributed to CO_2 increasing the most (Figure 1.4).

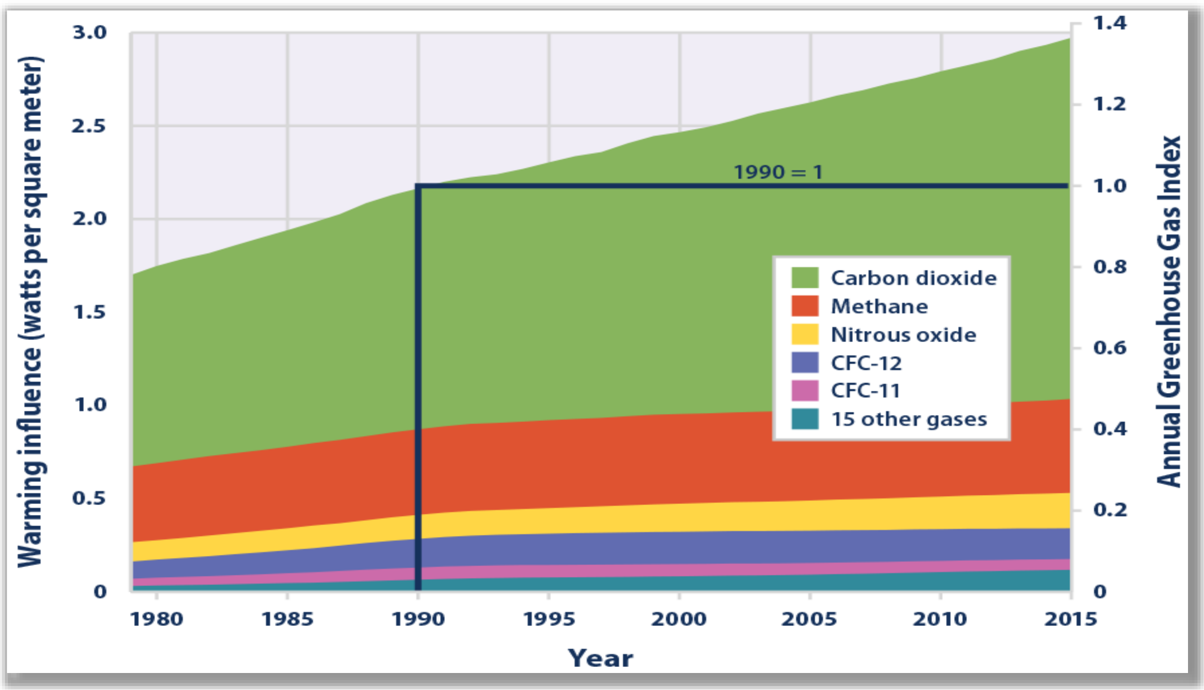

Figure 1.4: Radiative Forcing Caused by Major Long-Lived GHGs 1979-2015 (**Source: https://www.epa.gov/sites/production/files/styles/large/public/2016-07/climate-forcing-download1-2016.png)**

According to the Report given by Working Group I of the Fifth Assessment Report of the IPCC which deals with the Physical Science Basis show that there is a difference in the scientific understanding of different RF effects.It has been observed that emissions can result either in an increase or a decrease in RF at the global scale.Over the past 260 years (1750- 2010), emissions of CO_2, CH_4, N_2O, F-gases, black carbon, CO, and NMVOC all resulted in an increase in RF. On the other hand, emissions of SO_2, organic carbon and mineral dust all contributed to a decrease in RF. Emissions of halocarbons had both a positive and negative impact on RF. Also, the emissions of NO_X and NH_3 have had both a positive and negative RF effect, but with a negative net impact on RF. Figure 1.5 further highlights that interactions between aerosols and clouds resulted in a negative RF, but that the contribution of individual emitted compounds within mixes of aerosols is unknown.

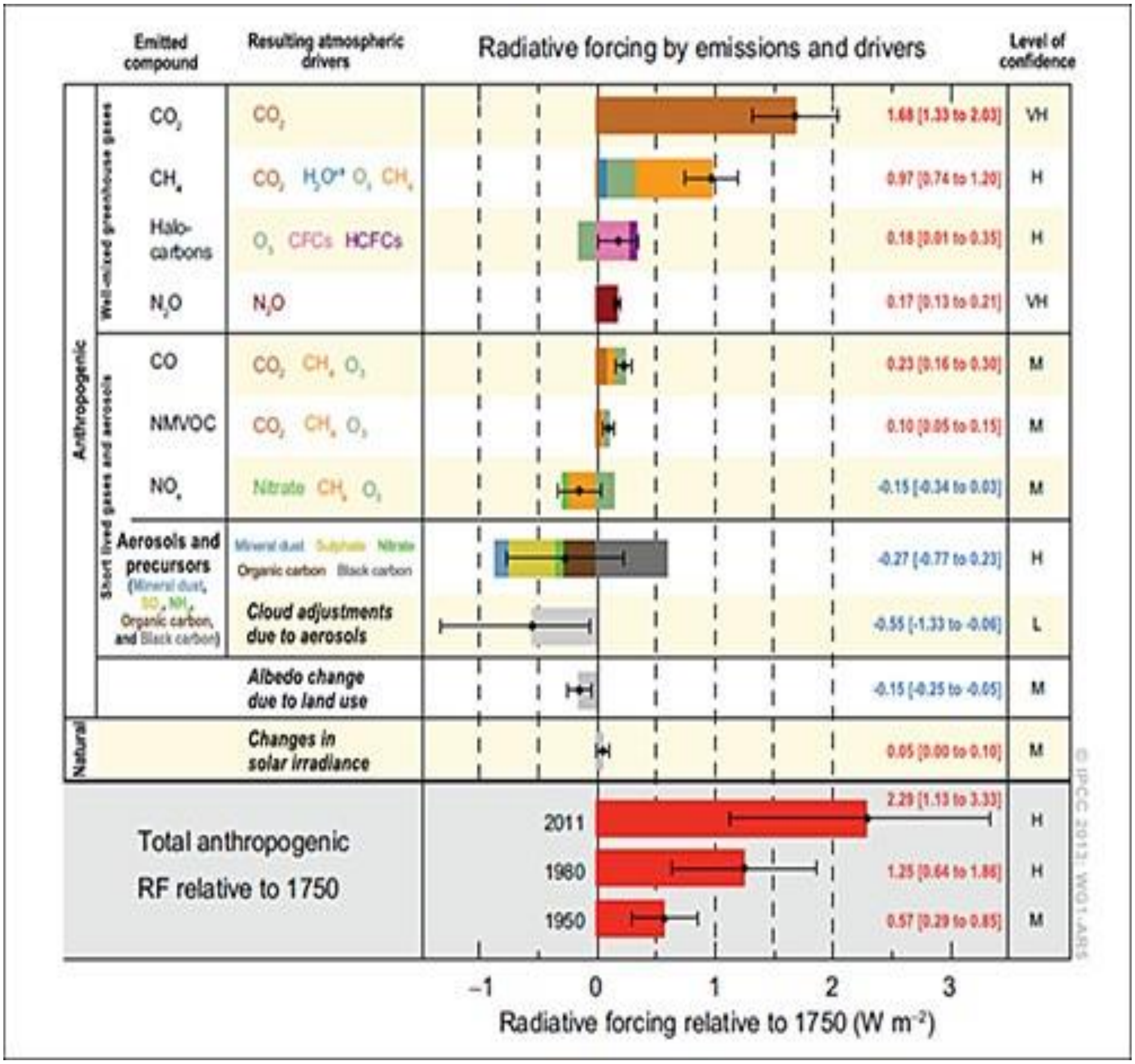

Figure 1.5: Radiative Forcing Estimates in 2011 in relation to 1750
Source: https://www.eea.europa.eu/data-and-maps/figures/radiative-forcing-estimates-in-2011/image_original

Anthropogenic Greenhouse Gas Emission and Climate Change

As mentioned in the previous module as well as in the initial section of this module that the increasing concentration of atmospheric $CO_2$and other greenhouse gases due to anthropogenic activities is the major cause for global climate change has now been established. According to an analysis undertaken by Mann and Kump has revealed that out of all the major greenhouse gases, percentage share of CO_2 emission is highest. Therefore, it plays a significant role in human induced climate change. If we analyse contribution of major GHGs, it has been observed that CO_2 accounted for more than three fourth of the emission (about 77%). The other GHGs which plays a significant role are methane (about 14%), nitrous oxide (about 8%), and the chlorofluorocarbons constitute the remaining 1% (Figure 1.6). The same has also been reported by IPCC Fourth Assessment Report (AR4).

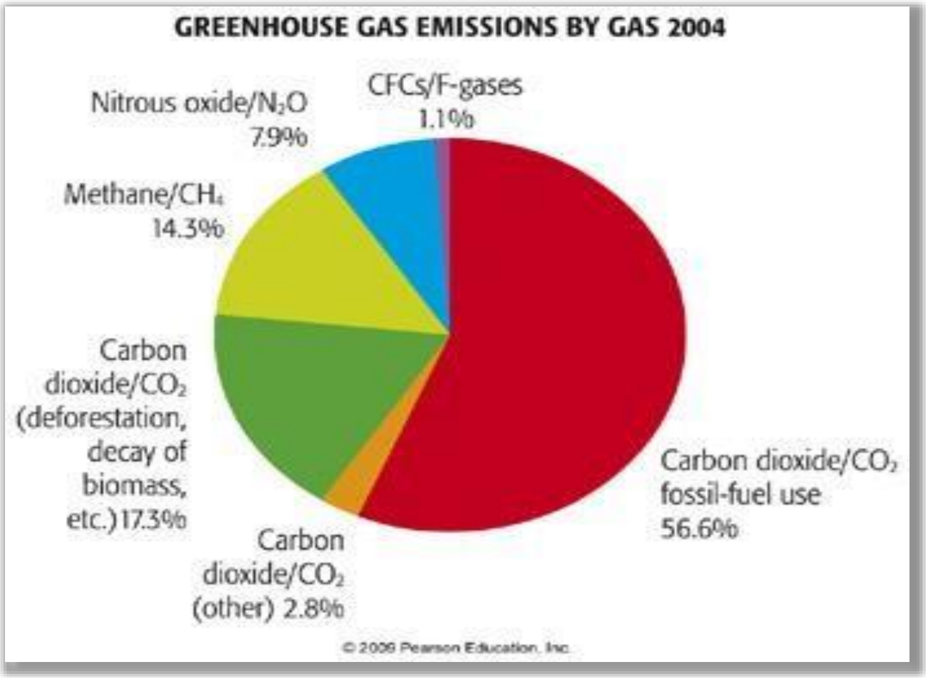

Figure 1.6: Greenhouse Gas Emissions by Gas: 2004
Source:https://www.e-education.psu.edu/meteo469/node/181

According to IPCC Fifth Assessment Report titled 'Climate Change 2014 Synthesis Report,cumulative anthropogenic CO_2 emissions to the atmosphere between 1750 and 2011 were 2040 ± 310 $GtCO_2$(Gt=Gigatonne, one gigatonne is equal to one billion tonnes). Out of the total cumulative anthropogenic CO_2 emissions, about 40% have remained in the atmosphere (880 ± 35 $GtCO_2$). The remaining was removed from the atmosphere and stored in plants and soils on land and in the ocean. These vegetation and soil on land and in oceans are major source of carbon sinks. If we analyse CO_2 emission over the time period, it has been observed that about half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years. The trend analysis has also revealed that total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010 (Figure 1.7).This has happened despite of a growing number of climate change mitigation policies implemented across the world.

Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 GtCO2-eq/yr. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010. As mentioned earlier, at global level, economic and population growth continued to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonisation of the world's energy supply.Do you know what decarbonisation is? Decarbonisation refers to reducing the carbon intensity of energy.

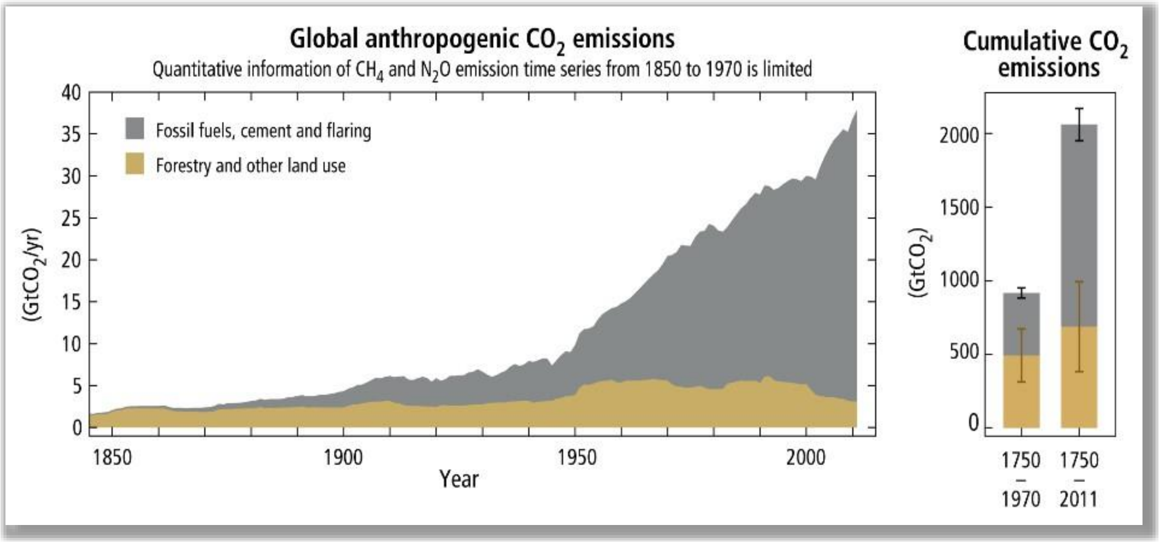

Figure 1.7: Trends of Global Anthropogenic CO_2 Emissions: 1750-2011
Source:https://www.ar5-syr.ipcc.ch

Therefore, major strategies for reducing the greenhouse gas emissions are to control the release of greenhouse gases from fossil fuel combustion, land-use change and the burning of vegetation. If we succeed in doing so, then this would lead to decrease in the projected rate and magnitude of warming. In other words, future climate change would be determined by historic, current and future emissions of these greenhouse gases.

Impact of Human activities on Climate Change: Analysis of Economic Sectors

Analysis of the main sources of greenhouse gas emissions according to the sectors of the economy (Figure 1.8) reveals that energy supply is the largest (26%) contributors of GHG, followed by industry (19%), the forest sector (17%), agriculture (14%), transport (13%), the building sector (8%), and waste management (3%). Confusion can arise around sector contributions because emissions can be counted in different ways. The numbers given above are based on emissions at the point where they enter the atmosphere (so-called 'point of emission allocation'). So emissions from electricity generation are counted under the energy supply sector. However, it can be more useful to count such emissions under the sector where that electricity is used (socalled ''end-use allocation''). That can give a better picture of how electricity emissions.

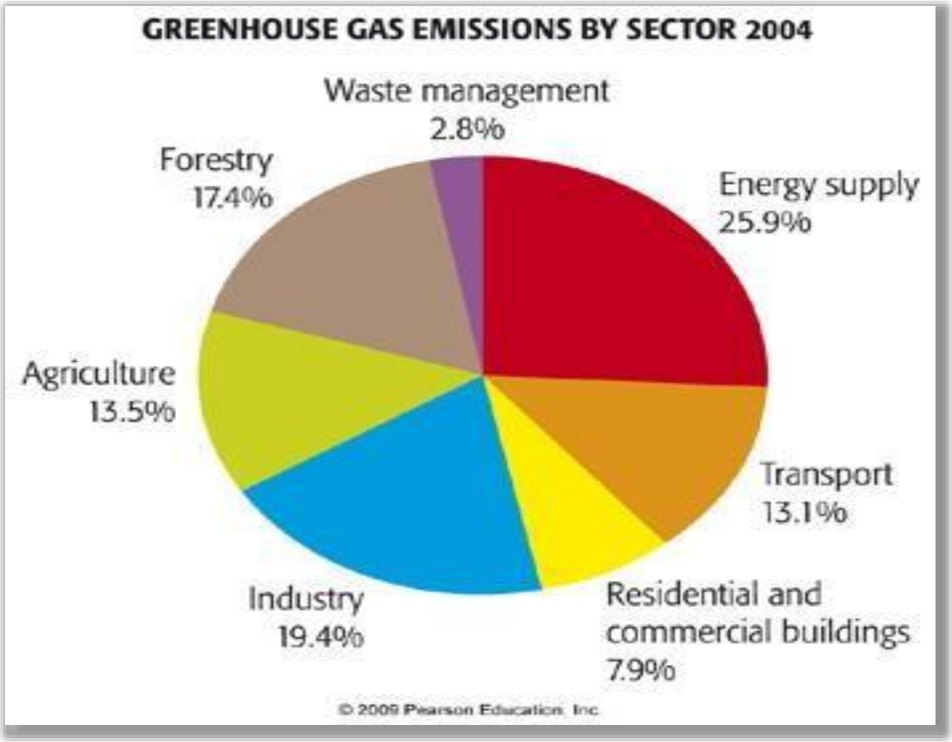

Figure 1.8: Greenhouse Gas Emissions by Sector: 2004
Source: https://www.e-education.psu.edu/meteo469/node/181

It is useful to know what the historical contributions to our emissions have been from the various sectors. Looking forward towards the future, it is also important to know which sectors are growing most rapidly in their contribution to anthropogenic greenhouse emissions. By comparing emissions rates during the middle of the past decade with those at the beginning of the 1990s, it has been observed that the largest absolute increase (an increase of nearly 3 gigatons/year of CO_2 released) has been in the energy sector. Other sectors such as transport and forestry have shown similar (35-40%) increases in emissions over this time frame. It is logical to conclude that these sectors might demand special attention in considering possible emissions mitigation approaches.

According to the latest IPCC Fifth Assessment Report 2014, the total annual anthropogenic GHG emissions have increased by about 10 $GtCO_2$-eq between 2000 and 2010. This increase directly came from the energy (47%), industry (30%), transport (11%) and building (3%) sectors (medium confidence). Accounting for indirect emissions raises the contributions by the building and industry sectors (high confidence). Since 2000, GHG emissions have been growing in all sectors, except in agriculture, forestry and other land use (AFOLU). In 2010, 35% of GHG emissions were released by the energy sector, 24% (net emissions) from AFOLU, 21% by industry, 14% by transport and 6.4% by the building sector (Figure 1.9). When emissions from electricity and heat production are attributed to the sectors that use the final energy (i.e., indirect emissions), the shares of the industry and building sectors in global GHG emissions are increased to 31% and 19%, respectively.

Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. According to the Working Group III Report on Summary for Policy Makers revealed that the contribution of population growth between 2000 and 2010 remained roughly identical to that of the previous three decades, while the contribution of economic growth has risen sharply (high confidence). The Report has also revealed that between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity of gross domestic product (GDP). This has happened due to increased use of coal relative to other energy sources. This has reversed the long- standing trend in gradual decarbonisation of energy of the world's energy supply.

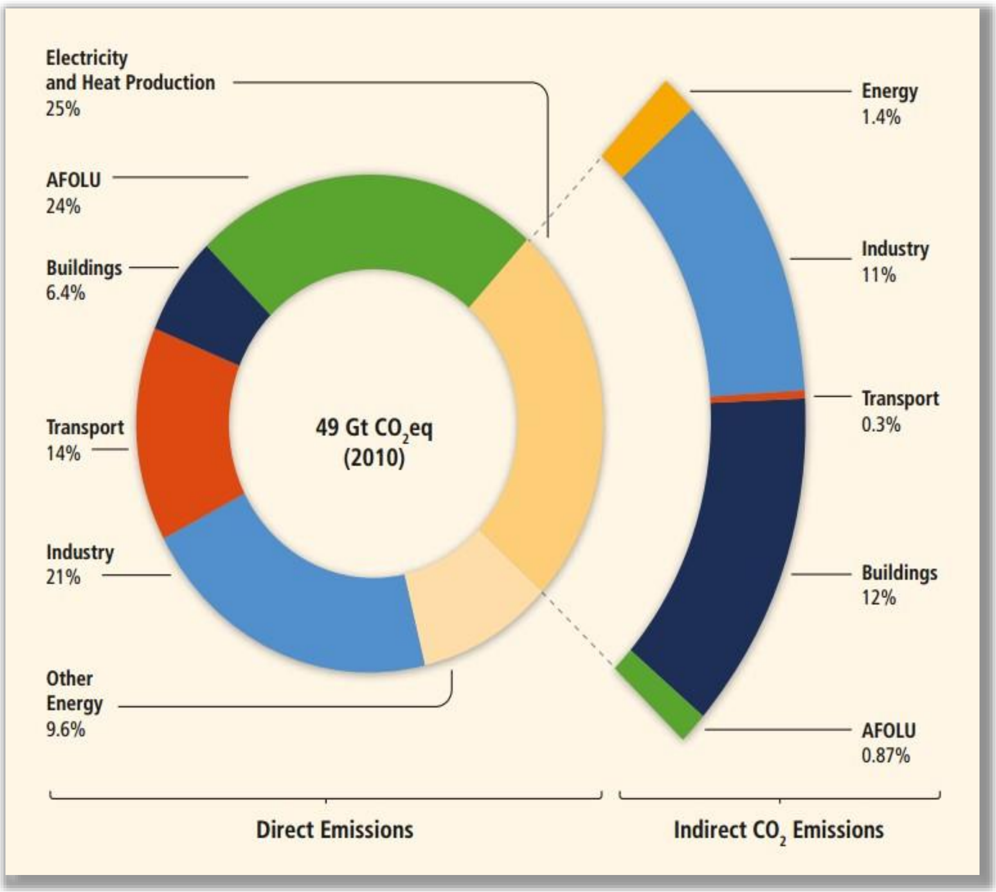

Figure 1.9: Greenhouse Gas Emission by Economic Sector: 2010
Source: http://www.bestclimatepractices.org/wp-content/uploads/2015/02/IPCC-WGIII-AR5-2014-emissions-by-economic- sectors-fig-TS3-Crop.png

Remedial Measures to Overcome the Effects of Climate Change

In climate change discourse, there are two approaches to address human induced climate change. These are mitigation and adaptation. Mitigation has the long history in the climate policy, whereas the adaptation has recently gained importance.

The Concept of Mitigation and Adaptation: The concept 'mitigation' in general means the reduction of the atmospheric GHGs, and hence, we can avoid the likelihood of the occurrence of the climatic variability and extreme events. IPCC defines mitigation as *"an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases."* On the other hand, the notion 'adaptation' in general refers to the individual, communities, and societies to adjust their activities, life courses and location to take an opportunity, to get advantage from the fluxes of the social-ecological systems. The climate change literature views it as "*the adjustment in human and natural systems to actual or expected climatic stimuli, which can reduce the negative impacts and take advantage of the positive"* (UNFCC 1992).

The Need for Mitigation and Adaptation: As mentioned above, climate change has severe non-linear impacts on the wellbeing of the human society. Many developing nations have already experienced weather related extreme events in terms of floods, droughts, heat waves and tropical cyclones that are more frequent or intense than previous experiences. In general, it affects different sectors, such as fresh water resources and their management, food and fibre and forest products, coastal system and low lying areas, and health etc. The resulting impacts will have significant consequences on the environment, production systems and livelihood from future climate variability and change. Importantly, the developing nations are facing more burdens as compared to the developed nations (Stern, 2006; and Mendelsohn et al., 2006). Meanwhile, Stern has estimated "if we don't act, the overall damage cost will be equivalent to at least 5 percent of GDP now and forever, and if wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 percent of the GDP or more" (Stern, 2006).

Mitigation and Adaptation Measures by AR5 for Policy Makers

IPCC Fifth Assessment Report has given the following major suggestions related to mitigation and adaptation. There are two broad suggestions related to mitigation and adaptation. Under these two broad suggestions, there are five important specific suggestions. Let us discus broad suggestions as well as specific suggestions given under broad suggestions.

1. **Future Pathways for Adaptation, Mitigation and Sustainable Development:** Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21^{st} century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development.

2. **Climate Change Risks Reduction by Mitigation and Adaptation:** Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (high confidence). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term

mitigation efforts.

3. **Characteristics of Adaptation Pathways:** Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.

4. **Characteristics of Mitigation Pathways:** There are multiple mitigation pathways that are likely to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales.

5. **Adaptation and Mitigation:** Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

6. **Common Enabling Factors and Constraints for Adaptation and Mitigation Responses:** Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioral and lifestyle choices.

7. **Response Options for Adaptation:** Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options.

8. **Response Options for Mitigation:** Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors.

9. **Policy Approaches for Adaptation and Mitigation, Technology and Finance:** Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation.

10. **Trade-offs, Synergies and Interactions with Sustainable Development:** Climate change is

a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (high confidence). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (medium confidence).

1.7 ECOSYSTEM PRODUCTIVITY

The productivity of an ecosystem is of two types i.e. primary productivity and secondary productivity. The primary productivity of an ecosystem is the rate at which organic matter is produced during photosynthesis. There are two variations in the primary productivity; The gross primary productivity (GPP) is the total fixation of energy by photosynthesis which is expressed in Kcal/m^2/yr. Part of this energy is used as plant matter and rest of the chemical energy is metabolised by the plant's own respiration and released to the environment a heat. Subtracting this respiration(R) from GPP gives the Net Primary Productivity (NPP),it represents the actual rate of production of new biomass that is available for consumption by heterotrophic organisms. Biomass is the mass of an ecosystem component per unit area and per unit time.

$$Net\ Primary\ Productivity = Gross\ Primary\ Productivity - Plant\ respiration$$

The productivity of an ecosystem is rate of generation of new biomass, it may be expressed either in energy per unit area or as weight. The total quantity of organic matter available in at any given time in an ecosystem is called biomass. The productivity depends on various factors such as sunlight, temperature, rainfall, availability of nutrients and also indirect impact of intervention of human activities. For comparing different ecosystems productivity is usually included over the year to compute annual production that means generation of new biomass per unit area in a year. A common ecological measure of efficiency is the trophic level efficiency, the rate of production at one trophic level to that of the next lower trophic level. The rate of production of new biomass by heterotrophs or consumers from the net primary production available to them is called secondary production. Though there are large variations from one ecosystem to another ecosystem, with reference to energy content, the transfer is only about 10 percent, and grossly for every 10kcal of plant obtainable to herbivore, about 1kcal is consumed and 0.1 kcal is absorbed in the form of body weight and in the similar way amount of energy transfer is dwindles with each transfer.

There are optimum conditions for an organism, low and high limiting factor creates a condition of tolerance threshold and may become acute if conditions are not corrected, where the survival is at stake. The disturbance from the external environment include the sudden events of flood, storms, draughts etc these situation disrupts the flow of the basic components of the photosynthesis for example extreme soil erosion will reduce availability of nutrient, or physical damage of plant foliage due storm. Ecosystems are in state of incessant adjustments with these sudden and progressive changes.

The ratio of net primary production that gushes along these pathways depends on transformation efficiencies in the way energy is used and transferred from one level to the next. Ecological efficiency is the ratio of the biomass integrated by consumer trophic level to the biomass from its lower trophic category. Some of the efficiencies are explained here. Photosynthetic efficiency (PE) is the percentage of received solar energy a plant utilises in complete photosynthesis process. It can be derived by dividing GPP by the solar input of energy per unit area per unit time. Consumption efficiency (CE) is the percentage of total productivity available at one trophic level which is consumed by a trophic category one level up. Assimilation efficiency (AE) is the percentage of food energy ingested by the consumers in a trophic category and the remainder is lost as faecal waste and enters the decomposers system. Production efficiency (PE) is the percentage of assimilated energy which is included into new biomass and remainder is entirely lost as heat. Exploitation Efficiency (EE) is the net productivity of each trophic level as a proportion of the net productivity of the previous level.

Table 2 : Ecological Efficiencies

S.N.	Type of Efficiency	Method to derived
1	Photosynthetic Efficiency (PE)	$PE = \frac{\text{Energy equivalent to carbon compound produced/unit area/unit time}}{\text{Energy input/unit area/unit time}} \times 100$
2	Consumption Efficiency (CE)	$CE = \frac{\text{Total productivity available at one trophic level}}{\text{Actually ingested by trophy category next level up}} \times 100$
3	Assimilation Efficiency (AE)	$AE = \frac{\text{Food energy consumed by trophic category}}{\text{Energy absorbed by the body}} \times 100$
4	Production Efficiency (PE)	$PE = \frac{\text{Energy incorporated in new biomass}}{\text{Percentage of assimilated energy}} \times 100$
5	Exploitation Efficiency (EE)	$EE = \frac{\text{Net productivity of a trophic level}}{\text{Net productivity of preceding trophic level}} \times 100$

1.8 SUMMARY

- All terrestrial habitats are naturally quite different from aquatic habitat.
- Terrestrial ecosystems in their natural state are found in different types of forests, grasslands, semiarid areas and deserts.
- The forest ecosystem includes a complex assemblage of different kinds of biotic communities.
- The forest ecosystem has been classified into various categories arranged on a gradient from north to south or from high to lower altitude.

- Coniferous forests are found in cold regions around Northern Hemisphere with long winters and very short summer and are characterized by evergreen forests.
- Temperate deciduous forest is moderate climate forest characterized by moderately humid condition with an annual rainfall of 75-150 cm. The plants of these forests bear broad-leaves which are shed in fall season.
- Temperate evergreen forests are found in warm, dry summers and cool regions. These are commonly inhabited by low evergreen trees having broad leaves.
- Temperate rain forests are giant forests occurring in cool climate than other rain forests.
- Tropical rain forests are evergreen having broad leaves that occupy low altitude zones near the region of equator.
- Tropical seasonal forests are found in regions where total annual rainfall is very high but segregated into pronounced wet and dry periods.
- Tropical Broadleaf Woodlands and Thornlands are composed of small trees, which replace tropical seasonal forests in areas towards drier climates.
- Forests have great biological importance as reservoirs of genetic diversity apart from playing an important role-in regulating earth's climate.
- Forests provide habitat, food as well as protection to wildlife species against extremes of climate and help in balancing carbon dioxide and oxygen in the atmosphere.
- Forests, being home of wildlife are important assets of aesthetic, touristic and cultural value to the society.
- IPCC Fifth Assessment Report concludes that the primary cause of climate change is human activities in 95%–100% of the cases. The Report has also concluded with 95% certainty that humans are responsible for the temperature increase during the period of 1951- 2010.

1.9 REFERENCES

- Climate Change 2014, Synthesis Report, Summary for Policy Makers, Contribution to the Fifth Assessment Report of the IPCC, pp. 17-31.

UNIT-2- FORMULATION OF PRIMARY PRODUCTIVITY

Contents:

2.1 OBJECTIVES

After reading this unit the learners will be able to

- Understand the primary productivity
- Understand photosynthetic pathways and their significance
- Understand the allocation of Net primary production and accumulation of biomass
- Understand the measurement of biomass and primary productivity in forest ecosystem of the world
- Understand plant biomass and turnover, efficiency of energy captured and human use of productivity

2.2 INTRODUCTION

Productivity refers to rate at which energy is accumulated by green plant in unit time in the form of organic substance that can be used as food. It can be defined as the rate of biomass production or the amount of food energy produced or obtained or stored by a particular trophic level per unit area in a unit time is called productivity. It can also be defined as the energy accumulated in plants by photosynthesis. The unit of productivity is gm/m^2/year or kcal/m^2/year. According to Odum there are three types of productivities: primary productivity, secondary productivity and community productivity.

Primary Productivity: At the producer level, primary productivity is the productivity. It is the quantity of organic matter generated by plants in a particular location over time, which they produce from Solar Energy. Approximately 1-5% of solar energy that falls on the plant is converted to organic matter.

Gross Primary Productivity (GPP): GPP refers to the total amount of organic matter produced. The respiration used by the producer also constitutes part of this. The entire amount of energy that is captured by the photosynthetic organism can be defined as such. It is up to the photosynthetic efficiency of the producer and environmental factors. In tropical rain forests the mean net primary yield is high and in deserts, it's low.

Net Primary Productivity (NPP): When referring to productivity, we mean gross production less loss from respiration and decomposition. The terms apparent photosynthesis and net assimilation are also used to describe this.

$$NPP = GPP - Respiration$$

It can alternatively be described as the residual biomass or balance of energy after producers' respiration costs have been covered. It is the net energy that is held in living things. The biomass that acts as food for herbivores and decomposers has accumulated subsequently in this area. The amount of organic matter produced in a community during a specific period of time and made available to heterotrophs is said to be measured by NPP.

Secondary Productivity: This is referring to consumer-level productivity. The secondary productivity only takes into account how food is used to produce consumer biomass. It is also known as the net rate of increase in heterotrophic biomass. The next trophic level uses the secondary productivity as food (Fig. 2.1).

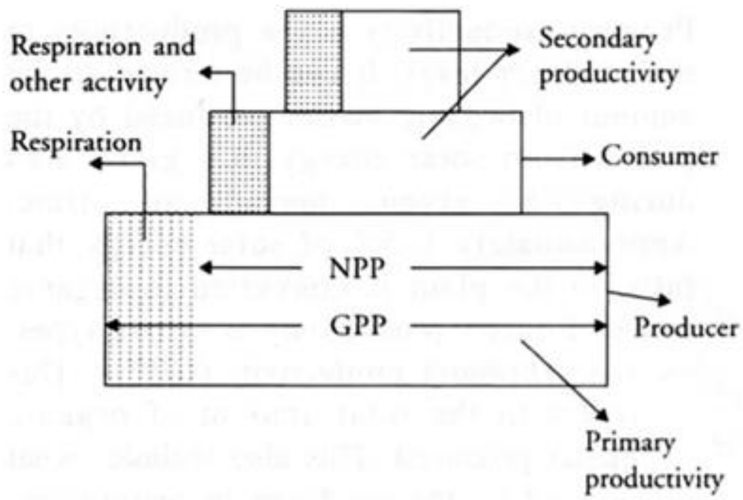

Figure 2.1: Primary and secondary productivity

Community Productivity: This is the amount of organic matter that a community overall synthesizes each unit of time and space.

Energy Flow in Ecosystem: Energy transfer from one level to another is the primary purpose of an ecosystem. The two laws of thermodynamics serve as the foundation for energy flow. According to the first law of thermodynamics, energy cannot be generated or destroyed. But it is capable of changing from one form to another. For example, solar energy can be converted into heat and food energy. According to the second rule of thermodynamics, heat is a constant source of energy loss during this process. In the process of moving food based energy from one creature to another, some energy is wasted at each stage. For all living things, the sun is the only source of energy. Three types of sunlight can be distinguished: visible light, also known as photo synthetically active radiation (PAR), infrared light, which aids in heating, and UV light, which is reflected back by ozone. An estimated 30% of incident solar radiation is reflected, 20% is absorbed by the atmosphere, and 50% is visible light. Only 2-10% of this 50% of visible light is used for photosynthesis, which accounts for the majority of gross primary output. The remaining 40–48% is converted to heat and dispersed on Earth. The plants use some energy, leaving just the net primary productivity, which is only 0.8–4% of incident solar radiation. It is evident from the aforementioned factors that energy flows in a single direction and continuously decreases at every level.

Trophic Levels: The food levels are represented by trophic levels. Trophic levels are created using the stages of food chain as a basis. A food chain typically has four to five trophic levels and just one direction in which energy flows. The autotrophic producers occupy the first trophic level. They possess the ability to use solar power. The main consumers, which are herbivores, live on the second floor. Carnivores and omnivores, which are secondary consumers, are found in the third trophic level. The tertiary consumers, which are huge carnivores, are at the fourth trophic level (Fig. 2.2).

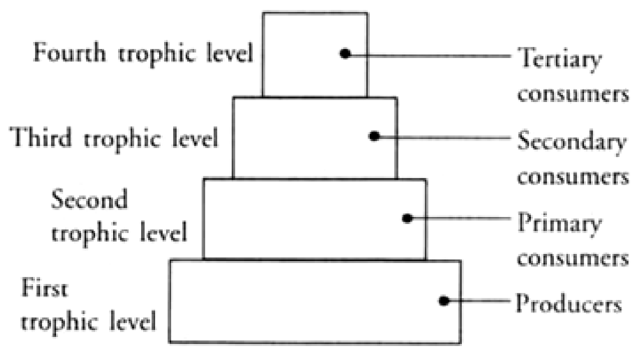

Figure 2.2 Trophic level in a food chain

2.3 PHOTOSYNTHESIS, PHOTOSYNTHETIC PATHWAYS AND THEIR ADAPTIVE SIGNIFICANCE

The process of photosynthesis, in which green plants use incident solar energy and CO_2 to produce O_2 and complex organic materials through a combination of biophysical and biochemical processes, forms the basis for all energy transfers in the ecosystem. This process is fueled by radiation with wavelengths of roughly 400–700 nm, which are absorbed by the chloroplasts. Interdependent light and dark reactions comprise of the series of various stages. One of the two main pathways—Calvin-Benson or Hatch and Slack might actually fix CO_2 in the atmosphere. Because phosphoglyceric acid (PGA), the first stable product of the Calvin-Benson pathway, is a 3-carbon molecule, Calvin-Benson plants are also known as C_3 plants. CO_2 is initially linked to ribulose-1, 5-diphosphate (RuDP) through the activity of the enzyme RuDP carboxylase (Rubisco).

PEP carboxylase, an enzyme involved in C4 photosynthesis, binds CO_2 to phosphoenolpyruvate (PEP) to create oxaloacetate. The latter is quickly transformed into the 4-carbon acids malate or aspartate. In thick walled bundle sheath cells, where these acids are carried, CO_2 is liberated.

Because bundle sheath cells' thick walls function as a physical barrier to CO_2 diffusion, the gas is concentrated in these cells and eventually enters the Calvin-Benson cycle. As a result, the C_4 cycle improves the C_3 route. Additionally, the vascular bundle's water supply is close by where the photosynthetic activity takes place in the bundle sheath. Thus, the effects of water stress, to which the photosynthetic equipment is very sensitive, are reduced. Large, dense chloroplasts are seen in the bundle sheath cells that surround the vascular bundles in the leaves of C_4 plants, which is a characteristic morphological trait known as Kranz anatomy.

The fact that C_3 and C_4 plants react in different ways to water and light temperature is of enormous ecological significance. We find that C_3 plants prefer to reach their peak photosynthetic rate at moderate light intensities and temperatures when comparing photosynthetic rate per unit of leaf surface. Strong temperatures and strong light levels can both hinder the photosynthesis of these plants. In contrast, C_4 plants are evolved to high temperatures and light intensities, and under these circumstances, their photosynthetic rates far outpace those of C_3 plants. The former has a maximum growth rate that is four times higher than the latter.

Additionally, the C_3 plants need substantially less water (less than 400 g water against 400-1000 g water per gram of dry matter produced in C_3 plants) to produce each unit of dry matter. The higher net CO_2 fixation rates of C_4 plants are probably crucial for adaptability and survival, but even more crucially, the ability of these plants to thrive under tremendous stress is unquestionably advantageous for selection. Under conditions of high water stress, high temperature, high irradiance, and low CO_2 concentrations, the C_4 species survive and are more adapted than many C_3 species. In order to control transpiration in hot, dry regions, such as those found in the tropics, stomata may only be partially open for a significant portion of the day. This results in less CO_2 diffusing into the chloroplast.

As a result, reduced CO_2, which may initially be in very low concentration, is converted into oxaloacetate before being released at high concentration in the bundle sheath area for RuDP carboxylase to work upon. While the C_4 cycle needs five ATP molecules and three NADPH molecules to decrease one CO_2 molecule, the C_3 cycle only needs three ATP molecules and two NADPH molecules. But the ability of C_4 plants to utilise more light, function effectively at lower CO_2 concentrations, consume less water per gram of dry weight, and show nil or minimal photorespiration, as opposed to C_3 plants, makes up for the extra energy needed for the C_4 cycle.

The majority of C_4 plants are tropical in origin. While C_3 grass canopy operates better at higher latitudes (temperate and alpine), C_4 grass canopy is more effective at lower latitudes (towards the tropics) in terms of net primary productivity C_4 plants thrive in the warm season when they are found in the temperate region. The C_4 grasses are known as warm-season grasses and the C_3 grasses are known as cool-season grasses due to evolutionary patterns (Sims et al. 1978; Singh et al. 1983). Farmers in India's northern plains cultivate several C_4 crops, such as maize, sorghum, sugarcane, etc., in the warmer months and C_3 crops, such as wheat, mustard, gramme and pea, in the cooler months. It should be recognised, however, that all tree species are C_3 plants.

Conditions in arid regions with temperature variations of up to 40°C (leaf temperatures up to 50°C) and down to 15°C at night may have required additional changes to the photosynthetic pathway. Under these circumstances, water loss would happen at a pace that would be deleterious if the stomata opened significantly during the day. Another carbon fixation method, known as cassulacean acid metabolism (CAM), has been developed to address the issue of delivering CO_2 for photosynthesis in this circumstance. Numerous desert dwelling plants, such as members of the Crassulaceae, Cactaceae, and Euphorbiaceae families, exhibit this mechanism. 10% of the planet's surface is capable of CAM photosynthesis.

These plants typically flourish in xeric habitats or in areas with high light levels, such as epiphytes or plants growing under tropical forest canopies. They keep their stomata closed during the hotter hours and open them at night during the cooler hours when there is less water loss. A mechanism like that of plants is used to fix the carbon dioxide that is taken in during the night by PEP carboxylase and store it as organic acids, primarily in the vacuoles. When light is present during the day, organic acids emit CO, which is then repaired by the Calvin-Benson cycle. The optimal temperature for dark CO_2 fixation is low (10-15°C). The delayed photosynthesis and tight stomata prevent water loss, allowing the plants to preserve their water content.

Due to the temporal gap between nocturnal CO_2 fixation and daytime CO metabolism, this cycle is crucial for plants in dry environments. Some plants can fix carbon by CAM photosynthesis in dry environments, and ecosystems can gain carbon even in settings with very little soil moisture. These plants resemble C_4 plants in that they lack the differentiation of mesophyll cells into palisade and spongy parenchyma, have higher optimum photosynthesis temperatures (30-35°C), exhibit low photorespiration, and are found in open, warm, and frequently salty sites; They are similar to C_3 plants in that they have no need for Na and a lower light saturation point for photosynthesis. They differ from C_3 and C_4 plants, however, in that they have a very low maximum growth rate (roughly 0.02 g dm^2 day) and a very high water use efficiency (roughly 80 g H_2O g CO_2 fixed).

While the C_4 and C_3 cycles are situated apart in C_4 plants (C_3 occurs in bundle sheath cells), they are temporally separated in CAM plants (C_4 occurs at night and C_3 during the day).

2.4 PHOTOSYNTHETIC CAPACITY

The capacity of plants to photosynthesize varies greatly. Photosynthetic capacity is the highest rate of net photosynthesis under ideal conditions (saturating light intensity, perfect temperature, and sufficient water supply) and natural CO_2 content (0.03 percent by volume). A list of plant groups with their photosynthetic capacity was compiled by Larcher (1982).

Table 2.1 *A cross section of values for photosynthetic capacity of plant groups (after Larcher 1982)*

Plant group	**CO_2 uptake (mg/dm2 illuminated leaf surface /hour)**
Herbaceous C4 plants	30-80
C_3 crop plants	20-45
C_4 heliophytes	20-40
C_3 sciophytes	4-20
CAM plants (in light)	3-20
CAM plants (in dark)	10-15
Tropical and subtropical forest canopy trees	12-24
Sun leaves of deciduous trees	15-25
Shade leaves of deciduous trees	5-10
Evergreen conifers	5-18
Subtropical evergreen broad leaf trees (sun leaves)	10-18
Deseret shrubs	6-20
Mosses	Upto 3
Emergent hydrophytes	28-40
Submerged hydrophytes	2-6

Source: Singh et al., 2014

Comparing the photosynthetic capacities of different plant groups has revealed some interesting patterns, including: (i) C_3 plants photosynthesize at significantly lower rates than C_4 plants; (ii) crop plants among C_3 plants photosynthesize at higher rates, possibly as a result of selection breeding; (iii) thallophytes and submerged aquatics have very low photosynthetic capacity; (iv) herbs perform better than woody species; (v) conifers and succulents only photosynthesize at moderate rates, and (vi) shade plants only manage to absorb half to one third as much carbon as sun plants.

Similarly, plants have different respiratory rates (measured as rates of dark respiration at standard temperature). According to Larcher (1982), heliophytes and herbaceous species both breathe twice as quickly as evergreen tree foliage. Heliophytes also breathe noticeably faster than sciophytes. The ability of foliage to create organic matter varies from species to species due to the varying photosynthetic capability. This is demonstrated by statistics on the fresh weight and foliage surface area required by specific tree species in Switzerland to create 1 m^3 of solid wood (Table 2.2). Evidently, Scots pine foliage is more effective than that of spruce or fir.

Table 2.2 *Efficiency of foliage of specific tree species in the production of commercial wood in Switzerland (based on Trendelenburg and Mayer-Wagelin, 1955).*

Species	**Fresh weight of foliage required to produce 1 m³ wood (kg)**	**Area of foliage needed produce 1 m of solid wood**
Scots pine	1200	6600
Spruce, even aged	3000	16500
Spruce, uneven aged	4000	20800
Fir	2400	13440
Oak	1100	13640
Beech	800	14080

In the context of plant development and production, relative growth rates (RGR) and net assimilation rate (NAR) are two crucial measurements.

Relative growth rate

Two main elements determine the relative growth rate (RGR), which is the daily rate of gain in dry weight. First, it depends on the net assimilation rate (NAR), which is the assimilation efficiency per unit of photosynthetic surface during the day. The second factor is the area ratio (LAR), which is the proportion of the plant's overall surface area to its assimilation surface area. If the leaf hasn't more than doubled in size over the time interval t, the following formulas can be used to estimate RGR and NAR: C

$$RGR = \frac{In\,Wt - InWo}{t}$$

$$NAR = \frac{Wt - Wo}{t} X \frac{In\,\mathrm{At} - In\,Ao}{\mathrm{A_t} - \mathrm{A_0}}$$

Where, the measurements are over a period of time t (in days), the initial values of the plant weight and leaf area are W_0, and A_0 respectively and the final values W_t and A_t, respectively.

2.5 DISTRIBUTION OF BIOMASS

The total biomass of all taxa on Earth is thought to be around 550 Gt C, of which 80% (450 Gt C) are plants, 15% (70 Gt C) are bacteria, and the remaining Gt C is made up of other groups, including fungi (12 Gt C), archaea (8 Gt C), protists (4 Gt C), animals (2 Gt C), and viruses (0.2

Gt C).The level of information on which each estimate of global biomass is based, as well as the degree of uncertainty in those estimates, varies. The estimate of plants, which is based on numerous independent sources and enables a reliable evaluation of the total plant biomass, is one estimate with a relatively high level of certainty. Marine prokaryotes, on the other hand, are an example of a typical situation with increased uncertainty because their cell densities are recorded at diverse sites around the world and categorised according to depth. Thus, Plants are the major category in terms of biomass with a likelihood of over 90%, regardless of the high degree of uncertainties surrounding the total amount of bacterial biomass.

Terrestrial plants, primarily vascular plants, make up the majority of all plant biomass, with bryophytes (such as mosses) and marine plants making up the remainder. This plant biomass takes into account the effects of land-use change and is a representation of both forest and non-forest ecosystems. Plant tissues are composed of an extracellular framework made up of cell walls (mainly cellulose and lignin), enclosing a cytoplasmic network, known as protoplasm. The amount of supporting tissue varies depending on the compartment of the plant, with leaves having the least amount while the stems of woody plants (like trees) have the most supporting tissue: The remaining 30% of plant biomass is concentrated in highly metabolically active plant tissues (mostly leaves and metabolically active root portions), which account for about 70% of the biomass of trees and other plants.

Of the total biomass, about 60% is found above ground (320 Gt C), with the remaining 40% made up primarily of microorganisms found in the soil and deep subsurface (100 Gt C) and plant roots (130 Gt C). About 90% of the deep underground biomass is made up of bacteria, which have very slow metabolic rates and related biomass carbon turnover times of months to thousands of years (mainly in water bodies and underneath the seafloor). Without these contributions, plants continue to make up the majority of the world's biomass, which consists mostly of over 150 Gt C of plant roots and leaves and about 9 Gt C of terrestrial and marine bacteria, which contribute almost as much as the 12 Gt C of fungi.

2.6 ALLOCATION OF NET PRIMARY PRODUCTION AND ACCUMULATION OF BIOMASS

Various parts of the plant body receive photosynthesized energy in accordance with the plant's development and survival strategies. Annual plants initially allocate a larger percentage of assimilates to leaves to promote the growth of the photosynthetic canopy and later to reproductive organs to ensure successful seed generation. The non-photosynthetic tissues (for support structure) and/or storage organs, from which the reserves can be remobilized to initiate growth at the beginning of the next growing season, tend to receive more attention in perennial herbs after their photosynthetic canopy has established. The perennial root system is also developed using a significant amount of assimilates.

The huge support organs like the trunk and branches of trees are developed using a large amount of the photosynthesized energy. A significant amount of resources are first allocated to foliage, which gradually decreases to a lower asymptote (Fig. 2.3). Peak allocation to the trunk and branches typically follows that to the leaves. In deciduous trees, new shoots and foliage may initially grow at the expense of labile material that was stored from the previous season; nevertheless, this reserve is replenished during the growing season. Prolific seed generation in trees may only take place every few years (the good seed years) due to the necessity of constructing vast support structures, when due to very favourable conditions a substantial amount of assimilates is created that can be allocated to reproduction.

Table 2.3 displays how much of the aboveground biomass and net above ground primary production (ANP) of the tree layer of four forests is made up of foliage, branches, and trunk. Even while leaves only make up 3.4 to 4.6% of the above-ground tree biomass, they represent the photosynthetic apparatus and contribute for 37 to 41% of the tree layer ANP. As a result, through litter fall, the majority of the ANP used in the formation of foliage would end up as debris each year. From 43 to 77 percent of the biomass is made up of tree trunks, although they only make up 25 to 46 percent of the ANP. While pine and old-growth sal woods only provide 14 to 26 percent of ANP for these organs, dry deciduous forests and evergreen oak forests provide 38 to 33 percent of ANP to their branches. In contrast to woods, grasslands give leaves the most ANP. Evidently, the long-lived components make up a larger amount of the ecosystem structure and the short-lived components account for a larger portion of ecosystem function (Singh and Singh, 1993).

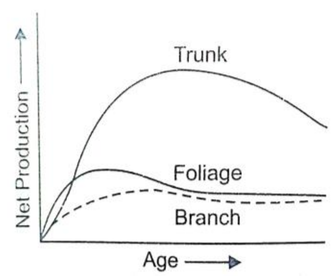

Figure 2.3: Changes in allocation of net primary production (NPP) to foliage, branch and trunk in scots pine (based on Albrekston, 1980)

The distribution of net primary production to roots is essential. According to Sims and Singh (1978), in temperate grasslands, more than 70% of net production is transferred to below-ground plant components. According to Vogt et al. (1982), roots and mycorrhizal fungi produce between 70 and 80 percent of the net primary production in the Pacific silver fir (*Abies amabilis*) ecosystem. Net photosynthate given to roots in substantial amounts is either excreted into the soil or redirected to mycorrhizal symbionts. In addition to supporting a varied population of soil organisms, photosynthates released from roots and mycorrhizal hyphae are crucial for preserving the physical and biological structure of soils.

Table 2.3 Allocation of biomass (B) and net aboveground primary production (ANP) to different tree components of four forest types (Source: Singh and Singh (1991,1993), Singh and Singh (1999), Chaturvedi and Singh (1987); Rawat and Singh (1988).

	Dry deciduous[1]		**Old growth Sal**[2]		**Pine forests**[3]		**Oak forest**[4]	
	B	**ANP**	**B**	**ANP**	**B**	**ANP**	**B**	**ANP**
Percent allocation								
Foliage (%)	4.3	37.2	3.4	40.7	4.3	39.4	4.6	39.7
Branches (%)	52.6	38.0	20.0	26.2	19.5	14.2	44.5	32.8
Trunk (%)	43.1	24.8	76.6	33.1	76.2	46.4	50.9	27.8
Total aboveground								
Tree biomass (t/ha)	62.94	-	561.8	-	171.7	-	301.5	-
Total tree ANP (t/ha/yr)	-	8.15	-	12.9	-	11.9	-	12.8

Depending on the amount of light available, various vegetation types (such as herbaceous, ligneous, or woody) contribute to the net primary output. The net primary productivity of a savanna, a dry deciduous forest, and an evergreen oak forest is compared in Table 2.4 in terms of the respective contributions of herbaceous and ligneous (trees and shrubs) layers. The savanna's small tree population allows for enough of light to reach the ground surface, which has helped the herbaceous layer thrive and produce up to 71% of ANP in contrast to the tree layer where it is 29%.

Table 2.4. Net aboveground primary production of ligneous and herbaceous layers vegetation types (Source: Pandey and Singh (1992); Singh and Singh (1991); [3]Rawat and Singh (1988).

	Savanna[1]	**Dry deciduous**[2]	**Oak forest**[3]
Ligneous layer (Tree+ shrub) (%)	28.6	90.7	924
Herbaceous layer (%)	71.4	9.3	7.6
Total ANP (Trees herbs) (t/ha/yr)	10.4	11.0	15.3

Less light reaches the ground as the tree layer thickens, and the relevance of the herb layer as a contributor to net output drops. As a result, the herb layer only accounts for less than 8% of the ANP in the evergreen oak forest, while ligneous vegetation accounts for up to 92%. The leaf area index (LAI) significantly increases with canopy closure.

Net primary production typically peaks at LAI 4, although in mature forests, LAI may be higher than 8 when GPP is present. Fig. 2.4 As a result of increased cost of respiration brought on by a decrease in the photosynthetic capability of shaded leaves, changes in ecosystem metabolism assume maximal rate and NPP drops. However, net output in areas with plants that have leaves that are inclined downward (80 degrees) may keep rising up to a LAI of 7 or higher. Age-NPP relationships (Fig. 2.4) also partially reflect the impact of LAI. While respiration continues to rise with ageing, GPP reaches an asymptote with canopy closure, while NPP drops after reaching a peak at or shortly before canopy closure. Additionally, the intensity of the light has an impact on the link between net production and leaf area index. A stand of *Trifolium subterraneum*, for instance, exhibits optimal LAI (i.e., LAI at which net production was maximum) of less than 4 when light intensity is 100 cal/cm/day and of 7 when the solar radiation is 700 cal/cm2/day.

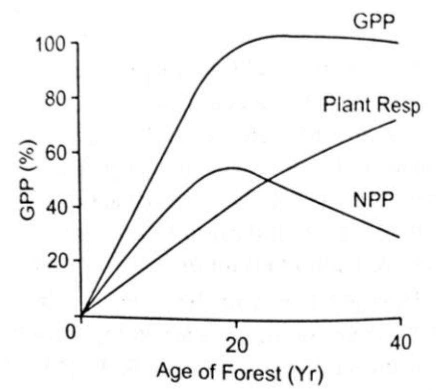

Fig. 2.4 Changes in the ecosystem metabolism during development of a forest from establishment to maturity (based on Waring and Schlesinger, 1985)

2.6.1 Factors Influencing Productivity

Plant production efficiency is influenced by a number of variables, including light intensity, light quantum efficiency, leaf arrangement, leaf area index, and plant type (C-3 or C-4). Warm temperatures, more rainfall, moving water that brings additional nutrients in natural ecosystems, irrigation application of fertilizers, and insect control in agricultural crops are environmental elements that aid in promoting net production.

2.7 MEASUREMENT OF BIOMASS AND PRIMARY PRODUCTIVITY IN FOREST ECOSYSTEM OF THE WORLD

Gross primary production is never measured directly; instead, it is typically estimated using measurements of net primary production plus estimates of plant respiration. The rate at which energy or biomass is produced per unit area/unit time is typically used to quantify productivity. Kilocalories per square meter per year (kcal/m2/yr), a unit of measurement for energy, or grams per square meter per year, a unit of measurement for biomass, are two ways to describe this rate. Here, a few common methods for calculating primary production in terrestrial and aquatic environments are explained.

- Light and Dark Bottle Method
- Radioactive Tracer Method
- Chlorophyll Concentration
- Carbon Dioxide Flux
- Harvest Analysis
- Dimension Analysis

2.7.1 Light and Dark Bottle Method:

In an aquatic ecosystem, such as a pond, this method is used to assess primary productivity. It is predicated on the idea that since one molecule of oxygen is produced for every fixed carbon atom, the amount of oxygen produced is proportionate to gross output. In paired bottles, water samples are collected from various depths. When two bottles are coupled, one is covered with black tape or aluminium foil to exclude light, while the other is left open to admit light and permit photosynthesis. By using Winkles' approach, the oxygen content of the bottles is calculated. With the use of thread, the bottles are suspended at the same depth as the sample collection point. The oxygen concentration in the bottles is measured after 24 hours and compared to the concentration at the beginning of the experiment.

The amount of respiration by producers and consumers is indicated by the fall in oxygen in the dark bottle, whereas the change in oxygen in the light bottle displays the net amount of oxygen consumed through respiration and oxygen generated. Estimates of gross productivity for a 24-hour period can be obtained by adding respiration and production together or by deducting the final oxygen concentration in the dark bottle from that in the light bottles. There are issues with this approach. Bacteria may be involved in some of the phytoplankton-related respiration. During the trial period, the phytoplankton population may increase in the bottle, but not in the dark bottle. Additionally, the technique is predicated on the idea that respiration in the dark is equivalent to that in the light.

2.7.2 Radioactive Tracer Method

One of the most effective and sensitive methods for determining primary productivity in aquatic ecosystems, particularly in lakes and oceans, is radioactive tracer method. It is based on the $_{14}CO2$ uptake measurement. The procedure is adding radioactive carbon as carbonate to a sample of clear water. Stable carbon is then digested into carbohydrates and turns into a component of phytoplankton protoplasm. To assess the level of radioactivity, the plankton material is taken out of the water, cleaned, dried, and placed in a counting chamber. Using the photosynthetic equation, the radioactive counts are utilised to determine how much carbon dioxide is fixed during photosynthesis. The estimation is predicated on the notion that the ratio of radioactive to stable carbon is constant. The method has some drawbacks. It does not distinguish between bacterial and phytoplankton respiration and the ability of various kinds of phytoplankton to exploit available light as well as the uptake and release of C-14 by bacteria and zooplankton.

2.7.3 Chlorophyll Concentration

This method is based on estimating the producer using the amount of chlorophyll and the amount of light passing through the water column. When plant physiologists discovered that photosynthesis and chlorophyll concentration are closely correlated at any given light intensity, they developed the approach as a result. Gross production can be calculated by extracting pigments and then measuring the chlorophyll content with a spectrophotometer if the assimilation ratio and the amount of light available is known. The technique was initially used to calculate primary productivity in huge quantities of water, like the ocean, but it was later applied to terrestrial ecosystems as well. This technique entails measuring the amount of phytoplankton chlorophyll in a particular volume of water.

All plants require chlorophyll in order to perform photosynthesis, hence the amount of chlorophyll in a given volume of water is a direct indicator of the total biomass, or standing crop, of phytoplankton that is present. Chemically, the chlorophyll is removed, and the chlorophyll content is measured. The concentration of chlorophyll and thus the biomass of phytoplankton are inversely proportional to colour intensity.
Chlorophyll concentration fluctuates with phytoplankton species and even within individual species cells, which presents a challenge for the method. Additional extraction methods might change the chlorophyll.

2.7.4 Carbon Dioxide Flux

One of the best techniques for determining primary productivity in terrestrial ecosystems, Carbon Dioxide Flux technique. Measurement of gross and net primary output is beneficial. It entails measuring the amount of carbon dioxide that is taken in during photosynthesis and released during respiration. In this method, a small sample of the community, such as a grassland sample taken on site, is enclosed in a transparent plastic tent. The sample can be as basic as a twig and its leaves, a piece of a tree stem, the ground cover, or even a fraction of the entire community. With the help of an infrared gas analyzer or by measuring the carbon dioxide concentration through absorption on a KOH column, air is drawn through the cage.

Any carbon dioxide that was taken from the entering air during the day is thought to have been absorbed by organic matter. Therefore, photosynthesis minus respiration equals the amount of carbon dioxide in the enclosure. A similar sample might be contained in a shadowy space. When photosynthesis ceases, the amount of carbon dioxide produced in the dark bag is a gauge of respiration. The sum of the carbon contents of the light and dark enclosures provides an estimate of gross production.

2.7.5 Harvest Analysis (Standing Crop Method)

The harvest method is frequently employed in terrestrial ecosystem estimation. It is especially helpful for predicting the production of cultivated land areas and communities of annual plants, when production starts at seedling or planting time and increases to its maximum at harvest, with little to no consumer usage.

The method includes drying the samples to a consistent weight and removing plants at regular intervals. A sample of plant biomass must be taken during the growing season in order to achieve an accurate assessment, and each species' contribution must be identified. During the growing season, several plant species attain their highest level of productivity at various times. Net primary productivity is calculated as the difference in standing crop biomass between harvest seasons given as grams per square meter per unit time. A calorimeter can be used to calculate the caloric value of a material, and biomass can be converted into calories. Then, the value is converted to kilocalories per square meter per year for net primary productivity.

Since low ground productivity demands samples of root biomass, which are quiet challenging, harvest method often offers information on above ground productivity. While some annual and agricultural plants roots may be dug out of the ground, doing so for grass and herbaceous species and even more so for forest trees becomes more challenging.

2.7.6 Dimension Analysis

Ecologists employ a modified harvesting method called dimension analysis because plants of various ages, sizes, and species make up the forest community. The standing crop and productivity can be estimated using this method using less thorough sampling. Measurements for dimension analysis include light, diameter, breast height, and diameter growth. Growth ring analysis is used to calculate age. The total weight of leaves and branches, both fresh and dry were also calculated. Frequently, the roots are removed and weighted. It is also assessed how much biomass there is in the ground vegetation litter.

Calculations are made on the annual net production of wood, bark, leaves, twigs, flowers, and buds. To determine the amount of trees and other vegetation that will grow in a sample unit, all of these details are employed. After doing a dimension analysis, the standing crop can be predicted using information such as (diameter) 2 x height x and annual productivity by observing present wood growth.

2.8 PLANT BIOMASS AND TURNOVER

Forests accumulate the most plant biomass among the different ecosystems, while the marine system accumulates the least (Fig. 2.5). Forest biomass often rises around the equator. But there are always exceptions. The Pacific Northwest old-growth *Sequoia sempervirens* forest, for example, may produce 3461 t/ha of stem biomass (Fujimori et al., 1976), compared to dry tropical forests, which may only produce 78–320 t/ha of total biomass (Murphy and Lugo, 1986). In general, the biomass of mature forests ranges from 20 to 60 kg/m2, that of woods from 4 to 20 kg/m2, that of shrub lands from 2 to 10 kg/m2, and that of deserts from 0.5 to 3 kg/m2. The biomass of the woods is primarily composed of perennial aerial structures, with roots making up only around one-fourth of the overall biomass (Table 2.5).

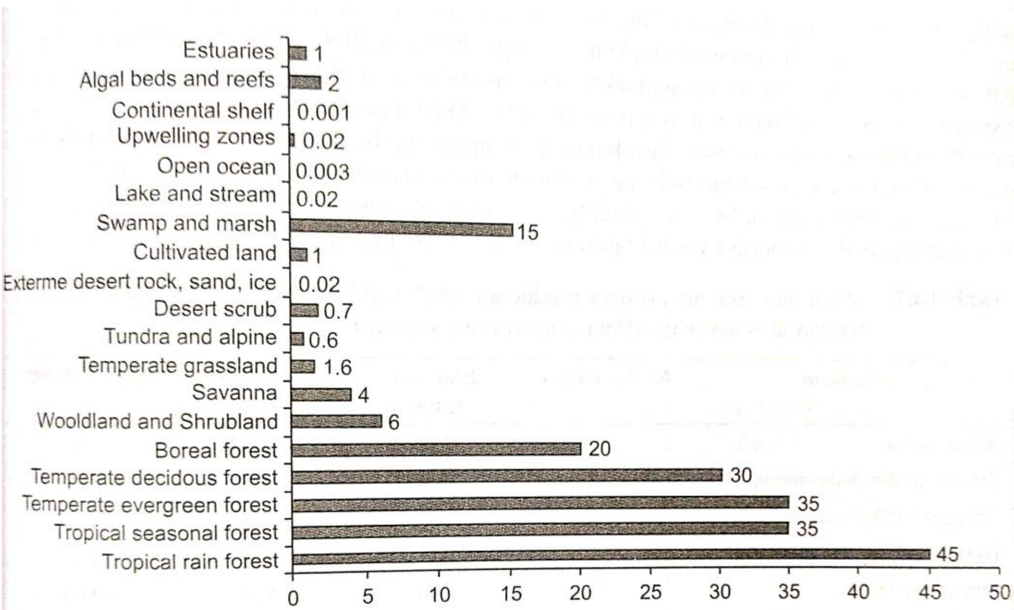

Figure 2.5: Trend in the variations in biomass of different terrestrial and marine ecosystems (source: Singh et al., 2014)

The rate of replacement of a system's component or of a substance in a component is known as the turnover rate, and according to Odum (1971), turnover may be defined as the ratio of productivity to content and can be expressed as rate fraction or as a turnover time. Turnover time is the reciprocal of turnover rate. The turnover rate is hence the ratio of production to biomass (P/B), which relates to the amount of time a given amount of substance stays in a defined compartment of a system. In a dry deciduous forest, for example, the foliage biomass is 2.7 t/ha and the net foliage output is 3.05 t/ha/yr (Table 2.3). Thus, the P/B ratio is 1.13, and the turnover time is 0.88 years (the reciprocal of the P/B ratio). This indicates that the foliage is totally regenerated in less time than a year (more than 10.5 months). Branch production in the same situation is 33.07 t/ha and 3.12 t/ha/year net branch production. The branch biomass turns over at a rate of 0.094 (or 9.4 percent annually) during a period of 10.6 years. As a result, more dynamic components of the ecosystem have a higher rate of turnover, Similarly, for dry deciduous forest the total aboveground tree biomass is 62.9 t/ha and net aboveground primary production is 8.2 t/ha/yr.

These numbers show that in this forest aboveground tree biomass is being replaced at a rate of 13% each year (P/B=0.130), with a turnover time of 7.7 years. In comparison, the turnover rate and time for the above-ground tree biomass of the oak forest are just 4.2% annually and 23.6 years respectively. Phytoplankton has a P/B ratio of 20–40 with a turnover time (B/P) of 0.05–0.025 yr (or 9–18 days). In comparison to plant biomass in grassland, which is replenished at a higher rate than that of a forest, phytoplankton biomass turnover is faster (Table 2.5). Low P/B ratios are indicative of substantial development of forest-supporting tissues. High P/B ratios in grasslands and phytoplankton suggest that herbivores have more energy available to them. In general, slower turnover results from longer lifespans and greater biomass accumulation. In comparison to cold habitats, plant biomass in warmer ecosystems recycles more quickly (Table 2.5).

Table 2.5. *Mean biomass, net primary production (NPP) and turnover of biomass in selected terrestrial ecosystems (Data from various sources).*

Ecosystem	**NPP (t/ha/yr)**	**Biomass (t/ha)**	**Turnover rate**	**Turnover time (yr)**
Boreal forest	7.5	200	0.037	26.7
Temperate deciduous forest	11.5	350	0.033	30.4
Temperate tall grass prairie	11.0	24	0.46	2.2
Tropical sub humid grassland	21.0	22	0.95	1.05
Tropical dry forest	15	200	0.07	14.3
Tropical wet forest	30	500	0.06	16.7

2.9 EFFICIENCY OF ENERGY CAPTURE

The efficiency of energy capture (EC), efficiency of photosynthetic energy utilisation, efficiency of energy conversion, or photosynthetic efficiency is the rate at which radiant energy is converted by photosynthesis into chemical energy. This is given by the formula:

$$EC(\%) = \frac{Energy\ stored\ in\ primary\ production}{Incident\ photosythetically\ active\ radiation} X100$$

In the northern hemisphere, the proportion of incident short-wavelength radiation that is photosynthetically active (PAR) (390–710 nm) is on average 47% (45–50%). Under non-limiting favourable conditions, large algal cultures and individual leaves may reach as high as 15% EC (in some C4 grasses, up to 24%). For stands or communities of plants and for the growing season, it is conventional and more appropriate to compute EC on the basis of net primary production rather than gross primary production. Several elements, including sub-optimal levels of soil water, nutrients, light (leaf shade), and temperature, put restrictions on photosynthetic efficiency in natural environmental conditions.

The majority of terrestrial plant communities exhibit a growth-season energy capture efficiency of between 1 and 3 percent of the PAR. Growing season EC for temperate grasslands ranges from 0.65 to 1.4% (for desert grassland 17%) and from 0.23 to 2.1% on an annual basis for tropical grasslands. Cooper (1970, 1975) reported EC values of up to 9.3% for tropical grasses (C4) and 2.2–7.8% for canopies of temperate grasses (C3) during their peak growth periods. The range of EC during the entire growth season is between 1 and 3%. The typical range of EC for forests appears to be between 0.9 and 2.9 percent.

2.10 HUMAN USE OF PRODUCTIVITY

A total of 172.5 x 1015 g product is thought to be produced by the earth, of which the terrestrial habitats account for 2/3. Less than 7% of the earth's surface is covered by tropical forests, but they account for around 25% of all productivity. In addition to using them directly as food and fibre, humans also use photosynthetic products indirectly as nourishment for domesticated animals. Only 4% of the terrestrial net primary production is directly utilised by humans, animals and other organisms as food, fibre, or fuel, according to estimates made by Vitousek et al. in 1986. About 44% of production is either destroyed by human activities like permanent settlements, burning of biomass, logging, and desertification, or taken over by people as non-edible production. All other life forms can therefore access only 50% of land productivity and the majority of aquatic production. Approximately 5 to 8% of the world's aquatic activity is collected for human use, mostly in areas with productive estuaries, lakes, and streams.

Rojstaczer et al. (2001) recently provided an estimate of 10 to 50% utilization of terrestrial photosynthetic products based on large-scale measurements and taking into account uncertainties associated with the amount of agricultural lands, forests permanently cleared for human habitation, and the precise extent of shifting cultivation in secondary tropical forests. In order to maintain the natural equilibrium, it is important to comprehend the energy requirements of typical food webs in various natural and agricultural systems.

2.11 SUMMARY

In nature, energy comes in a variety of shapes and forms. Energy cannot be made or destroyed. Energy is transformed from one form into another. There are two laws of thermodynamics that regulate how energy is used to cycle nutrients in the environment. Energy in ecosystems moves in a single direction. As it moves from one trophic level to another, energy is lost. However, the net energy of ecosystem inflow and outflow are balanced.

Productivity is the amount of energy held in reserve by living tissues at various trophic levels during a specific period of time. The ecosystem's productivity is expressed in various ways, including GPP, NPP, NCP and secondary production. Ecosystems are inefficient at transferring energy because energy is lost when it shifts from one trophic level to another. The ecological efficiency is the ratio of energy between two trophic levels or within one trophic level.
These energy ratios can be used to compare how different ecosystems use energy. Dynamic stability of ecosystem allows them to resume their equilibrium condition after being disturbed by negative feedback linkages. A large disturbance, however, will permanently destroy such ecological regulation.

Plants utilise some of the total energy fixed by photosynthesis as energy for maintenance. The rest of it is used to generate new plant biomass and to feed herbivorous animals. The amount distribution and turnover rate of biomass affect several important features of the community physiognomy, including the variety of herbivores and the activity of decomposers. These interactions are governed by the extent to which plants take in light, convert it into photosynthesize, and then convert that photosynthate into biomass.

Productivity is measured using a variety of techniques. A few of the techniques used to estimate productivity include computing photosynthesis and respiration rates, estimating changes in biomass over time, correlating biomass to an easily measured variable to estimate standing crops, and using computer models to compute productivity over large spatial scales and forecast responses to changing environmental conditions. The productivity of terrestrial ecosystems is influenced by many factors, including carbon dioxide, light, temperature, precipitation, nutrients and soil texture. The most productive ecosystems are those with the highest concentrations of these elements, which ultimately maximise photosynthesis. Because they affect and interact with one another simultaneously, these factors frequently operate outside of equilibrium.

2.12 GLOSSARY

ATP: Adenosine triphosphate (ATP) is the source of energy for use and storage at the cellular level
Autotrophic producers: Autotrophs are the producers in the food chain that can produce their own food using light, water, carbon dioxide, or other chemicals.
Carnivores: A carnivore is an organism that mostly eats meat or the flesh of animals
Gross Primary Productivity (GPP): GPP refers to the total amount of organic matter produced.
GtC : gigatonnes of carbon; 1 GtC is equal to 10^9 tonnes of carbon or 10^{12} kg.
Mychorrhizal symbionts: A mycorrhiza is a symbiotic association between a green plant and a fungus. The plant makes organic molecules such as sugars by photosynthesis and supplies them

to the fungus, while the fungus supplies the plant with water and mineral nutrients, such as phosphorus, taken from the soil.

NADPH: Reduced nicotinamide adenine dinucleotide phosphate (NADPH) is an essential electron donor in all organisms.

Omnivores: an animal or person that eats a variety of food of both plant and animal origin.

Photosynthesis: Photosynthesis is the process by which plants use sunlight, water and carbon dioxide to create oxygen and energy in the form of sugar.

Standing crop: The mass of living material at a trophic level at a particular time.

Temporal: It is used to indicate the passage of time or describe the position of an event in time

Thermodynamics: Thermodynamics is a branch of physics which deals with the energy and work of a system.

2.13 SELF ASSESSMENT QUESTIONS

2.13.1 Multiple choice questions

1. Primary productivity of an terrestrial ecosystem depends upon
   a. Photosynthetic capacity of plants
   b. Variety of environmental factors
   c. Availability of nutrients
   d. All of the above
2. The basic requirements for any ecosystem to function and sustain is
   a. Enormous amount of water
   b. Constant input of solar energy
   c. Fertile soil
   d. Oxygen
3. The amount of biomass or organic matter produced per unit area over a time period by plants during photosynthesis is called as
   a. Biomass production
   b. Primary production
   c. Secondary production
   d. Assimilation
4. Which of the following is not correctly matched
   a. Productivity- rate of biomass production
   b. Gross primary productivity of earth- rate of productivity of organic matter during photosynthesis
   c. Net primary productivity- available biomass for consumption by heterotrophs
   d. Secondary productivity – formation of new organic matter by producers
5. The secondary productivity means
   a. Rate of increase in the biomass of autotrophs
   b. Rate of increase in the biomass of heterotrophs
   c. The rate at which the organic molecules are used by an autotroph
   d. The rate at which inorganic molecules are used by an autotroph.
6. Net primary productivity is the gross primary productivity minus
   a. That is consumed by herbivores

   b. That which is consumed by producer in metabolism
   c. Secondary productivity
   d. Loss due to mortality
7. What do you mean by productivity?
   a. Rate of biomass production
   b. Amount of biomass production
   c. Biomass produced in an area
   d. Biomass produced in a time period
8. The mass of living material at a trophic level at a time is called
   a. Gross primary productivity
   b. Standing state
   c. Net primary productivity
   d. Standing crop
9. Which of the following contributes the maximum to the net primary productivity?
   a. Ocean ecosystem
   b. Terrestrial ecosystem
   c. Pond ecosystem
   d. Man made ecosystem
10. Primary production is expressed in terms of
   a. Grams
   b. Grams/year
   c. Gram/m^2
   d. Gram/ m^2/year

Answer Key 2.13: 1. a, 2. b, 3. b. 4. c, 5. b, 6. b, 7. a, 8. d, 9 b, 10, d.

2.14 REFERENCES

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2.15 SUGGESTED READINGS

- J.S. Singh, S. P. Singh, S. R. Gupta (2014) Ecology Environmental Science and Conservation. S. Chand & Company Pvt. Ltd. 7361, Ran Nagar, New Delhi
- Sharma P.D. Ecology and Environment. Rastogi Publication.

2.16 TERMINAL QUESTIONS

2.16.1 Short answer type questions

1. Write a short note on photosynthetic capacity.

2. Write a short note on distribution of biomass on earth.
3. Write briefly about plant biomass and turnover.
4. Discuss in brief the efficiency of energy captured
5. Write shortly on human use of productivity.

2.16.2 Long answer type questions

1. Discuss in detail the methods of measuring biomass and primary productivity in forest ecosystem.
2. Give a detailed account of allocation of Net primary production and accumulation of biomass.
3. Write a detailed account on photosynthetic pathways and their significance.

UNIT-3- LITTER FALL IN FOREST ECOSYSTEM

Contents:

3.1 OBJECTIVES

After reading this unit the learners will be able to:

- Understand the types of litter
- Understand the forest litter mass
- Understand various factors affecting forest litter
- Understand the determination of litter fall

3.2 INTRODUCTION

One of the most recognizable aspects of a forest ecosystem is the forest floor, also known as detritus, duff and the O horizon. It mostly comprises of vegetative elements that have been shed such as leaves, branches, bark and stems which are present above the soil surface in varying states of decomposition. The forest floor is primarily made up of non-living organic matter, although it also contains a broad range of animals and plants. Due to the abundance of decomposers and predators, usually in the form of invertebrates, fungi, algae, microorganisms, it is one of the most biologically diverse parts of the ecosystem. In tropical woods, where rates of metabolism and species variety are far higher than in colder regions, certain (adapted) plants could be more prominent.

The growing plant, forest floor and soil are the main containers for storing organic materials and nutrients within systems. The transmission of nutrients through the biogeochemical cycle depends on the forest floor, which acts as a link between the soil and the above-ground live vegetation. The breakdown of organic matter in the forest floor and soil surface provides a significant fraction of the nutrients needed by forest ecosystems, while litter fall contributes a significant amount of the energy and carbon fixed by forests that are periodically added to the forest floor. The decay of shed plant materials, especially the nutrient-rich foliage, is strongly related to the continued productivity of forests. The forest floor is another significant fuel source for forest fires.

3.3 FOREST LITTER

Plant litter, also known as leaf litter, tree litter, soil litter, litter fall, or duff is dead plant matter that has fallen to the ground, including leaves, bark, needles, twigs and cladodes. The nutrients contained in this detritus, or dead organic waste, are added to the soil's top layer, also known as the litter layer or O horizon (O for organic). Litter plays a significant role in the dynamics of ecosystems because it indicates ecological productivity and can help in determining regional nutrient cycling and soil fertility.

Fresh, undecomposed, and readily recognisable (by species and type) plant waste is referred to as litter fall. Anything from leaves, cones, needles, twigs, bark, seeds or nuts, logs or reproductive organs can be used in this (e.g. the stamen of flowering plants). Coarse litter refers to objects with a diameter greater than 2 cm, whereas fine litter or litter refers to anything with a diameter less than that. The type of habitat has the biggest impact on the kind of litter fall. For example, around 70% of the litter that falls in forests is made up of leaf tissues, but the amount of woody litter tends to rise with the age of the forest. Because there is so little aboveground perennial tissue in grasslands, there is extremely little yearly litter fall, which is almost equal to net primary production.

In soil science, soil litter is divided into three layers that develop on the surface of O Horizon. The L, F, and H layers are as follows:

- L- organic horizon, which is distinguished by largely undigested plant matter (described above).
- L layer is followed by the organic horizon F, which is characterized by a buildup of partially degraded organic matter.
- The organic horizon H, below the horizon F, is characterized by the buildup of mostly undetectable completely disintegrated organic materials.

Seasonality, plant species, climate, soil quality, elevation and latitude all have an impact on the thickness of litter layer, rate of decomposition and nutrient content. When collecting and classifying plant litter fall throughout the year, it is possible to determine that each individual species of plant experiences seasonal losses of specific plant parts, which in turn affects the thickness of the litter layer. This is where the most extreme variability of litter fall is thought to be related to seasonality. The bulk of the debris that falls in tropical regions occurs in the early wet season and toward the end of the dry season. The decomposition rate for any particular location will vary as a result of the seasonal variations.

The rates and thickness of litter fall are also strongly influenced by latitude. In particular, litter fall decreases as latitude rises. Due to the quick decomposition in tropical rainforests, the litter layer is thin, however in boreal forests; the rate of decomposition is slower, resulting in the buildup of a thick litter layer, also known as a mor. The inverse relationship between this trend and net primary productivity indicates that the decomposition rate is mostly responsible for the formation of organic matter.

Surface debris makes it easier for rainwater to be captured and absorbed into the deeper soil layers. The release of clay and silt particles that clog soil pores is prevented by soil litter, which shields soil aggregates from the impact of raindrops. Clay and silt particles released into the air decrease the soil's ability to absorb water and enhance cross-surface flow, which speeds up soil erosion. Additionally, soil litter prevents wind erosion by retaining soil moisture and acting as a barrier to the movement of dirt.

Accumulation of organic matter also helps shield soil from harm caused by wildfires. Depending on the season and the severity and intensity of the wildfires, the soil debris can be totally eliminated. The amount of soil litter accumulation and vegetation density has both decreased in areas with frequent wildfires. The depth of plant litter is influenced by climate as well. Organic matter layers and horizons are often thinner in humid tropical and subtropical climates because of year-round breakdown and dense, expanding flora. Because the growing season is shorter in temperate and cold areas, trash tends to build and disintegrate more slowly.

Litter fall and net primary output are closely related. The biggest portion of net primary output in every terrestrial ecosystem is dissipated to herbivores and litter fall. Global patterns of litter fall and net primary productivity are similar because of their interdependence. All terrestrial ecosystems produce a significant amount of above-ground net primary output from plant litter, which can be composed of fallen leaves, twigs, seeds, flowers, and other woody debris. The process of recycling the nutrients from the plant litter back into the ecosystem is significantly aided by fungi.

3.4 TYPES OF FOREST LITTER

3.4.1 Coarse woody debris (CWD) or coarse woody habitat (CWH)

The terms coarse woody debris (CWD) and coarse woody habitat (CWH) refer to dead trees that have fallen to the ground and the remains of huge branches in forests and rivers or wetlands. Many of the same roles are performed by dead standing trees known as snags. Depending on the source, woody debris must be at least 2.5–20 cm (1–8 in) in diameter to be considered as coarse.

The forest management authorities all around the globe have been urged to allow dead trees and woody debris to stay in woods since the 1970s because this increases biodiversity by recycling nutrients locked in the wood and supplying food and habitat for a variety of organisms. The quantity of coarse woody debris is considered to be a significant component in the assessment and regeneration of temperate deciduous forest. In wetlands, particularly in deltas where woody debris builds up, coarse woody debris is also important. Natural tree death, disease and insects, as well as catastrophic occurrences like fires, storms and floods, are the main causes of coarse woody debris.

An old growth forest with its dead trees and woody debris lay where they fell to nourish new plants, constitutes the perfect woodland in terms of recycling and regeneration. Dead wood makes up to 30% of all woody biomass in healthy temperate forests. Recent investigations found that recently harvested forests had essentially no CWD and less fallen debris than unmanaged woodlands that had been left untouched for many years.

CWD levels were reported to range from 72 metric tons/hectare (64,000 pounds/acre) in drier locations to 174 t/ha (155,000 lb/acre) in moister sites in old age Douglas fir forests of the Pacific Northwest of North America (Spies et al., 1988). Woldendrop and Keenan (2005) suggested that depending on the type of forest, mean CWD levels in Australian native forests range from 19 t/ha (17,000 lb/acre) to 134 t/ha (120,000 lb/acre).

3.4.1.1 Role of CWD in nutrient cycling:

The decomposition of coarse woody waste and the subsequent recycling of its nutrients, including carbon, nitrogen, potassium and phosphorus are necessary for the survival of all living organisms. By consuming dead wood, saprotrophic fungi and detritivores like bacteria and insects release nutrients by transforming it into various types of organic matter that can be ingested by other species and a decomposition resistant organic substance called humus. The majority of the organic matter in the lower soil profile is made up of humus. Humus ensures that nutrients from decomposing and dead organisms are present in the soil. However, the CWD itself lacks many vitally needed nutrients. In order to satisfy nutritional needs of consumers, CWD must first be nutritionally supplemented by the transportation of nutrients from outside of CWD. Therefore, CWD is a significant contributor to the cycles of soil nutrients. Although CWD does not contain a much of nitrogen, it nonetheless adds nitrogen to the ecosystem by serving as a host for free-living, nonsymbiotic nitrogen-fixing bacteria.

Researches shows, coarse woody debris can significantly contribute to the biological sequestration of carbon. Using photosynthesis, trees capture atmospheric carbon and store it in their wood. After the trees die, some of the carbon from CWD is transferred into the soil by fungi and other saprotrophs. In old-growth woods, this sequestration can last for hundreds of years.

3.4.1.2 Role of CWD in providing microhabitat

Coarse woody debris contributes to the preservation of the biodiversity of forest ecosystems by offering a variety of species with food and microhabitats. CWD is necessary for up to 40% of all forest wildlife. According to studies conducted in western North America, only 5% of living trees contained living cells by volume, compared to 40% of dead wood, which was primarily made up of fungi and bacteria. The process of metabolizing the biomass is continued by colonizing organisms that reside on the cambium and sapwood fragments of dead trees. These organisms promote decomposition and lure predators that feed on them.

Bacteria, fungi, lichens, mosses and other types of plants are among the organisms that depend on CWD for habitat or as a food source. In the animal kingdom, invertebrates like termites, ants, beetles, snails, amphibians like salamanders, reptiles like the slow-worm, as well as birds and small mammals are also included. In the cavities of dead tree trunks, one-third of all woodland birds reside. Living in dead trees are woodpeckers, tits, chickadees and owls while grouse find shelter behind woody debris.

Coarse woody debris serves as a habitat for some plants. In addition to regenerating ferns and trees on top of logs, mosses and lichens may cover logs. The term ‘nurse logs’ refers to substantial CWD fragments that serve as habitat for herbs, shrubs and trees. By acting as barriers to browsing animals, CWD can also shield young plants from herbivore damage. When an ecosystem is severely disturbed, such as by a wildfire or logging, species might seek shelter in coarse woody debris.

The Trees for Life organisation discovered in Glen Affric, Scotland, that the black tinder fungus beetle (*Bolitothorus reticulatus*) depend on a specific fungus (*Fomes fomentarius*), which can only be found on dead birch trees. Another bug that needs decaying Scots Pine in order to breed is the pine hoverfly (*Blera fallax*). Coarse woody debris in the temperate deciduous woods of Eastern North America provides home for anything from ferns to salamanders. It serves as a crucial indicator for analysing and regenerating this kind of forest.

3.4.1.3 CWD, Wetlands and Rivers

By altering the flow of water and silt, fallen debris like trees in streams provide cover for fish, amphibians and animals. Many species of turtles may also use coarse woody debris for resting. Near wetlands, musk turtles may lay their eggs under logs.

3.4.1.4 CWD and Soil:

Coarse woody debris, especially on slopes, stabilizes soils by reducing the rate at which organic matter and mineral soil are carried downward. Behind CWD, a buildup of leaves and other detritus promotes decomposition and precipitation infiltration is also improved. CWD slows down soil moisture evaporation in dry weather and creates moist microhabitats for humidity sensitive species.

3.4.1.5 CWD and Wildfire

Coarse woody debris can be a substantial fuel source for wildfires in forests that are prone to fire. Larger and more severe fires may result from the presence of abundant fuels. In particular in forests where fire suppression has led to the buildup of fuels, CWD may be managed to lower fuel levels. The retention of CWD for its habitat and other benefits should be balanced against any reductions in CWD for fire safety. Fire managers categorise CWD as 1000-hour fuel, referring to the length of time required for the moisture content of the wood to respond to the environment.

The amount of CWD left standing or lying depends on what might be found to be safe in the course of reasonable fire prevention in certain subtropical areas, such as Australia, where bushfire poses a serious threat. However, invertebrates take shelter in or under dead tree logs when fires do break out. The fact that bears in Canada seek dead tree logs to feed on ants and beetles in it which has led the authorities to allocate a sufficient amount of coarse woody waste for these uses. The use of CWD as barriers to stop deer and elk from destroying young trees is common in North America as well.

3.4.2 Large woody debris

The logs, sticks, branches and other pieces of wood that fall into streams and rivers are referred to as large woody debris (LWD). The flow and shape of stream channel may be affected by this material. The three main sources of flow resistance large woody debris, grains and the structure of the stream bed have a significant impact on the structure of stream channel. Because watershed management removed some stream channels for flood management and aesthetic purposes, some stream channels have less LWD than they would naturally.

Because of the implications for forestry management, the study of woody waste is significant. Plantation reduction can decrease the likelihood that LWD will be attracted to nearby streams. In the Pacific Northwest, the creation of pools that serve as salmon habitat depends on the presence of big woody debris. Large woody debris entrained in a stream may also contribute to erosion and scouring around and beneath the LWD. The ratio of the piece's diameter to the stream's depth, as well as its embedding and orientation, all affect how much scouring and erosion occur. While quickening flow in the congested area downstream of the obstruction, large woody debris restrict the flow through a bend in the stream.

3.5 FACTORS INFLUENCING THE ACCUMULATION OF LITTER IN FOREST ECOSYSTEMS

There are a number of natural and anthropogenic elements that have an impact on the accumulation of litter in forest ecosystems. Each of these factors either alone or in combination has a significant impact.

3.5.1 Natural and anthropogenic disruption

Forests are evidently complicated systems with a range of variables and these variables interact with one another over a wide range of geographic regions (Scheer 2009; Krishna and Mohan 2007). In contrast to stands with higher structural complexity, stands with lower structural complexity typically have lower species variety and support less stability and ecological functioning (Argao et al. 2009; Scheer 2009). The composition and structural characteristics of forests are highly susceptible to degradation due to anthropogenically induced disturbances such as crop and livestock cultivation, logging, fires and the removal of trees for firewood. The quantity and quality of yearly litterfall, litter depth, stand basal area, volume of coarse woody debris and understory density can all be negatively impacted by both natural and artificial disturbances (Mishra et al. 2004).

The degree of disturbances at different places will have an impact on the percentage of litter such as leaf litter, reproductive parts, and twigs (Seta and Zerihun 2018). In comparison to highly disturbed sites, less disturbed sites produce more yearly litterfall (Wiebe 2014; Seta and Zerihun 2018). Lower structural complexity will be achieved by consistently cutting snags and removing logs for use as firewood (Wiebe 2014). The understory will be eliminated and altered as a result of the construction of roads for timber extraction and logging operations (Mishra et al. 2004; Melo et al. 2013).

Researches shows that the level of difficulties was also three to five times less in logged plots as compared to undisturbed plots (Mishra et al. 2004; Wiebe 2014). According to Aravena et al. (2002) the undisturbed plots have a higher basal area than the plots with combined fire and logging, , understory density basal area, and litter depth of stands are seriously affected by the presence of cattle alone or in association with other disturbances (Franklin et al. 2002; Gonzalez et al. 2005). Additionally, livestock grazing and destroying the herbaceous layer had a bigger detrimental impact on the regeneration of forests and the structure of the understory (Gonzalez et al. 2005).

3.5.2 Seasonal variations and climatic factors

The production of litter fall has a significant effect on the exchange of carbon from terrestrial sources to the atmosphere, but this effect can vary with the seasons (De Weirdt et al. 2012; Zhang et al. 2014). In other words, environmental factors like light, temperature, and rainfall determine the variation in litterfall among the species within the forests (Bray and Gorham 1964; Qiulu et al. 1998; Zhang et al. 2014). This has a significant impact on the dynamics of ecosystem carbon and nutrient cycling (Franklin et al. 2002).

According to Seta and Zerihun (2018), seasonal rainfall and environmental temperature have a major effect on litterfall production. Rainfall has a dual effect on litter formation since it may promote the shedding of senescent leaves and may also lead non-senescent leaves to shade during periods of intense precipitation (Liu 2012). (Scheer 2009). Contrary to popular opinion, Zhang et al. (2014) found that in tropical forest ecosystems, wet season litterfall production is lower than dry season litterfall production. As stated by a number of researchers (including Sundarapandian and Swamy (1999), Qiulu et al. (1998), Liu (2012) and Giebelmann et al. (2013)), peak litterfall mass was seen in the seasons of autumn, summer and spring as compared to winter.

All of these research demonstrated that while the amount of litter produced in tropical forest ecosystems changes depending on the age and habitat of tree species, it is greatly influenced by the seasonal and local climate conditions.

3.5.3 Species diversity

In addition to fine litter fall, such as roots, reproductive parts and leaves Taylor et al. (1989) found that 10–30% of net primary production (NPP) enters the aboveground litter layer and tropical forest soils as well. Accordingly, it is expected that the total input of dry plant matter from dead plants that penetrates soil is 12 tonnes per hectare each year. The fact that distinct forest ecosystems are made up of a range of different tree species, however, means that each one contributes to the annual litter intake in a different way. This has a significant impact on the total litter production and litter pool (Taylor et al. 1989; Gonzalez et al. 2005).

3.5.4 Pattern of vegetation structure

Ruiz-Benito et al. (2014) studied that the basal area of the tree strata, which positively correlates with litter productivity, is also positively correlated with the strong presence or dominance of specific species due to a selection impact. Ruiz-Benito and coworkers also studied that a significant leaf loss may occur throughout the year in dominant species, which have higher basal areas and volumes and this increases nutrient addition to the soil. Litter production is directly impacted by the basal area of species, volume and level of dominance. Meanwhile in some tree species, basal area, volume and dominance, for instance, have been shown to have positive relationships in the top stratum but negative relationships in the lower stratum.

3.5.5 Age, tree density and tree basal area

Vivanco and Austin (2008) studied that the litter production increased as the age of *Tectona grandis* increased. Contrarily, Bray and Gorham (1964) discovered that litterfall has a linear relationship with age alone because litter production may decline as the tree canopy closes. Although tree age did not affect litter fall output on its own, other workers (Chaubey et al. 1988; Mishra et al. 2004) have demonstrated that age, density and basal area, all in combination, could have a significant impact on litter production.

3.5.6 Importance of litter production in functioning of forest ecosystem

The practical understanding of the consequences of litter is well established in many traditional agricultural methods. Plant litters have been used for a variety of things, such as mulching in low-tech agriculture, gardening, and modern horticulture (Gartner and Cardon 2006), protecting against weed infestation (Cornwell et al. 2008), preventing soil freezing and soil erosion (Cornwell et al. 2008), improving mine remediation (Giebelmann et al. 2013), preserving humidity and reducing evapotranspiration, and enhancing the function of the forest ecosystem

In forest ecosystems, nutrient cycling directly effect productivity by making nutrients available for plant development (Krishna and Mohan 2007). Major production is typically measured by litter generation because litter is the primary source of soil organic carbon (SOC) and plant nutrient cycling (Vitousek 1982). In the forest ecosystem, litter is another measure of primary production in addition to tree heights and diameters (Vitousek 1982). Although the breakdown of plant litter governs the carbon cycle, it also regulates the amount of carbon dioxide (CO2) in the atmosphere, which in turn affects the temperature on earth (Swift et al. 1979; Krishna and Mohan 2007).

The decomposition of litter, in which the litter is broken down into smaller pieces and ultimately mineralized into inorganic compounds, is caused by the interaction of decomposers, litter quality, and abiotic variables (Cadish and Giller 1997; Chapman and Koch 2007). The influence of the following key processes (Mishra et al. 2004; Chapman and Koch 2007; Lira et al. 2007) can be used to understand the changes in litter over time.

a. Leaching is the process of removing soluble material to a deeper soil layer where it can be further broken down by microbial organisms.
b. Fragmentation physically reduces large pieces of debris into smaller ones, generating new surface areas for decomposers.
c. Chemical alteration is the change in the chemical composition of the litter. It occurs when the decomposers identify molecules or utilise only a portion of a molecule to produce decomposer biomass.

The decomposition of litter contributes towards the most important ecosystem processes such as conversion of dead organic matter into carbon dioxide and availability of nutrients for microorganisms and plants (Cadish and Giller 1997; Mishra et al. 2004). Furthermore the capacity of soil to absorb water and nutrients is enhanced by the addition of litter to the various soil layers (Cadish and Giller 1997; Chaubey et al. 1988). The high species diversity of forest trees may result in an increase in the soil organic carbon and C/N ratio (Vitousek and Sanford 1986).

Additionally, diversified combinations outperform monocultures in terms of litter outputs (both quantity and quality), which could raise aboveground productivity and carbon stock (Chapman and Koch).

According to Scheer (2009), the reduction in the amount of forest litter produced as a result of climate change has led to a drop in the amount of organic matter and nutrient concentrations in the soil.

A common environmental friendly technique for evaluating the productivity and turnover of organic materials in the forest is litter mass compilation. It influences the moisture state, run-off pattern, and nutritional characteristics of the land (Garkoti & Singh, 1995) and is one of the most significant mechanisms by which nutrients are returned to the forest floor (Bellingham et al., 2013). The study of litter fall dynamics and available litter nutrient stocks in a given period of time is an essential component of terrestrial ecosystem functioning (Maritus et al., 2004). To calculate the annual return of elements and organic matter to the soil, one must take into account both the biomass of the litter and its chemical composition (Hansen et al., 2009). Density, basal area, age structure, seasons, and altitude all have a significant impact on litterfall dynamics in natural forest ecosystems (Sundharapandian & Swamy, 1999; Stonhlgren, 1988). According to Vitousek et al. (1994), the altitudinal difference affects the microclimate and the activities of microorganisms that slow down or speed up the turnover of leaf litter.

3.6 DETERMINATION OF LITTER FALL IN TERRESTRIAL ECOSYSTEM

During the process of litter fall, a significant portion of the terrestrial aboveground net primary output is transported to the soil surface. Senescent leaves, dead twigs and branches, bark, dead bole, dead blooms and fruit are examples of aboveground litter or debris that occasionally or continuously fall to the ground. Similar to this, fine and coarse roots make up the underground litter or detritus which is the initial stage for saprophagic or detritus food chain.

3.6.1 Aboveground litter fall: Plant species and communities differ in the pattern of litter fall. In temperate coniferous and equatorial evergreen forests, litter fall is largely a continuous process, but there may be distinct range. The majority of litter fall in deciduous forest occurs just over a few months of the year.

3.6.2 Below ground litter: The significance of roots as detritus contributors in grasslands has long been known (because to their greater proportion in biomass) but the importance and extent of their contributions to the total detritus pool are only currently beginning to be acknowledged for forest ecosystems. Fine root inputs to total detritus may range from 20–77 percent, according to Vogt et al. (1986). In yellow poplar stand, Douglas fir stand and silver fir stands, belowground inputs to total detritus transfer may be 2.3 to 5.2 times more than aboveground transfers.

The biomass and chemical composition are measured for litter. The Litter traps are useful for collecting litter. They come in a variety of sizes and designs. They are generally boxes made up of wood or metal those are open at the top and bottom. A nylon or wire mesh screen is attached to the bottom for water drainage. For areas with more sunlight, fibre glass mesh has been recommended since UV light will break down nylon and other materials (Harmon and Lajtha 1999).

The dimension and contents of litter bag is important factors in litterbag investigations. In various plant communities where leaves are large and a larger litterbag is suitable, litterbags of 20 X 20 cm are generally used (Robertson and Paul 1999).

Each box has legs so that when it is set on the forest floor, the bottom will be approximately 10-15 cm above the ground. On the forest floor, the traps are randomly distributed. Litter that enters the traps is periodically collected, separated into components (such as leaves, bark, twigs, fruits, etc.), and sorted out on the basis of species. Afterwards, these components are dried and weighed. The total litter fall for annual cycle is then determined by combining the data from periodic collections.

Litter fall must be measured at least once per week during the rainy season due to the increased rate of accumulation. Measurements may be reduced to once monthly or even twice monthly in some locations during the dry season. When taking samples, only include plant parts that are inside the trap or directly above it. For example, long branches are chopped and only the part of it inside the trap is collected.

After the sample has been taken, it is sorted into the following categories viz; leaves, reproductive organs, fine woody material and residue. Any animal part or adherent mineral material should be discarded. The samples should then be dried, weighed after being added to obtain the biomass and stored for chemical analysis.

3.7 SUMMARY

In a forest, litter production is defined as the process of shedding of vegetative and reproductive plant parts during a specific time period as a result of senescence, stress, mechanical causes (such as wind and storm), a combination of these elements or death and weathering of the entire plant. It is composed of dead plant parts that are detached from the standing plant (Krishna and Mohan 2017). Litter fall is an essential source of nutrients and organic matter for controlling forest productivity and energy flow since it phenologically reflects the impact of climate change on the forest (Hansen et al., 2009) and also supports nutrient cycling (Li, 2014). Leaf litter and other types of litter make up the majority of the litter fall (Bisht et al., 2014). However, compared to other types of litter, such as twigs, roots, flowers etc, the proportion of leaves in the litter is always larger. In tropical forests litter might completely degrade in a year (Meentemeyer, 1984).

According to Carrera et al. (2008), the pattern of litter fall coincides with the growth and development of the canopy, which differs for various species. Due to variations in forest structure and plant richness, forest creates variable amounts and compositions of litter (Indriyanto, 2009). The topsoil formation varies from site to site depending on plant species, climate, land use, decomposer population and their activities (Fernandes et al. 1997). The amount and kind of litter fall affects the physical, chemical and biological characteristics of the soil, altering its formation and fertility and in turn, the growth of the trees (Panda et al.2007).

The production of litter and its decomposition are the significant processes that determine and regulate the plant soil relationships by controlling the nutrient turnover and accumulation of soil organic matter. Furthermore, the primary source of organic matter for the soils in the forest ecosystem is litter. After the decomposition of litter, vital nutrients are made accessible for the growth and development of a forest.

Different litter components contain different amounts of nutrients which on decomposition make soil organic matter. The quantity of nutrients contributed by litter decomposition varies depending on the types of forests, the species present, the characteristics of the stands, and the seasonal environmental conditions. The physico-chemical characteristics of the litter are used to evaluate the nutrient return from organic materials. Additionally, the amount of litter produced, the quality of the litter, the release of nutrients, as well as the climatic factors and the pre-existing microbial communities in the soil system, all have a significant impact on the rate of decomposition and the release of nutrients. The dynamics of carbon and nutrients in the litter layer have a significant ecological impact on a forest ecosystem. The carbon sequestration capacity of trees depends on the quantity and quality of litter produced and its decomposition and release of nutrients (Rai et al., 2016).

3.8 GLOSSARY

Anthropogenic: relating to or resulting from the influence of human beings on nature

Biogeochemical: It is more generally a **cycle of matter**, is the movement and transformation of chemical elements and compounds between living organisms, the atmosphere, and the Earth's crust.

Detritivores: Detritivores are heterotrophs that obtain nutrients by consuming detritus

Detritus: organic matter produced by the decomposition of organisms

Foliage: the leaves of a plant or tree, or leaves on the stems or branches on which they are growing

Horizon: A layer of soil or rock with particular characteristics

Leaching: By the action of percolating liquid, especially rainwater, a chemical or mineral drain away from soil, ash or similar material.

Microhabitats: a habitat which is of small of limited extent and which difers in character from some surrounding more extensive habitat

Mor: a layer of humus, usually matted or compact, that accumulates on the surface of moist, cool soil

Non symbiotic: not living or occurring in a state of mutualism or symbiosis

Saprophyte: An organism, especially a fungus or bacterium that lives on and gets its nourishment from dead organisms or decaying organic material

Senescent: loss of a cell's power of division and growth

Stratum: A layer within any structure

Weed infestation: any plant that grows wild and profusely, esp. one that grows among cultivated plants, depriving them of space, food, etc

3.9 SELF ASSESSMENT QUESTIONS

3.9.1 Multiple choice questions

1. The forest floor is also known as

a) Detritus c) O horizon
b) Duff d) All of them

2. Decomposers convert the dead plants and animals into

a) Humus c) Oxygen
b) Litter d) Fertilizers

3. O horizon is

a) Mineral layer c) Plant litter layer
b) Micro organism layer d) Sand and loam layer

4. Coarse litter refers to objects with a diameter greater than

a) 2 cm c) 7 cm
b) 5 cm d) 10 cm

5. Fine litter refers to objects with a diameter less than

a) 2 mm c) 5 mm
b) 2 cm d) 5 cm

6. The term 'nurse logs' refers to Coarse Woody Debris fragments that serve as

a) Habitat for herbs, shrubs and trees c) Habitats for large animals
b) Habitats for humans d) None of the above

7. Accumulation of organic matter also helps shield soil from harm caused by.

a) Wind c) Wildfires
b) Rain d) All of the above

3.9.2 Fill in the blanks

1. Some microorganisms feed on dead and decaying animal tissues and convert them into a dark coloured substance called _______.
2. _________ is the initial stage for saprophagic or detritus food chain.
3. Age, density and basal area have a significant impact on ______ production.

4. **______**serve as a host for free-living, nonsymbiotic nitrogen-fixing bacteria.
5. The forest floor is primarily made up of **________** organic matter.

3.9.3 True and False:

1. The presence of humus ensures that the nutrients from dead and decaying organisms are present in soil.
2. The dimension and contents of litter bag are not important for litter estimation.
3. Litter bags of 20 X 20 cm size are generally used for large leaves in litter investigations.
4. A reduction in the amount of forest litter produced led to a reduction in the amount of organic matter and nutrient concentrations in the soil.
5. The rates and thickness of litter fall are not influenced by latitude.

Answer Key:

3.9.1: 1. (d); 2. (a); 3. (c); 4. (a); 5. (b); 6. (a); 7. (c).
3.9.2: 1. Humus; 2. Detritus; 3. Litter; 4. CWD; 5. Non-living
3.9.2: 1. True; 2. False; 3. True; 4. True; 5. False.

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3.11 SUGGESTED READINGS

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3.12 TERMINAL QUESTIONS

3.12.1 Short answer type question

1. What is plant litter made of? What are its characteristics?
2. Write a short note on coarse woody debris.
3. Write a short note on role of coarse woody debris in nutrient cycling.
4. Write a short note on large woody debris.
5. Write an essay on factors influencing the accumulation of litter in forest ecosystem.
6. Write a short note on coarse woody debris and wildfire.
7. Write a note on determination of litter fall in terrestrial ecosystem.

3.12.1 Long answer type question

1. What do you understand by forest litter? Discuss the type and importance of litter in forest ecology.
2. Discuss the factors influencing the accumulation of litter in forest ecosystems.
3. How would you determine the litter fall in terrestrial ecosystem?

BLOCK-2- ENERGY FLOW AND NUTRIENT DYNAMIC

UNIT-4- DETRITUS PATHWAY OF ENERGY FLOW AND DECOMPOSITION PROCESSES

Contents:

4.1 OBJECTIVES

The present topic provides an overview on detritus pathway of energy flow and decomposition processes in environment. After reading this topic, learners will be able to answer the:

- What is detritus food chain?
- What is decomposition?
- Process of decomposition in nature
- Litter decomposition
- Decomposition rate

4.2 INTRODUCTION

There are many distinct sorts of living species in an ecosystem, including all species of flora and fauna, all of which rely on one another for food and energy. The food chain is formed by the transfer of energy and nutrients between different living beings at different trophic levels. A **food chain** is a linear sequence of organisms through which nutrients and energy pass as one organism eats another.

The food chain also illustrates the different feeding patterns and types of relationships involved between living organisms have. The successive stages in the food chain, starting from the bottom as producers and moving up to the primary consumers, secondary consumers and tertiary consumers. Each of the following stages is known as the trophic level. Based on the amount of energy production, the food chain can be divided into two types:

1. **Grazing food chain:** It is a form of food chain in which the lowest trophic level obtains energy from sunlight and fixes it through the process of photosynthesis. The grazing food chain starts with producers, such as green plants, who make their own food through photosynthesis, and then progresses to herbivores and carnivores. Energy is obtained from the sun in the grazing food chain. Let us look at an example to better understand the concept of energy flow in the grazing food chain at different trophic levels. Here, the food chain is dependent on autotrophic plants capturing solar energy and transferring the flow of energy from herbivores to carnivores. The grazing chain can also categorized into two. i.e.,

    - Predator chain: Where one organism consumes another one and their relationship is called prey and predator. The prey is the animal that is being eaten and the predator is the animal that is eating the prey.
    - Parasitic chain: Where the parasites have infected the plants and animals.

2. **Detritus food chain:** It is a short food chain that starts with decomposing organic substances. Detritivores or decomposers are those organisms (mostly micro and some time macro) that feed on dead and decaying organic substances. Predators consume these detritivores. The ecosystem obtains a significant amount of energy from the detritus food chain. Decomposition of dead organic material is carried out by microorganisms. As part of the detritus food chain, one organism's waste products are devoured by another. Detritus food chains can be found in a range of habitats, including the floor of lakes, ponds, sea and ocean etc. Let us explain it with an example:

   Leaves → Insect larvae → Fishes → Larger predators

   Here, you can see that the food chain is begins with a tree's leaves is seen here. Only approximately 5% of the leaves of a tree that fall into a shallow water body are consumed by phytophagous (plant eating insects) before they fall. Smaller critters such as bug larvae, crabs, copepods, and others devour the leaves' components. These organisms are later devoured by carnivorous fish. Finally, larger fishes or fish-eating birds consume these fish.

Characteristics of detritus food chain

1. It isn't limited to a single habitat, as it may be found in a range of locations, including lake and ocean bottoms.
2. The detritus food chain ecosystems are not depended on the sun for energy because sunlight is not normally available on these habitats.
3. Detritus or dead and degraded stuff provides energy for this form of the food chain.
4. Detritus food chain has a continual energy flow as compare to other.
5. By optimising the usage of debris while reducing waste, this type of food chain obtains energy from detritus.
6. Inorganic nutrients are supplied through the detritus food chain.
7. Subsoil species that are macroscopic or microscopic are included in the detritus food chain.
8. In a terrestrial ecosystem, the detritus food chain has a substantially higher energy flow than other types of food chains.

The implication of the detritus food chain

The detritus food chain can found in divergent habitat, therefore, not restricted to a single habitat. These habitats are generally too dark thus the process of photosynthetic cannot be carried out successfully in most of these locations. As a result, the trash food chain ecosystems are seldom dependent on solar energy to function fine.

1. This type of food chain obtains energy from detritus by utilizing detritus to the greatest degree feasible with the least amount of waste; this type of food chain obtains energy

from detritus by utilising detritus to the greatest extent possible with the least amount of waste.

2. It aids in the breakdown of inorganic nutrients. The detritus food chain includes subsoil creatures that can be macroscopic or microscopic in size.
3. The detritus food chain has a significantly higher energy flow in a terrestrial environment as compare to other type of terrestrial food chain.

4.3 DECOMPOSER ORGANISMS AND THEIR TROPHIC INTERACTIONS

A biological process, where complex compounds are broken down into the simpler substances with the help of microorganisms. These groups of microorganisms are called decomposers and the whole process is called decomposition. Bacteria and fungi are the major class of decomposers in natural ecosystem. Decomposers are heterophytes in mode of nutrition as they get their energy from decomposing and dead stuff. These microorganisms are an important part of the food chain, as they are responsible for the breakdown the organic and inorganic content of the dead and decaying products, recycling it and making it available to the ecosystem. The green plants or producers absorb or take up this organic and nutritional stuff, and these important components re-enter the food cycle. Decomposers are lays at the bottom of the ecological pyramid, yet they provide a necessary foundation for life further up the ladder.

Decomposers are the most vital component of soil ecology because they rely on dead matter, which is broken down into necessary molecular constituents like carbon, calcium, nitrogen, and other nutrients and made available them to plants in the soil. Digestive enzymes are secreted by the decomposers helps to break down the complex organic dead matter and alter it to simpler components. For example, carbohydrates are break down into simple sugars, proteins into amino acids, lipids/fats into fatty acids and glycerol.

The rate of decomposition is controlled by a number of factors. The presence of O_2, high moisture content and humidity, balanced pH, and temperatures in the range of 1-35°C (25°C is optimum temperature of the growth) are some favorable conditions for survival and growth of microbes in natural conditions. *Rhizopus, Mucor,* Yeast, molds, *Penicillium* etc are few examples of decomposer organisms.

Properties of decomposers

1. The majority of decomposers are microscopic organisms (protozoa, fungus, and bacteria) but some can be seen with necked eyes (some macroscopic fungi, termites, millipedes earthworms etc).

2. Decomposers utilized dead plant debris (leaf litter and wood) as well as animal waste and faeces. As Earth's cleaning team, they provide crucial services. Dead organisms would accumulate everywhere if this group of organisms doesn't exist.
3. They facilitate in the ecosystem building by breaking down complex organic substances into simpler substances such as water and carbon dioxide, as well as simple nitrogen, phosphorus, and calcium compounds. All of these elements are necessary for plants to flourish.
4. Decomposers consume a wide range of materials in general but some are specialised and decompose only specific types of dead substances. Decomposers return nutrients to the soil or water, allowing producers to use them to develop and reproduce.
5. This group is vital to the health and cleanliness of ecosystems. They release and recycle nutrients by breaking down dead material and trash that can be used as building blocks by primary producers. Decomposers play a critical role in the flow of energy through an ecosystem.

Types of decomposers

The majority of decomposers come into three categories: fungi, bacteria, and invertebrates.

1. **Fungi:** In term of nutrition, fungi are heterotrophs in nature. They cannot synthesized their own food as the photosynthetic pigment is absent in this group of plant. Instead of photosynthesis, fungi get their nutrients from decaying and dead materials that they break down with action of some specific enzymes. In ecosystem, they are the principal group of decomposers. They break down the dead substances or litter by the releasing of various pre-digesting enzymes, which is eventually taken up or absorbed by the fungi itself. High humidity and moisture is a must for the growth and survival of the fungi and also for the process of decomposition. Fungi are important decomposers, especially in forests. Some kinds of fungi are *Rhizopus*, *Mucor*, Yeast, molds mushrooms etc.

2. **Bacteria:** Bacteria are also heterotrophs. These are microscopic, ubiquitous and one of the most important sources of litter decomposition. Bacteria play a major role in facilitating the recycling of nutrients (nitrogen, carbon, phosphorus, etc) in the ecosystem and making them accessible to producers in the food chain.

3. **Invertebrates:** This group includes some insects and worms. Ants flies, maggots dung beetles etc are the few examples that assist in the decomposition of matter in ecosystem. Insects are classified as detritivores because they use their intestinal tract to breakdown litter. There are several types of insects that are involved in the decomposition process, which are categorised according to the sort of substances they consume viz;

- Insects feed on dead animals or tissue (eg., Beetles, Flesh Flies, Blow Flies, Ants and Wasps).
- Insects feed on dead or decaying plant tissues (eg., termites, beetles etc)
- Excrement feeding insects (eg: dung beetle)

Another important part of the soil ecology and nutrients dynamics is worms. The typical example of worms that enhance the soil quality by digesting litter is earthworms. The earthworms consume dead materials and faeces. The litter is treated by enzymes in the intestinal tract of earthworm, resulting in the breakdown of the litter, which is subsequently ejected into the soil. These worms add important nutrients to the soil, such as phosphate and calcium.

Importance and functions of decomposers

The major purpose of decomposers in an ecosystem is to assist in the disintegration or decomposition of dead or decaying organisms.

1. **Ecological cleansers and balance providers:** Decomposers are ecological cleaners that decompose the dead remains **of** plants and animals. Decomposers aid in the formation of a biosphere for new life by decomposing debris of organisms, therefore, essential in sustaining environmental balance.

2. **Recycling of nutrients:** Decomposers break down complex dissolved chemical substances into their fundamental components (C, H_2, O_2, N, P, and so on), making these primary vital elements available for plants to absorb, hence recycling nutrients. These nutrient elements can be taken by the producers (e.g. green plants) of the food chain. Decomposers are the most important component of the food web, despite they occupies the lowermost position in the food web.

Trophic Level:

The term "*trophic"* derived from a Greek word *trophē* meaning "food". A trophic level refers to a level or a position of an organisms in a food chain, or in food web, or in ecological pyramid. Trophic levels represent a group of organisms with analogous feeding habits. In ecological pyramid, the trophic level is represent by primary producers (*autotrophs* or producers or green plants: place base on a pyramid and highest in number), consumers (heterotrophs: categorised as primary Secoundry and tertiary etc: place mid on pyramid) and predators or top consumer (heterotrophs: place top on pyramid and very few in number). Apart from these, a group of organisms also exist in nature called decomposers. The primary producers fundamentally provides nutritional inputs in an ecosystem, therefore, they impose direct impact on trophic level transfer efficiency. Predators assist primary producers by restricting or regulating excessive herbivores. They act as biological controls of lower trophic levels. Another way by which predators are able to promote primary productivity is through intraspecific competition. Both primary producers and predators are major factors of regulatory control.

Categories of trophic level:

The trophic levels can be broadly classified into two parts: *autotrophs* and heterotrophs.

1. **Autotrophs:** They are also known as producers. These are the group of green plants which synthesized their own food from the simple inorganic substances in the presence of sun light with the help of chlorophyll pigment. They do not require or rely on other organisms for their biological growth and development. They do not require or rely on other species in order to food, grow and development.

2. **Heterotrophs:** They are also called consumers because they are not able to synthesize their own food, therefore, depends on the other organisms for the food. Heterotrophs are further categorized as primary consumers (called herbivores and get their food from plants; e.g., grasshopper, deer, goat etc), secoundry consumers (feed on primary consumers; e.g., snakes, owls, wolves, etc) and tertiary consumers (feed on secoundry consumers; e.g., lion, eagle, large fishes etc) and so on.

Another very important group of organism, called decomposers or reducers, is responsible for breaking down dead organisms at all trophic levels into simple molecules called nutrients. Hence, the decomposers are placed at a special place on the side of the trophic pyramid. These nutrients frequently infiltrate the soil and dissolve in water, where they are merely absorbed by plant roots or fungal mycelium, or they can be absorbed through the water by algae and cyanobacteria. The producers then reintroduce these important nutrients into the food chain (plants, algae and cyanobacteria).

Trophic level structure

The various or most common trophic levels in an ecosystem is discussed below (Fig 4.1):

Trophic Level 1 (T1): producers: Trophic level 1 is considered as the base of the ecological pyramid is inhabited by green plants, including algae collectively known as primary producers. Typically, a food chain begins at trophic level 1. The organisms in this trophic level are to produce their own food from abiotic elements through photosynthesis.

Trophic Level 2 (T2): primary consumers: In a food chain or ecological pyramid, trophic level 2 is the next trophic level. The organisms that occupied this level are known as primary consumers or herbivores because they feed on the primary producers. Their structural and metabolic characteristics allow them to adapt to a plant-based diet. For example they usually have mouthparts that allow them to rasp or grind plant and plant products, large flat teeth for crushing vegetation and tree bark, having gut flora (comprised of cellulose-digesting protozoans or bacteria) that helps digest cellulosic material and many more other adaptive features of the survival. Cattle, deer, goats horses etc are example of herbivores.

Trophic Level 3 (T3): secondary consumers: All organisms that feed on primary consumer are categorized as secondary consumers at Level 3. They are also known as carnivores or predators. Predation is a kind of interaction between the different species in an ecosystem where a predator hunts, kills and eats its prey. Predators are physiologically and anatomically adapted for an animal diet. Since the grasping of prey can include chasing or ambushing, they frequently have highly developed senses for vision, touch, hearing and smell. They have sharp, pointed claws and strong jaws to capture and bite their prey. Similarly, preys eventually acquired the evolutionary characteristics to thwart hunting. They developed counter-adaptation and defense strategies, such as alarm calls, warning coloration, thanatosis, spines, chemicals, toxins, venom, camouflage and mimicry.

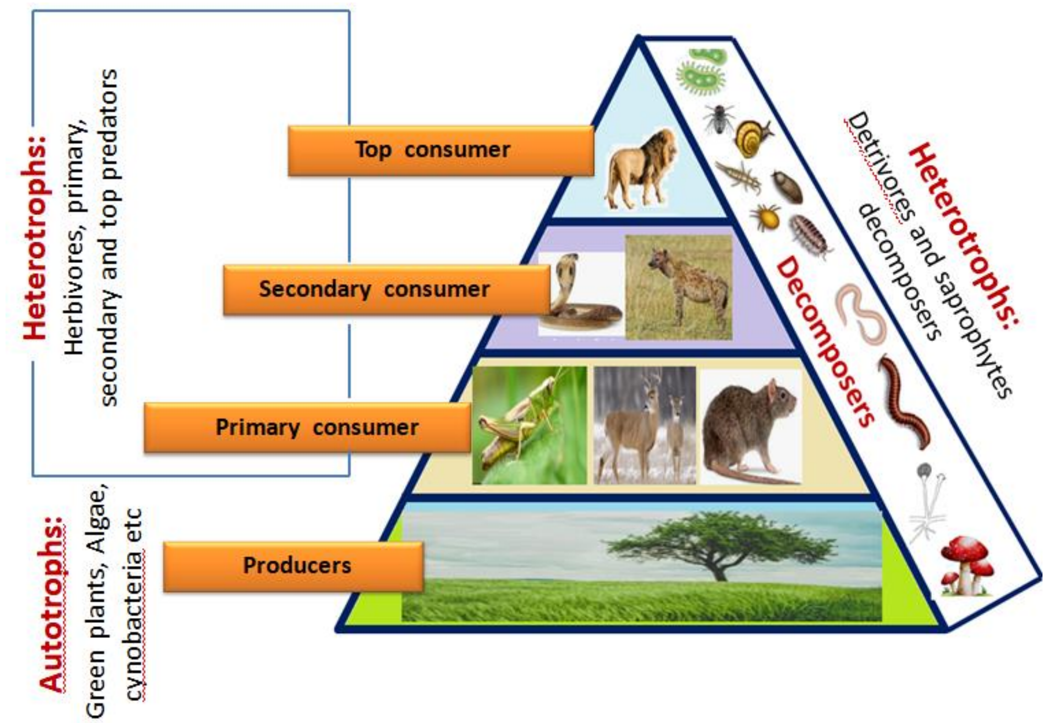

Fig 4.1: Various trophic level in an ecosystem

Not all predators strictly feed on flesh only but there are some predators which are facultative carnivores and plant byproducts may be included in their diet. These types of organisms which feed on both types of food stuff (plant and animal) are called omnivores. Fungi, algae, bacteria and plant's byproducts may also provide food for omnivores. Omnivores, unlike carnivores and herbivores, lack particular specializations in food acquisition and processing. Examples: Human, chimpanzees, orangutans, gorillas, most bears, hedgehogs, dog, squirrels, rats, rodents, raccoons, and other omnivores are examples. These organisms eat at multiple trophic levels.

In plant kingdom, insectivorous plants (pitcher plant and Venus flytrap) may also be included in this category. Predation is another way for these plants to receive nutrients in addition to photosynthesis. Marine organisms that feed on zooplankton are also considered as secondary consumers. Examples: crabs, whales, and lobsters.

Other trophic levels (T4 and T5): A tertiary consumer is an organism that feeds on a secondary consumer, and a quaternary consumer is an organism that eats a tertiary consumer. The trophic levels 4 and 5 are occupied by tertiary and quaternary consumers, respectively.

Decomposers: The last of the trophic level is occupied by the decomposers or in some available literatures it is mentioned that decomposers constitute their own trophic level. As a group, they consume dead, decaying material and waste products that come from organisms at various other trophic levels. They would happily devour decaying plant matter, left over of consumers and all organisms of different trophic levels. Therefore, the decomposers run parallel to the standard hierarchy of primary, secondary, and tertiary consumers.

If we summarized all trophic level, the first trophic level is represented as T1. It includes producers i.e., all photosynthetic plants. The second trophic level is represented as T2. It includes primary consumers or herbivores. The third trophic level is represented as T3 and includes secondary consumers or carnivores. Decomposers are organisms which decompose the organic matter from dead animals and plants. They occupy the top level in the ecological pyramid. They release essential nutrients back in the environment.

4.4 DECOMPOSITION PROCESSES

Each and every living thing on the planet eventually perishes. After death, the process of decomposition must begin in order for life to continue on Earth. Decomposition is an essential step in the recycling of key materials in the food cycle. The decomposition process is fundamentally encompassed of five stages which are briefly discussed below:

1. **Fragmentation:** The dead mass is fragmented, as the name implies of this stage. Fragmentation is a process in which large parts are broken down into smaller ones. The surface area of the debris grows when the huge bulk is fragmented. This phase begin the process of decomposition, which is initially carried out by detritivores. They consume the dead matter and break it down into small sections in their gastrointestinal tract, allowing the saprophytes for their enzymatic action.

2. **Leaching:** The fragmented trash contain abundant of water-soluble nutrients including both organic (simple molecules) and inorganic matter. By the process of leaching, water

that percolates through the soil absorbs these water-soluble nutrients and nourishes the soil with them.

3. **Catabolism:** Enzymes secreted by decaying fungi and bacteria operate on the detritus once it has been fragmented and water-soluble nutrients have been eliminated. These enzymes further catabolize the trash, breaking it down into simpler molecular nutrients.

4. **Humification:** The catabolic process is followed by the humification process. Making humus is the process of humification. Humus is a nutrient-dense, dark layer of soil made up of amorphous components with a high nutritional content. This layer is particularly resilient to microbial activity. This layer of soil contributes significantly to the soil fertility.

5. **Mineralization:** In the final stage of decomposition, inorganic chemicals including Mg^{+2}, Ca^{+2}, K^{+1}, $NH4^{+1}$, etc as well as CO_2 and H_2O, are released into the soil, enriching it with nutritional matter.

Nutrient Immobilization

Under some specific circumstances, sometime certain soil nutrients get bonded with microbial biomass during the process of decomposition, rendering the nutrients unavailable to other organisms. Such phenomenon where the nutrients being integrated with live microorganisms is called as nutrient immobilization. The period of immobilization and availability of such nutrients is, however, unpredictable and they may only become mineralized after microbial death. This nutrient immobilization prevents such nutrients from being washed out of the ecosystem.

Factors affecting decomposition

The process of decomposition is influenced by a number of factors. Majorly the quality of detritus and the environmental conditions affect the process of decomposition. The relationship between various factors which affect the process of decomposition is briefly discussed in Fig. 4.2.

1. **Aeration:** Decomposers, especially decomposing bacteria, are primarily aerobic organisms. Therefore, oxygen becomes an essential component of the decomposition process. The aerobic bacteria and fungi cannot exist without oxygen, and the process of decomposition will come to a halt. Although anaerobic bacteria do exist in nature, and they do not need oxygen from the atmosphere, but their numbers are small in nature. In soil, oxygen is present in the pores of the soil.

2. **Temperature:** Temperature has long been known to influence microbial growth and activity. As a result, changes in temperature under various geological circumstances have

an impact on the breakdown process. The process of decomposition is considerably slowed by lowering the temperature, as seen at higher altitudes with low temperatures. This is due to the delayed microbial development that occurs at cold temperatures.

3. **Moisture:** The presence of water or humidity is a critical factor for the growth and physiological functions of microorganisms. The amount of moisture influences the proliferation of microbes, which in turn influences the decomposition process.

4. **Soil pH:** The pH that allows decomposers to flourish optimally will speed up the decomposition process. Decomposers prefer a pH that is neutral or slightly acidic. The whole mechanism of decomposition is not aided by an alkaline pH. Surprisingly, this concept is used to fix tissue/organ specimens on slides for microscopy with the use of formaldehyde.

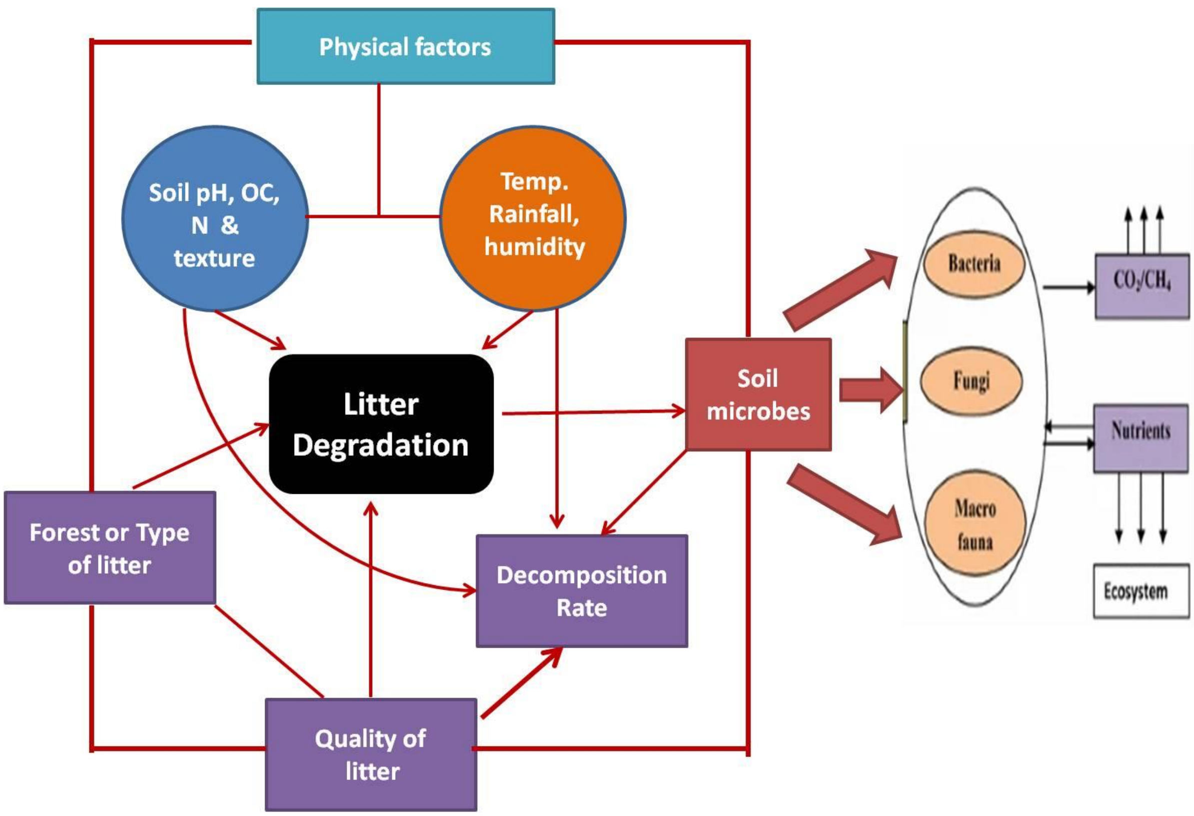

Fig. 4.2: Diagrammatic representation of factors affecting litter decomposition (the litter degradation is influenced by the various physio-chemical and biological factors. These factors are governed by the climate and the type of the decomposing matter. (Recreate Image by author; credit: Krishna and Mohan 2017).

5. **Inorganic chemicals.** The rate of decomposition is influenced by the chemical nature of debris. The presence of inorganic minerals can slow down the process.

6. **Quality of litter:** The structural and chemical properties of litter have a significant impact on the rate of decomposition. Litter that contains more soft tissues, for example, decomposes faster than litter that contains lignin (Padalia et al. 2015).

7. **Biotic factors:** Biotic factor critically influence the process of decomposition. The rate of litter decomposition is known to be affected by the amount and organization of soil fauna and microbial communities at distinct stages of decomposition. Microbial biomass play a significant role in the process of decomposition and recycling of nutrients in an ecosystem (Padalia et al. 2018; Bargali et al. 2019; Padalia et al.2021).

4.5 MEASURMENT OF LITTER DECOMPOSITION

Litter decomposition is the principal mechanism for nutrients return in ecosystems. The quantity of carbon stored in the forest floor is influenced by the balance between litter inputs and heterotrophic litter breakdown. Periodic studies of litterfall and litter decomposition using established procedures will offer critical information on nutrient dynamics in ecosystem. Some most commonly use techniques to determine the decomposition is described below.

(1). Mass balance

Introduction: When direct measurement of is too expensive, mass balance method is used to estimate litter decomposition for entire ecosystems.

Principle: The mass balance technique, when applied to aboveground litter decomposition, proposes that annual litter decomposition should equal annual fresh litter intake as long as the mass of detrital litter stored in the ecosystem remains constant (Olsen 1963). This approach assumes that a constant fraction, k, of the detrital litter mass decomposes, where,

$$Litterfall = k\ (detrital\ litter\ mass), \text{ or}$$

$$\frac{Litterfall}{detrital\ litter\ mass} = k$$

In forest ecosystems, where decomposition rates are rapid and there is little surface, litter accumulation, values for k are greater than 1.0. Ecosystems with slow decomposition rates and surface litter accumulation, for comparison, have k values that are less than 1.0.

Methods: According to the equation, this method necessitates the collection of two variables: litterfall and detrital litter mass to estimate the rate of decomposition. *Litterfall* is assessed using litter traps placed across the study site at randomly. Litter trap apertures are typically 0.5 to 1 m wide, with netting or a mesh screen containing litter within the trap. Traps should empty at regular intervals, and the materials collected must divide into categories based on litter type, species, and/or component. After oven drying, the materials are weighed. *Detrital litter mass*, also known as forest floor and defined by USDA Soil Survey Soil classification as the Oi, Oe and Oa horizons, is assessed by removing the forest floor from a known area. Dry weight should record after drying the litter.

The forest floor is collected from inside the quadrat (normally 1×1 m^2 size) and sorted by component. Fresh weights can be measured and a subsample obtained for dry weight measurement, or the complete sample can be oven dried for dry weight determination. Forest floor mass should be corrected by sample combustion to estimate the ash-free component of the sample because the Oa can contain up to 20% mineral mass and dirt can contaminate upper forest floor layers.

Advantages:

1. This method is used independently to estimation of litter decomposition, or as a check on model forecasts.
2. When short-term estimations are required yet forest floor mass is not in a constant state, mass balance-based predictions of litter decomposition are imprecise.
3. This method provides a reliable estimate of litter decomposition at the stand level, while assumptions regarding steady-state stand conditions and continuous forest floor decomposition dynamics make the calculated litter decay rates difficult to understand.

Limitation: In young stands when the forest floor is rapidly aggrading, this strategy may not be appropriate. The technique would overestimate decomposition rates in this context.

(2). Litterbags technique

Introduction: Bocock and Gillbert introduced the litterbag technique in 1957 (Gupta and Malik 1999). It is the most extensively used method for determining decomposition rates at the soil surface.

Principle: The decaying litter material from litterbags is removed or after an extended period of exposure on the field and evaluated for dry mass, moisture content, and nutritional composition at varied time intervals. The contamination of decomposing litter materials by soil particles must be corrected by determining the percentage litter mass remaining on an ash free dry weight basis. Some loss of water soluble components occurs during deionized water rinsing of litterbags, which can be quantified by calculating the drop in litter weight owing to loss of water soluble under laboratory circumstances.

Method: In this method, fresh leaf litter is deposited on the ground enclosed within litter bags (20×20 cm) and collected at regular intervals to determine the mass left (Fig. 4.3). The subsamples of the litter are oven dried so that wet to dry conversions can be made afterwards for comparison. Although mesh size can be changed to exclude functional groupings of litter decomposers, mesh size is normally set to optimise access to the litter by all organisms while limiting excessive particle loss. Not only will a very small mesh size keep certain organisms out, but it will also prevent particle loss to mineral soil. Though litterbag mesh sizes of 1-2 mm are most acceptable in research (Robertson and Paul 1999), if the goal is to allow macrofauna entrance, the mesh size should be bigger than 2 mm.

Fig. 4.3: Litter bags in the field (Image Source: http://www.oikosjournal.org/blog/effects-monoculture-plant-litter-decomposition)

To compare pre- and post-decomposition sample mass, the litterbags are oven dried. Mineral soil contaminates litterbag samples, just as it does forest floor samples, and should be compensated for by quantifying the ash content of litter before and during decomposition. Litter decomposition rate is calculated by applying a regression approach and the first order negative exponential decay equation, where the fraction of litter remaining after 1 year is given by:

$$\frac{X_t}{X_0} = e^{-kt}$$

Where, $\frac{X_t}{X_0}$ is the proportion of original mass remaining at time *t*, and k is the decomposition rate constant. The decomposition rate constant, k, can be calculated by fitting the exponential decay model to a scatter plot of *t* vs. $\frac{X_t}{X_0}$ (Harmon et al. 1999).

Precautions:

1. Collected litter should be freshly senesced.

2. Litter bags size (most recommended 20×20 cm) should be appropriate to the litter-specific ecosystem under consideration and are characteristically built for only one species.
3. The quantity of litterbags deployed at a site is determined by the site variability, number of collections per year and duration of research period.
4. To accurately calculate k, for forest with varied stand characteristics and microclimate will require more litterbags as compared an even-aged plantation.

Advantage:

1. Litterbags technique is classic at minimal expenses method of measuring decomposition rates in the field.
2. This method used experimentally to quantify rates at different time scales and the impact of diverse factors (e.g. temperature, moisture content etc).

Limitations:

1. Certain macroinvertebrates are not allowed in the litterbags through the mesh size, resulting in decreased litter comminution rates.
2. Contamination by soils with high organic matter contents requires corrections.

(3). Litter basket technique

Litter basket technique put forward by Blair et al. (1991) to understand the interaction between microorganisms, fauna and litter quality in decaying litter. The litter baskets ($10 \times 10 \times 10$ cm) were formed of wire hardware cloth with a 6 mm mesh and a plastic window screen (mesh 1.5×1.8 mm) unraveling the forest floor profile (L-layer, F-layer and soil). Microarthropods should exclude using high gradients extraction and by Tullgren Funnels. Subsamples utilize for inventory of nematodes fungi and bacteria. The direct count analysis is useful in the estimation of microbial populations.

The litter basket method has countless advantages i.e., easy extraction of invertebrates and quantification of microbial populations, analysis of nutrient content change, reduced microclimatic effects, and ability to quantify the moment of radioactive or stable tracers from the litter.

(4). Tethered leaves method

Introduction: This method is analogous to the litterbag technique, with a difference that individual leaves are tied together in bundles using nylon thread or monofilament fishing line in Tethered leaves method rather than positioned in litterbags.

Principle: Subsamples of each line of senescent leaves are oven dried to establish the ratio of air-dry/oven-dry. While leaves on a given line usually are weighed individually, mass loss and elemental concentrations calculate for the group to account for any loss of whole leaves.

Method: In the laboratory, a representative collection of individual senescent leaves is air-dried and connected to a single line by their petioles. One end of the line is tied to an identifying tag, and the other end to a flagged washer. Several groups of strings are tied to each washer in this manner: the washer provides the hub, and individual lines the spokes (Fig 4.4). At each collection interval, one or more lines are snipped from the hub, and measured for decomposition (Karberg et al. 2008).

Fig 4.4: Tethered birch leaves strung up in boxes before their installation into experiment. Source of Image: Jackson BG (2012)

Advantages:

1. It's beneficial for investigating the early phases of decomposition, thus the length of the study isn't as critical in litterbag methods.
2. As leaves begin to fragment, this technique will over-estimate decomposition rates relative to the litterbag approach.

Limitations: This method permits the leaf utilization by macroinvertebrates such as crabs and snails, whose access would otherwise be restricted by mesh bags.

(5). Cohort layered screen method

Introduction: In this technique, layers of mesh screen are used to separate successive layers of litter on the forest floor; leaf litter then decomposes in-situ.

Principle: Long-term decomposition studies, usually lasting three or more years, are subjected to the cohort layered screen approach. A layer of window screen is laid over the forest floor after a significant annual litterfall. Window screening of 1×1 m aluminium or fibreglass with a mesh size of 2-3 mm is commonly use. The screen size will be determined by the size of the sampled stand, and the mesh size will be determined by the ecosystem under investigation.

Method: For the entire duration of the research period, a new layer of screen is laid directly over the previous year's screen after each annual litterfall. Subsamples of the original screen can be cut from the original after a set sampling period to acquire data while enabling the experiment to continue. Subsamples are gathered, weighed, and dried in the oven.

Advantage:

1. It is relatively easy to monitor the resources as compare to litterbag studies.
2. Useful for long term research as it allowing for complete decomposition of the litter.

Limitations: The cohort layered screen method also excludes certain macrofauna that are prevented from accessing leaf litter by the mesh screen, which can change the microclimate of the forest floor.

(6). ^{13}C Nuclear Magnetic Resonance (NMR)

Introduction: It is an advanced procedure to estimate the rate of decomposition. This method allows for the direct identification of organic components in entire soil or isolated fractions. To examine diverse carbon compounds in whole soil, the cross-polarization and magic angle spinning (CP/MAS) approach was developed (Gupta and Malik 1999).

Principle: Barron and Wilson (1981) and Baldock et al. (1991) found well resolved spectra of organic components of soil organic matter using ^{13}C CP/MAS NMR spectroscopy for the total soil and its density fractions.

The resonance at 10-45 ppm (mathly and alkyl-C) was mainly from aliphatic lipids, fatty acid, waxes and hemicelluloses. The small signals in the aromatic region (110-160) were at tribute to aromatic C in lignin and lignins at 60-90 ppm (0-alkyl-C) resulted from oxygenated C in carbohydrates.

Method: Norden and Berg (1990) used high resolution ^{13}C NMR (CP/MAS) spectroscopy for analyzing the decomposing Pine litter. This method is briefly discussed here. Take the litter samples (approximately 1.5 g air-dried needles) enclosed in litterbags (8×8 cm^{-2}, 1-mm mesh terylene net). The litter bags should always place on the surface of the litter layer (A_{oo}) in subplots (1×1 m^{-2}) within each of 25 main measurement plots according to the randomized block design. The litterbags can recover three times in a year or according to the research design, processed for removing extraneous materials and dried those bags 82°C. After drying, all the subsamples get mix to prepare a composite sample for a particular species. Grind that composite sample in laboratory mill and analyze for chemical composition in replicates. The replicates will analyze for ^{13}C CP/MAS NMR spectra (Bruker MSL-100, 25.178 MH_2, 7.5-mm rotors made up of Al_2O_3 and equipped with Kel-F caps). The chemical shift scale will determine with reference to external adamantine whose methylene resonanace is set at 38.3 ppm.

In the initial undecomposed material ^{13}C signals from the carbohydrate region will evident (60-100 ppm). The NMR signals show a decrease in carbohydrate content with the progress of litter decomposition. By using multivariate data analysis method and NMR data, lignin content will also determined in the decomposing litter.

Advantages:

1. It is a valuable approach for understanding the continuum between plant decomposition and soil organic matter.
2. The NMR is that is a nondestructive method that does not alter the chemical composition of the material.

Limitation: Analysis by NMR is an expensive approach.

4.6 DECOMPOSITION RATE

There are so many variables that influence decomposition, therefore, the rate of decomposition differ from different places. These rates can be articulated in total terms as the weight of litter that disappears in any site. The decomposition rate constant (k) for different forests, defined as the ratio of amount of annual litterfall to the amount of organic matter in the forest floor. Higher values of *k* indicate more rapid long-term decomposition rates. The inverse of *k* is called the mean residence time and gives an estimate of how quickly litter decomposes. (Olson, 1963). The following data can aid in determining that how much of a nutrient is available throughout the year. A ratio of how much litter (or, better still, total necromass) falls in a year relative to the amount of organic matter stored on the forest floor is an equally relevant measure for the forest ecologist to gain a sense of the overall long-term decomposition rate.

If a large amount of litter falls in a year and very little organic matter remains in the soil (so k is high), then the litter must be disappearing quickly and decomposition rates must be high. In contrast, if the same amount of litter is delivered but there is a significant amount of organic matter in the soil (resulting in a low value of k), then decomposition rates must be slow over time. The value of k varies widely over the world, from over 4 in some tropical forests to less than 0.01 k in subalpine forests with a short, cold growing season. As a result, organic matter content in tropical forest soils should be low, while it should be high in boreal forest soils. This is true in general, but there is a great deal of variety, including various organic-rich tropical soils, such as those found in cloud forests, deep tropical peat bogs, and freshwater swamp forests merging with mangroves, as well as highly sandy, impoverished northern soils caused by severe fires. Vogt et al. (1986) estimated values for organic matter accumulation in different forest floors in their study (15-1001 ha^{-1} in northern boreal forests, 7.5-12.5 tha^{-1} in temperate broadleaved forests, and 1-2.5 and up to 10-12 tha^{-1} in tropical forests).

The soil scientists, mainly those engaged in carbon storage and climate change have categorized soil organic matter into three distinct pools of organic matter because the different fractions of soil organic matter decompose at varying rates. The active carbon pool, which is made up of root exudates and the fast degrading components of fresh litter, has a short residence period and is hence particularly susceptible to rapid change. The slow carbon pool is made up of the material coming from the active pool which is more resistant to decomposition and typically contains a higher proportion of components such as lignin. This pool has a turnover time that is measured in decades. Finally, the passive carbon pool contains the humus which, despite continual microbial attack, is the most stable organic matter with a turnover time of millennia.

Factor affects the decomposition rate

The rate of decomposition is chiefly governed by three factors:

1. **Physical environment:** The rate of decomposition is in optimum under moist condition with adequate levels of oxygen. The rate of decomposition becomes lower under extreme wet or dry conditions. The wet soils liable to become oxygen deficient (this is especially true in wetlands), which ultimately adversely affect the growth of microbial population. In dry soils, the rate of decomposition get slow as well, however the bacteria community continue to grow (albeit at a slower rate) even when soils become too dry to sustain plant growth. The osmotic gradient between the bacterial cells and the soil water leads the cells to gain water quickly when the rains return and the soils become wet. Many bacterial cells explode under these conditions, producing a burst of nutrients (Chapin et al. 2002).

   The soil texture has also a significant role in the process of decomposition. Acidic soils also have a slower decomposition rate. Clay minerals-rich soils have slower decomposition rates, resulting in larger quantities of organic matter. Clay particles are smaller, which results in a bigger surface area that can store water. The higher a soil's water concentration, the lower its oxygen content and, as a result, the slower it decomposes. Clay minerals bond organic material particles to their surfaces, making them less accessible to bacteria. Soil disturbance, such as tilling, promotes decomposition by boosting soil oxygen levels and exposing fresh organic matter to soil bacteria.

2. **Quantity and quality of litter:** The quality and quantity of the material available to decomposers is another major factor that influences the rate of decomposition.

Substances like sugars and amino acids decompose readily and are considered labile. Cellulose and hemicellulose, which are broken down more slowly, are "moderately labile". Compounds which are more resistant to decay, like lignin or cutin, are considered recalcitrant.

3. **Nature of the microbial community:** Litter with a higher proportion of labile compounds decomposes much more rapidly than does litter with a higher proportion of recalcitrant material. Consequently, dead animals decompose more rapidly than dead leaves, which themselves decompose more rapidly than fallen branches. As organic material in the soil ages, its quality decreases. The more labile compounds decompose quickly, leaving an increasing proportion of recalcitrant material. Microbial cell walls also contain recalcitrant materials like chitin, and these also accumulate as the microbes die, further reducing the quality of older soil organic matter.

4.7 SUMMARY

The term "*trophic"* derived from a Greek word *trophe* meaning "food". A trophic level refers to a level or a position in a food chain, or in food web, or in ecological pyramid. A food chain is a linear sequence of organisms through which nutrients and energy pass as one organism to another. Based on the amount of energy production, the food chain can be divided into two types (Table 4.1): (1). *Grazing food chain* and (2). *Detritus food chain.*

Table 4.1 Comparison between grazing and detritus food chain

Particulars	Grazing food chain	Detritus food chain
Definition	In this food chain, producers serves as the primary source of energy and constitute the first trophic level	In this food chain, dead and decaying matter serves as the primary source of energy. Detritivores or decomposers feed on this matter and release the nutrients back into the atmosphere.
Examples	It involves all macroscopic organisms	It involves subsoil organisms, which can be macroscopic or microscopic.
Source of energy	Energy for the grazing food chain is obtained directly from the sunlight.	Energy for the detritus food chain is obtained from the organic debris.
First trophic level	Here, green plants form the first tropic level	Here, the first trophic level is occupied by the decomposers
Food chain	It is usually larger compared to the detritus food chain	It is usually smaller compared to the grazing food chain
Significance	It release energy into the ecosystem	It utilized energy from the ecosystem.
Importance	It helps in adding energy	It helps in fixing inorganic nutrients.

Trophic levels represent a group of organisms with analogous feeding habits. The trophic levels can be broadly classified into two parts: (1). Autotrophs: They are also known as producers. These are the group of green plants which synthesized their own food from the simple inorganic substances in the presence of sun light with the help of chlorophyll pigment. (2). Heterotrophs: They are also called consumers because they are not able to synthesize their own food, therefore, depends on the other organisms for the food. Another very important group of organism, called decomposers or reducers, is responsible for breaking down dead organisms at all trophic levels into simple molecules called nutrients. Hence, the decomposers are placed at a special place on the side of the trophic pyramid.

Decomposition is a biological process, where complex compounds are broken down into the simpler substances with the help of microorganisms known as decomposers. Bacteria and fungi are the major class of decomposers in natural ecosystem. Decomposers are heterophytes in mode of nutrition as they get their energy from decomposing and dead stuff. These microorganisms are an important part of the food chain, as they are responsible for the breakdown the organic and inorganic content of the dead and decaying products, recycling it and making it available to the ecosystem. The rate of decomposition is controlled by a number of factors. The presence of O_2, high moisture content and humidity, balanced pH, and moderate temperatures are some favorable conditions for survival and growth of microbes in natural conditions. The major purpose of decomposers in an ecosystem is to assist in the disintegration or decomposition of dead or decaying organisms. They are also useful in ecological cleaning and recycling of nutrients in an ecosystem.

Table 4.2: Difference between saprophytes and detritivores

Saprophytes	Detritivores
Saprophytes are more inclusive group of organisms that decay the dead matter. They include detritivores and saprotrophs	Detritivores are the organisms that feed orally on the dead matter to gain nutrients and energy.
Examples of Saprophytes: Fungi, bacteria, earthworm, insects	Examples of Detritivores: millipedes, earthworms, crabs, flies etc
Saprophytes act on the dead matter, e.g., by secreting the enzymes and digesting the matter externally.	Detritivores contribute to the decomposition process, particularly by ingesting the dead matter and then digesting it in their digestive tract.
Saprophytes cannot act on the clumps of the dead matter	Detritivores can feed upon large clumps of the dead matter.

Decomposers are a cluster of organisms that decomposes decaying organic substances. There are two major categories of decomposers: (i). *detritivores* that include the animal decomposers feed on dead matter and (ii). *Saprotrophs* which are exemplified by bacteria and fungi. Although detritivores and decomposers are sometimes used synonymously but they are two different terms. Although "decomposer" is a broader term that encompasses not just saprotrophs but also detritivores. The difference between saprophytes and detritivores is listed above (Table 4.2):

Decomposers, like scavengers, play a crucial role in the ecological recycling of nutrients and organic materials in an ecosystem. The working mechanisms of the two classes of organisms, however significantly differ from each other. Scavengers are the ones who start the process of simplification of dead and decaying matter, which is later taken over by decomposers. The table shows the key differences between the decomposers and scavengers (Table 4.3).

Table 4.3: Difference between decomposers and scavengers

Decomposers	Scavengers
Act on the small particles that are made available due to the action of scavengers and break down further to yield the basic elements like carbon, calcium, phosphorus etc.	Initiate the process of the decomposition by breaking down the dead mass into small particles.
Finisher of the decomposition process	Initiators of the decomposition process
Majority of this class included bacteria and fungi. Some invertebrates (millipedes etc) are also serves as decomposers.	Insects (files, cockroach etc), birds (Crow, Eagle, vultures etc), fishes and crabs etc

Decomposition is an essential step in the recycling of key materials in the food cycle. The decomposition process is fundamentally encompassed of five stages which are: fragmentation, leaching, catabolism, humification and mineralization. The process of decomposition is influenced by a number of factors i.e., aeration, temperature, moisture, soil pH, inorganic chemicals, quality of litter, biotic factor etc.

Litter decomposition is the principal mechanism for nutrients return in ecosystems. Mass balance method, Litterbags technique, Litter basket technique, Tethered leaves method, Cohort layered screen method, ^{13}C Nuclear Magnetic Resonance (NMR) etc are some commonly use techniques to determine the decomposition of litter. There are so many variables that influence decomposition, therefore, the rate of decomposition differ from different places.

The decomposition rate constant (k) for different forests, defined as the ratio of amount of annual litterfall to the amount of organic matter in the forest floor. Higher values of k indicate more rapid long-term decomposition rates. The inverse of k is called the mean residence time and gives an estimate of how quickly litter decomposes. The following data can aid in determining that how much of a nutrient is available throughout the year. The rate of decomposition is chiefly governed by three factors including physical environment, quantity and quality of litter, nature of the microbial community.

4.8 GLOSSARY

Abiotic: Non-living; usually applied to the physical and chemical aspects of an organism's environment; e.g. salinity, pH, humidity, light etc.

Adaptation: Characteristics of organisms evolved as a consequence of natural selection.

Biodiversity: Refers to aspects of variety in the living world

Biogeochemical Cycle: The movement of chemical elements between organisms and non-living compartments of the atmosphere, lithosphere and hydrosphere.

Biomass pyramid: A graph that illustrates the productivity (in terms of biomass) within the various trophic levels comprising a food chain. Also called an *ecological pyramid*.

Biotic: Living; usually applied to the biological aspects of an organism's environment, i.e. the influence of other organisms (opposite of abiotic).

Climate: The accumulation of seasonal weather patterns in an area over a long period of time.

Community: The species that occur together in space and time;

Consumer: An organism within an ecosystem, plant or animal that derives its food from another organism (see predator).

Decomposer: Any organism that breaks down organic matter into simpler compounds.

Decomposer: Organisms (bacteria, fungi, heterotrophic protists) in ecosystems that break down complex organic material into smaller inorganic molecules that then are recirculated.

Decomposition: The process by which tissues of dead organisms are broken down by both biotic and abiotic processes into simpler forms of organic matter, thereby clearing the limited available space in a biome.

Detritivore: A heterotrophic organism which feeds primarily on detritus – decomposing bits of organic matter, such as plant litter.

Ecosystem: All of the organisms of a given area and the encompassing physical environment.

Environment: The combination of all the external conditions and the potential effect of the inner environment.

Food chain: A group of organisms interrelated by the fact that each member of the group feeds upon the one below it.

Food: Organic compounds used in the synthesis of new biomolecules and as fuel in the production of cellular energy; i.e. carbohydrates (glucose), starch (amylose, amylopectic), proteins (from aminoacids), fatty acids, vitamins, trace elements.

Habitat: The environment of an organism; the place where it is usually found.

Microclimate: The climate within a very small area or in a particular, often tightly defined habitat; e.g., temperature gradient a few mm above a leaf, or along a tree trunk, etc.).

Nutrient cycle: The movement and exchange of organic and inorganic matter back into the production of living matter. Also called *ecological recycling*.

Nutrient: Chemical elements and compounds that provide organisms with the necessary nourishment.

Plant litter: The layer of dead plant material on the ground, providing a habitat to plants, microorganisms and animals. It plays an important role in the nutrient cycle.

Prey: An individual liable to be, or actually, consumed (killed) by a predator. Productivity: The rate at which biomass is produced per unit area by any class of organisms.

Prey: An organism upon which a predator feeds.

Species: In taxonomy, a group of organisms whose members have the same structural traits and who can interbreed with each other.

Trophic Level: A step in the movement of energy through an ecosystem, represented by a particular set of organisms.

4.9 SELF ASSESSMENT QUESTIONS

4.9.1 Multiple Choice Questions

1. A ____ is a linear sequence of organisms through which nutrients and energy pass as one organism eats another.
   (a) Food chain (b) Food web
   (c) Both a and b (d) None of the above
2. It is a form of food chain in which the lowest trophic level obtains energy from sunlight and fixes it through the process of photosynthesis.
   (a) Detritus food chain (b) Grazing food chain
   (c) Both a and b (d) None of the above
3. It is a short food chain that starts with decomposing organic substances.
   (a) Detritus food chain (b) Grazing food chain
   (c) Both a and b (d) None of the above
4. ____ are those organisms that feed on dead and decaying organic substances
   (a) Autotrophs (b) Heterotrophs
   (c) Both a and b (d) Decomposers
5. In a terrestrial ecsystem, the detritus food chain has a substantially higher energy flow than other types of food chains.
   (a) Detritus food chain (b) Grazing food chain
   (c) Both a and b (d) None of the above
6. _____ are the major class of decomposers in natural ecosystem.
   (a) Bacteria and fungi (b) Tree and shrub
   (c) Dog and cat (d) All of the above
7. Which group is play critical role in the physical cleanliness of an ecosystem?
   (a) Tree and shrub (b) Decomposers
   (c) Autotrophs (d) Heterotrophs
8. Which of the following is the type of decomposers?
   (a) Fungi (b) Bacteria

(c) Invertebrates (d) All of the above

9. Which of the following is the method to determine the litter decomposition?
(a) Mass balance method (b) Litter bags technique
(c) Tethered leaves method (d) All of the above

10. The ^{13}C Nuclear Magnetic Resonance (NMR) technique is use to determine
(a) Decomposition rate (b) Trophic level
(c) Length of food chain (d) Number of microbes

4.9.2 True and False

1. The food chain is formed by the transfer of energy and nutrients between different living beings at different trophic levels.
2. A food chain is a circular sequence of organisms through which nutrients and energy pass as one organism eats another.
3. Grazing food chain do not depends on process of photosynthesis.
4. Detritus food chain starts with decomposing organic matter.
5. Inorganic nutrients are supplied through the detritus food chain.
6. Decomposition is a physical process, where complex compounds are build from simpler substances with the help of microorganisms.
7. Trophic level 1 is considered as the base of the ecological pyramid is inhabited by green plants.
8. Temperature, moisture, pH and inorganic chemicals, quality of litter do not affacts the rate of decomposition.
9. Bocock and Gillbert introduced the litterbag technique in 1957.
10. The rate of decomposition differs from different places.

4.9.3 Fill in the Blanks

1. The ____ is the animal that is being eaten and the __ is the animal that is eating the prey.
2. The ____ food chain is not depended on the sun for energy because sunlight is not normally available on these habitats.
3. A biological process, where complex compounds are broken down into the simpler substances with the help of microorganisms, is called ________.
4. The term "*trophic*" derived from a Greek word meaning ______.
5. The trophic levels can be broadly classified into two parts: ______ and _____.
6. Where the nutrients being integrated with live microorganisms is called as _______.
7. ________ is the principal mechanism for nutrients return in ecosystems.
8. _________ introduced the litterbag technique in 1957.
9. In _______ of decomposition, layers of mesh screen are used to separate successive layers of litter on the forest floor; leaf litter then decomposes in-situ.
10. The rate of decomposition becomes __________ under extreme wet or dry conditions.

Answer key

4.9.1: 1.(a); 2.(b); 3.(a); 4.(d); 5.(a); 6.(a); 7.(b); 8.(d); 9.(d); 10.(a)
4.9.2: 1. True; 2. False; 3. False; 4. True; 5. True; 6. False; 7. True; 8. False; 9. True; 10. True
4.9.3: 1. Prey, predator; 2. Detritus; 3. Decomposition; 4. Food; 5. Autotrophs, heterotrophs; 6. Nutrient immobilization; 7. Litter decomposition; 8. Bocock and Gillbert; 9. Cohort layered screen method; 10. Lower

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4.12 TERMINAL QUESTIONS

4.12.1 Short Answer Type Questions

1. Highlight the differences between grazing and detritus food chain.

2. Briefly describe the types of decomposers.
3. Discuss the role of decomposers in trophic level.
4. What do you understand by nutrient immobilization?
5. Discuss the litter bags technique for the measurement of litter decomposition.
6. What is decomposition rate? Describe factor affects the decomposition rate.

4.12.2 Long Answer Type Questions

1. Discuss the types of food chain in ecosystem. How the detritus food chain is differ from grazing food chain.
2. What do you understand by detritus food chain? Explain the characteristics and implication of detritus food chain.
3. What are the decomposers? Discuss the properties, types and importance of decomposers.
4. What is trophic level? Describe the trophic level structure in any ecosystem in detail.
5. Briefly describe the process of decomposition. Highlight the factors which affect the decomposition process.
6. Discuss some most commonly use techniques for determine the rate of decomposition.

UNIT-5 NUTRIENT CYCLING IN FOREST ECOSYSTEM

Content

5.1 OBJECTIVES

By the end of this Unit, learners will be able to do the following:

- Describe how plants obtain nutrients
- Know about the forest nutrient cycling models
- types of nutrient cycles in forest

5.2 INTRODUCTION

A forest, like all ecosystems, is made up of living beings that need nutrients to survive. So, just as humans require carbohydrates, proteins, lipids, and mineral elements to grow and live, plants, animals, and microorganisms in a forest require nutrients to survive. However, the form of these nutrients and the way forest organisms absorb and use them differ greatly from human beings. Plants cannot travel in search of food like humans. Everything they use must come entirely from the atmosphere and the soil in which they are grown. As a result, nutrients extracted in one area must be restored to allow plants to survive in the long run and, more broadly, for the ecosystem to function sustainably. Fortunately, nature "does things well," and each year in forest, amounts of nutrients released into the soil and atmosphere from bedrock weathering and/or decomposition of organic matter such as dead roots, leaves, trunks, branches, fungi, and animals. This exchange of elements between living and non-living components of an ecosystem is referred to as "forest nutrient cycling".

Nutrients are elements or compounds that are necessary for plant growth and survival. Plants need an excessive amount of nutrients like carbon (C), nitrogen (N), phosphorous (P), hydrogen (H), oxygen (O), calcium (Ca), potassium (K), and magnesium (Mg), but only small amounts of others like iron (Fe), boron (B), zinc (Zn), manganese (Mn), and copper (Cu). Forest nutrient cycling is the exchange of elements between an ecosystem's living and nonliving parts.

5.3 FOREST NUTRIENT CYCLING

Nutrient cycling in forests can be defined as the exchange of elements between living organisms and non-living components of the environment. The nutrient cycle in forest environments involves animals, plants, fungi, and bacteria living above and below ground, as well as mineral components of soil, dead leaves and wood, and water from rain and snowfall. Trees and other plants absorb mineral and non-mineral nutrients from the soil through their roots. These nutrients are stored in plant leaves, flowers, and other parts. When animals consume the plants, the nutrients are either transferred to the animals or returned to the soil. For example, when plants and animals die, arthropods, fungi, bacteria, and earthworms in the soil break them down. Arthropods are insects like mites. Arthropods and earthworms grind up decaying matter and mix it with soil. Some of the more complex compounds can be broken down into smaller components by fungi. Because all of these organisms eventually consume and respire much of the material back into carbondioxide gas, it eventually disappears. Thus, nutrient cycling plays an essential role to the cyclic exchange of nutrients in forest ecosystems.

Nutrient pool in vegetation: The amount of nutrients in an ecosystem's living biomass is referred to as the nutrient pool in vegetation. Each bio-geochemical cycle has two kinds of pools:

(i) Exchange or cyclic pool: It is a small, fast-moving component that exchanges rapidly between organisms and their immediate surroundings. For example, the plants and animals that move nutrients and store them for short periods of time in a cycle.

(ii) Reservoir pool: The various nutrient reservoirs or pools, including the rocks and the atmosphere, are referred to as reservoir pools. These are large, slow moving, and usually not biological. The main source and storage place for the element is the reservoir pool. The physical environment is where it usually occurs. The exchange of materials with organisms occurs very slowly in the reservoir. On the basis of movement of nutrients, bio-geochemical cycles are of two types:

a. **Perfect cycles:** A perfect nutrient cycle is one in which nutrients are replaced as quickly as they are depleted. The most of the gaseous cycles are considered to be perfect.

b. **Imperfect cycles:** Sedimentary cycles, on the other hand, are thought to be relatively imperfect because some nutrients are lost from the cycle into the soil and sediments and become unavailable for immediate cycling.

Plant uptake: The transfer of nutrients from the soil to the plants by absorption is called uptake process. The nutrients enter the plant via root and foliar uptake. Foliar uptake consists of ion uptake from wet deposition across the cell membrane or direct absorption of gases (e.g. NO_2 and SO_2). The annual uptake of a forest varies greatly from establishment to maturity. Nutrient uptake will increase with increasing gross ecosystem production during the early establishment phase. When nutrient uptake exceeds the amount recycled, a portion of the uptake is retained in the standing crop (the total dried biomass of the living organisms present in a given ecosystem at a given time). This type of retention of balance nutrients in the standing crop increases the nutrient content of the ecosystem. This means:

$$\text{Retention} = \text{uptake} - \text{recycle}$$

Nutrient uptake, retention, and recycling rates vary between ecosystems and can be calculated using a variety of chemical methods. The rate of uptake will peak around the time the canopy closes. After canopy closure, gross production slows due to competition and mortality, and more carbon is allocated to woody materials with lower nutrient content (e.g., stem). As a result, uptake rates will fall from their peak at canopy closure and remain relatively constant.

Growth requirement of nutrients

The growth requirement is defined as the total amount of a nutrient required by plants each year to meet its nutrient demands connected with annual increment, litter fall, and canopy leaching. The demand is fulfilled through uptake and re-translocation processes:

Growth Requirement = Uptake + Re-translocation
Growth Requirement = Annual Increment + Litter Fall + Canopy Leaching
Canopy Leaching = Through Fall + Stem Flow – Atmospheric Deposition

Re-translocation: The re-translocation of nutrients from leaves during senescence is a strategy for efficiently retaining P. This re-translocation by resorption serves to remove nutrients from leaves prior to abscission for later redeployment in developing tissues. Re-translocation has been identified as one of the most important strategies used by trees to conserve nutrients, which influences competition, nutrient uptake, and productivity. Despite similar soil conditions, foliar nutrient concentrations vary greatly within the same community between different species and individuals of the same species.

Annual increment: Annual increment refers to the net annual elemental addition of a nutrient to above-ground and below-ground biomass. In other words, the amount of a nutrient stored in vegetative biomass each year. The annual increase is quite minimal in comparison to the growth requirement and uptake. As a forest reaches a stable state, the yearly increment of a forest ecosystem approaches zero as biomass increase is balanced by mortality and litter fall returns.

Litterfall: Litter fall refers to the return of nutrients to the soil caused by senescence of plant tissues. Forest litterfall is the primary flux responsible for nutrient transfer to soil, and the amount, nature, and rate of decomposition of litterfall have a significant impact on the growth and productivity of forest ecosystems. It is an important component of the nutrient cycle in forest ecosystems, as it regulates the accumulation of soil organic matter (SoM), the input and output of nutrients, nutrient replenishment, biodiversity conservation, and other ecosystem functions. Litter is directly involved in plant-soil interaction because it helps to incorporate carbon and nutrients from plants into the soil. Tree species may affect nutrient cycling by varying their litter production, chemical composition, and nutrient release. Different tree species have different nutrient release patterns that are affected by litter quality and seasonal environmental factors. The quantity and quality of litter determine the functioning of the forest ecosystem and are also necessary for balanced ecosystem processes. The primary constituents of litter fall are roots, woody tissues, foliage, and reproductive tissues. The pattern of litter production differs between ecosystems based on soil fertility, tree species composition, climate elevation, and latitude. In most tropical forests, however, the amount of litter on the soil varies with the seasons. Duration of leaf-fall varied from species to species, being only one month (*Grewia tiliafolia*); two months

(*Acacia catechu, Sterculia urens*) three months (*Lannea coromendelica, Schrebera swietenioides, Wrightia tinctoria*) four months (*Albizzia odoratissima, Erythrina suberosa, Emblica officinalis*); five months (*Aegle marmelos, Boswellia serrata, Tamarindus indica*). Leaf fall in *Anogeissus latifolia* and *Zizyphus jujube* has been observed for six months.

Through-fall and Stem flow: Water can reach the forest floor after dripping from leaves and branches (through-fall) or flowing down tree stems (stem flow). In through-fall rain water reaches the under-canopy soil by dripping, splashing, and freely penetrating a vegetative canopy, and in stemflow rain water is transported down the trunk or stems. Net or effective precipitation is defined as the sum of through-fall and stem-flow.
Rainfall Water is distributed differently when it is partitioned by vegetation both horizontally and vertically. Nutrient concentrations can rise or fall in relation to the amount of atmospheric deposition (e.g., wetfall and dryfall).

Net Canopy Exchange = Total Deposition (Wet + Dry) – (Throughfall + Stemflow)

Herbivory: Herbivory refers to animals feeding on living plant parts. Plant nutrient turnover to litter is influenced by herbivores through plant fragments, nutrients leached from chewed surfaces, and excrement animal tissues. Leaves die and are decomposed on the forest floor by bacteria, fungi, and microarthropods. Herbivory and senescence are two mechanisms in the forest environment that connect herbivory to nutrient cycle. Herbivory refers to partial grazing of foliage by herbivores, whereas defoliation refers to complete grazing of foliage.

Decomposition: Decomposition is defined as the interconnected processes that break down organic matter into CO_2 and humus while also releasing nutrients. These processes are an important link in the intra-system nutrient cycling because they recycle nutrients.
Soil microorganisms and fauna play an important role in the decomposition process, in which soluble nutrients are initially leached and then either mineralized or immobilised based on the needs of the decomposer communities. Water availability, temperature, and litter quality are the most important factors influencing decomposer growth and efficiency. Three interrelated processes lead to the decomposition of litter:

(i) Leaching of soluble compounds and physical fragmentation by abiotic forces such as wind
(ii) Fragmentation (or comminution) by soil fauna
(iii) Microbial catabolism: These processes may be interdependent, as when earthworms consume leaf fragments that are then enriched and inoculated with bacteria and fungi during passage through the gut. Chemical composition of the litter has a significant impact on the first and third processes; comminution and feed of soil fauna may also be impacted by litter chemistry and "Palatability" to soil animals.

The chemical breakdown of litter by microorganisms is the process that could be most affected by rising CO_2 levels. Nitrogen transformations are especially important because plant growth in many of the world's ecosystems is limited by N availability. Microbially mediated lignin decomposition and humic substance production result in the immobilisation of at least a portion of photosynthetically fixed C into long-lived soil C pools. The process of nutrient cycling includes an important phase in which organic matter is decomposed by the microbial component of the soil biota, which is responsible for more than 90% of decomposition and mineralization.

Litter is broken down into smaller pieces by soil fauna as it decomposes, and organic matter derived from microbes is intimately mixed with the soil mineral component during the humus formation process. Typically, the formed humus dominates the soil organic matter pool and contributes to many of the environmental values of soil. Carbon locked in organic-mineral complexes known as humus has been resident in soil for decades, centuries, and millennia, so the majority of organic matter in soil is old and important for carbon storage. Humus contributes significantly to the formation of stable soil aggregates that increase the diffusion of water and air through soil due to its resistance to decay, and it forms an ion-exchange surface that holds nutrient.

Factors affecting Decomposition: Temperature, litter quality, soil pH, moisture, aeration, inorganic compounds, and microbial activity all have an impact on decomposition. The addition of litters to the various layers of soil affects the water and nutrient absorption capacity of soils, thereby improving soil water and nutrient absorption capacity. The high species diversity of trees in the forest ecosystem may result in an increase in the C/N ratio and soil organic carbon. The soil organic matter's ability to decompose is determined by the C: N ratio. Normal soils have a 10:1 C: N ratio. There are 10 units of carbon (C) and 1 unit of nitrogen (N) in the soil, according to the 10:1 ratio.

C and N dynamics during litter decomposition follow distinct patterns; for example, because fresh litters generally contain less N than the decomposers require, the decomposers are forced to immobilise nitrogen from the surrounding environment. However, over time, the N concentration will exceed the decomposers' demand, and the N: C concentration will rise, indicate the start of the N mineralization process and substrate assimilation. As a result, N:C determines the litter decomposition process as well as the N dynamics. Decomposition processes involves:

(i) **Immobilization**: It refers to the process by which a microorganism converts an element from an inorganic to an organic form.
(ii) **Mineralization:** It is the transformation of a nutrient from its organic (bound to carbon and hydrogen) form to its inorganic form.

Pathways in Nutrient cycling: A nutrient cycle is the cyclical process by which nutrients move in order to be recycled and used again. Only 18 of the 126 naturally occurring chemical elements have been identified as essential elements (or nutrients) without which plants cannot grow and complete their life cycles. Essential elements used by plants in relatively large amounts are known as macronutrients, such as C, H, O. P, K, S, N, Mg, and Ca, which have cycles with the atmosphere, while micronutrients, such as Cu, Fe, CO, Mn, B, Zn, Mo, Ni, and Ci (elements used by plants in small amounts), are derived from edaphic cycles in the soil. Because these elements remain in the soil as salts, plants take them as ions.

Life on Earth is dependent on the availability of energy and the circulation of approximately 33 to 40 elements that living things require for normal growth and development. These elements or nutrients are known as biogenic salts, and they are classified into two types: micronutrients and macronutrients. The macronutrients are elements and their compounds that play important roles in protoplasm and are required in large quantities, such as oxygen, nitrogen, carbon, calcium, magnesium, potassium, phosphorous, and so on. Micronutrients such as iron, copper, zinc, sodium, boron, molybdenum, cobalt, strontium, and others are required in trace amounts for various metabolic and ketabolic activities in plants and animals. The elements move from non-living to living and back again. Biochemical cycles are defined as the more or less circular path of chemical elements passing back and forth between organisms and the environment (Odum, 1963).

Three Aspects of a Nutrient cycle: Nutrient cycle can be conveniently considered under the following three aspects:

(a) **Input of nutrients:** An ecosystem receives nutrients from outside sources and stores them for use in biological processes. Nutrient input from the atmosphere and weathering of primary minerals, as well as nutrient export from the soil via leaching and gaseous transfers. The primary sources of nutrient inputs are:

(i) **Dry Deposition:** Nutrients enter an ecosystem as particulates from dust fall. Nitrogen fixation in soil is a symbiotic biological process. Weathering of rocks causes the release of nutrients from their state.

(ii) **Wet Deposition:** It is the nutrient intake into an ecosystem in a dissolved state. Wet deposition is mainly caused by rainfall. The input normally enters the atmosphere first in the form of gases.

(b) **Output of nutrients:** It is the loss of nutrients from an ecosystem caused by runoff water (for example, Soil erosion, nitrification, crop harvesting, tree felling, cattle grazing, and so on. Nutrients exit the ecosystem (are removed by animals and humans) via meteorologic (transport of gases and particulate matter), geologic (e.g., dissolved and particulate matter in moving water and soil), and biologic (removal by animals and humans) pathways.

(c) **Internal nutrient cycling:** Decomposers such as fungi, bacteria, and actinomycetes continuously regenerate and store nutrients in the soil through decomposition and store them in plant-available forms.

5.4 THE NUTRIENT CYCLE MODELS IN FOREST ECOSYSTEM

The nutrient cycling model (NUCM) is a high-level model that represents the cycling of N, P, K, Ca, Mg, S, and other nutrients. Mineral movement (imports and exports) is accomplished through the operation of various nutrient cycles that continually pass materials back and forth between organisms and their environments.

Biogeochemical Cycles: The nutrient cycle is also known as the biogeochemical cycle. The term biogeochemical is derived from "bio" meaning biosphere, "geo" meaning geological components, and "chemical" meaning elements that move through a cycle. The cycle is referred to as biogeochemical because it includes biological, geological, and chemical components. Biogeochemical cycles primarily refer to the exchange of nutrients and other elements between biotic and abiotic factors. Carbon cycle, nitrogen cycle and so on are all part of the gaseous biogeochemical cycle, while sulphur and phosphorous are part of the sedimentary cycle. Types of biogeochemical cycles are- Hydrologic Cycle (Water Cycle), Gaseous Cycle and Sedimentary cycle.

5.4.1 Hydrologic Cycle or Water Cycle: Water transports valuable nutrients through and across soils. As the landscape absorbs water, it also absorbs many of the nutrients dissolved in the water. This is a crucial connection between the hydrologic cycle and the nutrient cycle.

This is not an elemental cycle because it follows the path of a compound, water. The water cycle is essentially a link between the sedimentary and gaseous biogeochemical cycles. However, the movement of water within and between ecosystems is essential to understanding nutrient cycles for several reasons:

(i) Plants use large amounts of water to maintain their hydrostatic skeletons and move chemicals around their bodies
(ii) Plants use water as a source of hydrogen for photosynthesis
(iii) Plants take elements in aqueous solution from soil.

Water is essential to life, accounting for more than 80% of all living cells. The water cycle is a continuous cycle in which water evaporates, travels into the air and forms a cloud, falls to earth as precipitation, and then evaporates again. This cycle is driven by the evaporative power of solar radiation and requires 8.2 x 10 20 K Ja^{-1}, which is approximately 15% of the total radiation reaching the outer atmosphere. This percentage compares to the 0.2 percent used in global gross primary production.

Human impact on water cycle

1. Humans affect the water cycle by building dams and withdrawing water.
2. Toxic chemical use in agriculture and manufacturing.
3. Chemical fertiliser and pesticide runoff can pollute or seep into the ground, contaminating the water supply.
4. The amount of water that plants can return to the atmosphere through transpiration is reduced when forests are cleared.

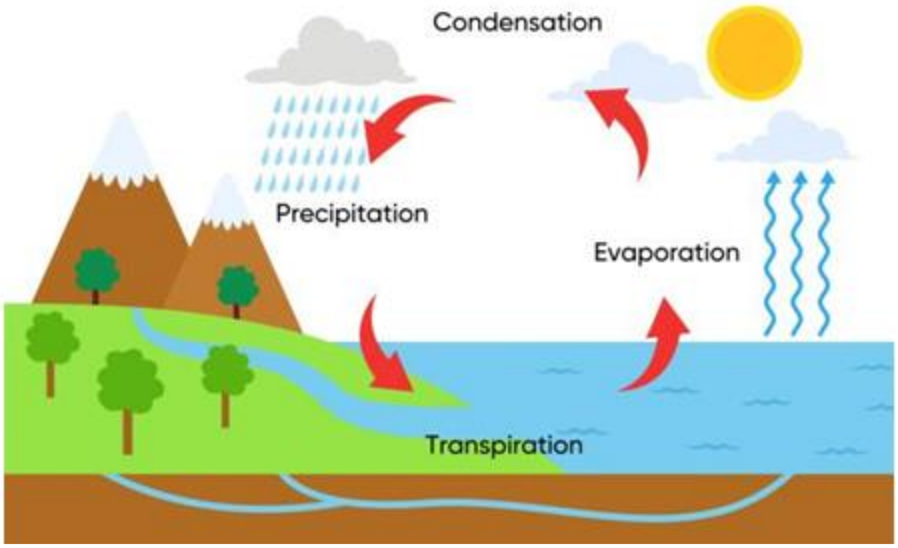

Fig.5.1 Water Cycle
(Source: https://www.istockphoto.com/search/2/image?phrase=water+cycle)

5.4.2 Gaseous Cycle

The elements have a main reservoir in the gaseous phase in gaseous cycles, and the reservoir pool is the atmosphere or water. Before completing the cycle, the compounds of these elements pass through the biotic components and enter a gaseous phase as well. As an example, consider the elements carbon and nitrogen. The atmosphere and oceans serve as the primary nutrient reservoirs for the gaseous cycles. Unlike the sedimentary cycle, the gaseous cycle moves quickly because it uses the atmosphere as a reservoir.

5.4.1.2 Carbon Cycle: The carbon cycle is the process by which carbon compounds are exchanged between the earth's biosphere, geosphere, pedosphere, hydrosphere, and atmosphere. Carbon is the primary component of all organic compounds found in protoplasm, including proteins, carbohydrates, nucleic acids, and fat. There are three major sources of carbon in the non-living world: (i) carbondioxide in air and found dissolved in water, (ii) carbonates of the earth's crust derived from rocks give rise to carbon dioxide on chemical changes, and (iii) fossil fuels like coal and petroleum give rise to carbondioxide on burning. Carbon dioxide is the primary source of carbon for all living organisms.

Carbon is transferred from one storage reservoir to another via a variety of mechanisms. for example, Plants move carbon from the atmosphere into the biosphere via photosynthesis in the food chain. They use solar energy to create sugar molecules by chemically combining carbondioxide with hydrogen and oxygen from water. Animals that consume plants digest the sugar molecules to obtain energy. Respiration, excretion, and decomposition all return carbon to the atmosphere or soil, thus completing the cycle. Carbon also circulates in the ocean, where photosynthetic algae fix carbon dioxide and generate biomass. Carbon from animals and plants that lived millions of years ago is stored in rocks like limestone and fossil fuels like oil and coal. When these organisms died, slow geologic processes trapped their carbon and converted it into these natural resources. Erosion, for example, releases carbon into the atmosphere slowly, whereas volcanic activity releases it quickly.

Carbon Cycle steps: The major steps in the carbon cycle process are as follows:

1. Plants absorb carbon from the atmosphere for photosynthesis. Plants, algae, and cyanobacteria use photosynthesis to remove carbon dioxide from the atmosphere and fix it or incorporate it into complex organic compounds like glucose. Carbon from abiotic sources is incorporated into biological compounds of producers during photosynthesis.

2. The producer who formed the compounds, the consumer who consumes the producer, or the decomposer who breaks down the producer's or consumer's remains use many of the compounds as fuel for cellular respiration. CO_2 is released back into the atmosphere during cellular respiration. Aquatic ecosystems experience a similar carbon cycle between dissolved CO_2 in water and aquatic organisms. Animals consume plants to obtain the carbon they need to make their own tissues. Carnivores consume these animals and use the carbon for their own survival. When these animals breathe, they release carbon dioxide into the atmosphere, and when they die, the carbon is returned to the soil during decomposition.

3. Millions of years ago, vast coal beds formed from the remains of ancient trees that were buried and subjected to anaerobic conditions before they decayed completely.

4. Marine plankton remains: The underground accumulations of oil and gas in the geologic past are likely the result of the oils of unicellular marine organisms. Coal, oil, and natural gas are referred to as fossil fuels because they are derived from the remains of ancient organisms. Non-renewable resources are fossil fuels. These resources are finite or limited on earth.

5. Combustion (Human and natural) - The burning or combustion process may release carbon from oil, coal, natural gas, and wood into the atmosphere. Organic molecules are

rapidly oxidised (combined with oxygen) and converted to carbondioxide and water during combustion, resulting in the release of heat and light.

6. Burial and compaction to form rock (Limestone) -The shells of marine organisms contain even more carbon that has been preserved over millions of years. When these organisms die, their shells sink to the ocean floor and are covered by sediments, which are cemented together to form limestone.

7. Erosion of limestone to form dissolved CO_2: When geologic uplift exposes limestone, chemical and physical weathering occurs. This returns carbon to the water and atmosphere, where it can once again participate in the carbon cycle. So, photosynthesis takes carbon out of the abiotic environment and adds it to biological molecules. However, carbon is returned to the abiotic environment through cellular respiration, combustion, and limestone erosion.

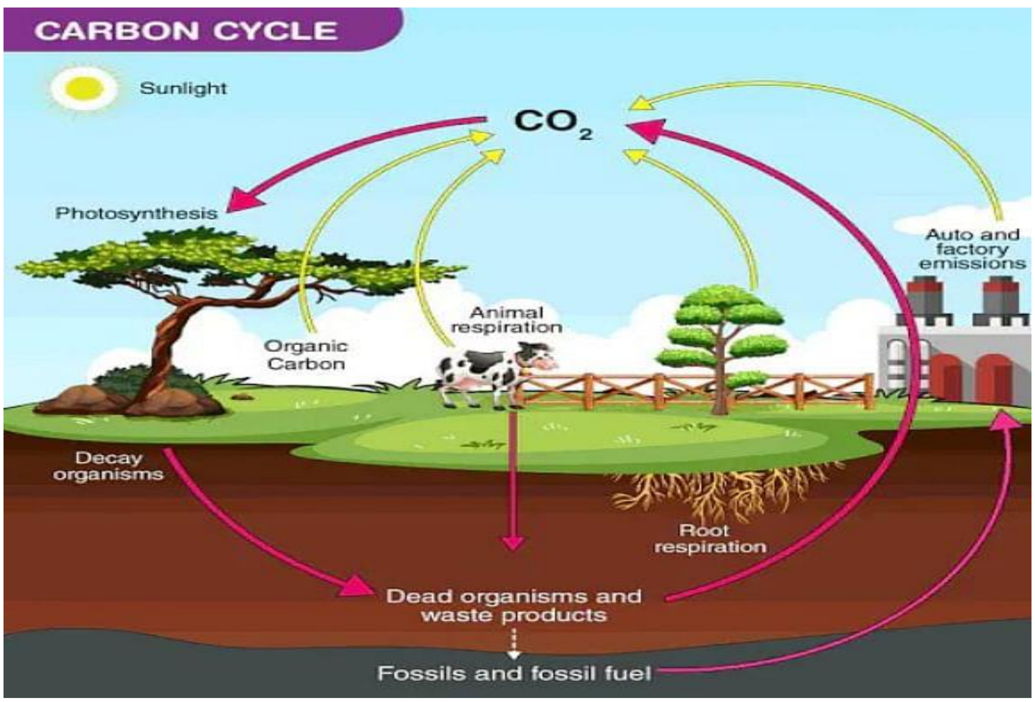

Fig.5.2 Carbon cycle
(Source: https://prepp.in/news/e-492-carbon-cycle-environment-notes)

Human Impacts on Carbon cycle

1. A massive amount of carbon is released into the atmosphere over a very short period of time when human's burn fossil fuels to power factories, power plants, automobiles, most of the carbon quickly enters the atmosphere as carbondioxide.

2. By cutting down trees and clearing vegetation that naturally absorbs CO_2. When there are fewer plants, less CO_2 is removed from the atmosphere.
3. Changes in CO_2 levels caused by human activities raise the earth's temperature due to the greenhouse effect.
4. Of the huge amount of carbon that is released from fuels enters the atmosphere and most of the rest becomes dissolved in sea water. Carbon moves from the atmosphere to the oceans. The oceans and other bodies of water, soak up some carbon from the atmosphere. More dissolved CO_2 in the water creates more carbonic acid which becomes the reason of acidification of the oceans.

5.4.2.2 Nitrogen Cycle: The nitrogen cycle is a biogeochemical process in which nitrogen is transferred from the atmosphere to living organisms and then back to the atmosphere in various forms. The nitrogen cycle is a cyclical process in which nitrogen moves from an inorganic form in the atmosphere to an organic form in living organisms. Nitrogen, abbreviated N, is a colourless and odourless element. The atmosphere is the biggest reservoir of nitrogen, predominantly as nitrogen gas (N_2). All living things require nitrogen since it is essential to plant growth. If there is insufficient nitrogen, plants will not thrive and provide low crop yields. If there is an excess of nitrogen, plants may become toxic. Nitrogen is an essential component of the nucleic acids DNA and RNA, which are the most significant biological molecules and are essential to all living beings. Plants cannot generate amino acids (substances that contain nitrogen and hydrogen that are found in many living cells, muscles, and tissue) if they do not receive adequate nitrogen. Plants cannot produce the specific proteins required by plant cells if amino acids are not present. Plant growth suffers when there is insufficient nitrogen. Nitrogen is the most crucial ingredient for plant growth that plants acquire from the soil. Nitrogen is necessary for the formation of amino acids, proteins, enzymes, chlorophylls, nucleic acids, and a variety of other substances. Green plants get nitrogen from soil solution in the form of ammonium, nitrate, and nitrite ions, but atmospheric nitrogen is the primary source of all these nitrogen molecules. Except for some prokaryotes such as blue-green algae (cyanobacteria), and nitrogen-fixing bacteria, atmospheric nitrogen is not directly available to organisms. So it is essential to transform nitrogen into different forms so that it may be absorbed by plants and other organisms.

Nitrogen undergoes several changes during the nitrogen cycle. The nitrogen cycle consists of the following steps:

(i) Nitrogen fixation: The majority of nitrogen enters ecosystems via certain bacteria in soil and plant roots that convert nitrogen gas into ammonia (NH3). Nitrogen fixation is the conversion of free nitrogen from the environment into biologically suitable nitrogenous molecules. This is the first stage of the nitrogen cycle. The nitrogen cycle starts with this phase. The transformation of atmospheric N2 into ammonia (NH3) defines this stage. In this process, bacteria like Azotobacter and Rhizobium play a significant role. They live in the roots of leguminous plants and contribute to the conversion of inert nitrogen to ammonia. This process is of two types:

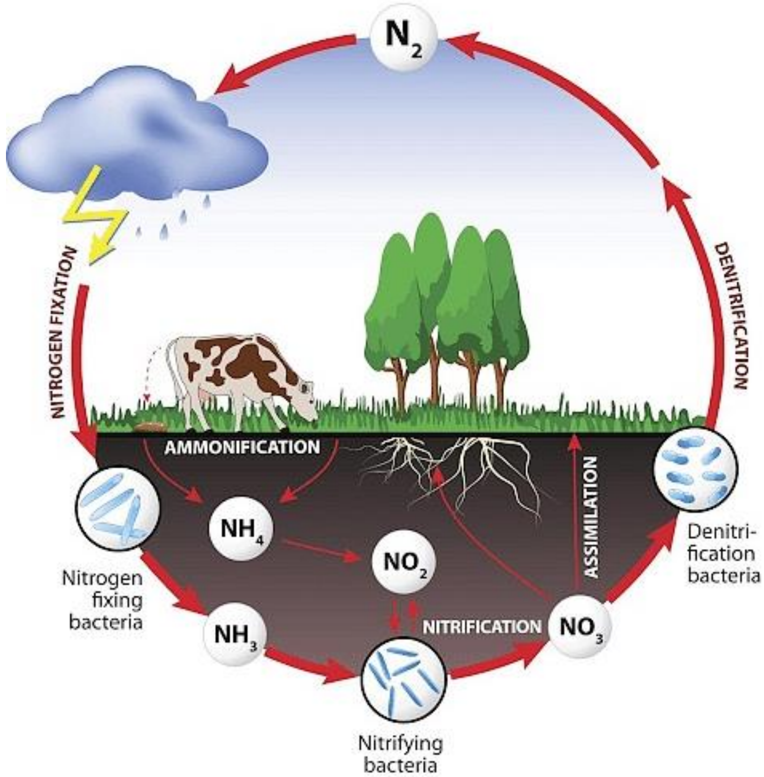

Fig.5.3 Nitrogen Cycle

(Source: https://prepp.in/news/e-492-nitrogen-cycle-environment-notes)

a. Physicochemical or non-biological fixation: During the physicochemical process of nitrogen fixation, atmospheric nitrogen mixes with oxygen during lightning or electrical discharges in the clouds, forming nitrogen oxide, NO, and nitrogen dioxide, NO_2. These nitrogen forms are then washed into soils by rain or snow.

$$N_2 + 2(O) \xrightarrow[\text{Discharge}]{\text{Electric}} 2NO$$

$$2NO + 2(O) \longrightarrow 2NO_2$$

$$2NO_2 + (O) \longrightarrow N_2O_5$$

Nitrogen oxides dissolve in rainwater and react with mineral components to generate nitrates and other nitrogenous compounds when they reach the earth's surface:

$$N_2O_5 + H_2O \longrightarrow 2HNO_3$$

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

Nitrogenous chemicals are produced through various types of combustion and are rinsed down with rain water. Nitrogen and hydrogen combine at high pressure and temperature to form ammonia (industrial nitrogen fixation).

b. **Biological nitrogen fixation**: Biological nitrogen fixation is the process by which nitrogen is fixed in plants with the help of anaerobic bacteria. In 1901, Dutch microbiologist Martinus Beijerinck discovered biological nitrogen fixing. Certain prokaryotes are responsible for it. Cyanobacteria (blue-green algae) fix huge amounts of nitrogen in the oceans, lakes, and soils. Symbiotic bacteria (Rhizobium) found in the root nodules of legumes and symbiotic cyanobacteria (Nostoc, Anabaena, etc.) found in the free state or in the thalli of Anthoceros (bryophytes), Azolla (water fern), coralloid roots of Cycas (gymnosperm) fix atmospheric nitrogen. Natural processes alone fix 95% of the total world nitrogen. They use nitrogenase, an enzyme, to catalyse the conversion of atmospheric nitrogen (N_2) to ammonia (NH_3). Plants may easily absorb NH3 and use it to make the aforementioned nitrogenous biomolecules.

   Certain free living nitrogen fixing bacteria, such as Azotobacter, Clostridium, Beijerinckia, and others, fix atmospheric free nitrogen in the soil. Frankia, a nitrogen-fixing actinomycetous fungus found in the roots of higher plants such as Alnus and Casuarina, is another nitrogen-fixing actinomycetous fungus. Nitrogen-fixing organisms mix atmospheric nitrogen with hydrogen from the respiratory system to generate ammonia, which in turn interacts with organic acids to form amino acids. Biological nitrogen fixation accounts for up to 140-700 mg/m2/year of fixed nitrogen, compared to 35 mg/m2/year from electrical discharge and photochemical fixation.

(ii) Ammonification: This is another method of producing ammonia. Dead Organic remains of plants and animals are broken down in the soil by bacteria, releasing ammonia into the soil. These bacteria, particularly actinomycetes and bacilli (Bacillus ramosus, B. vulgaris, and B. mesenterilus), feed on dead and waste material and release ammonia into the soil. This ammonia production process is known as ammonification. Ammonia is already present in the soil due to nitrogen-fixing bacteria. Ammonification raises the concentration of ammonia in the ground. Bacteria (Pseudomonas, Bacillus, Clostridium, Serratia), fungus (Alternaria, Aspergillus, Mucor, Penicillium), and actinomycetes (Streptomyces) can convert organic nitrogen compounds to ammonia. Ammonification is essential because it provides nitrogen to the soil in a form that plants can use and distribute through the food chain. Ammonification is the most effective method of getting nitrogen for many types of plants that grow in acidic soils.

(iii) Nitrification: Nitrification is the process by which ammonia is transformed into nitrites and then into nitrates. Nitrification is a natural process in which ammonia (NH4+) is transformed to nitrites (NO2-) and then to nitrates (NO3-) by a group of specialised bacteria. Nitrosomonas are a type of specialised bacteria that convert ammonia to nitrates. This takes place in two steps:

(a) **Conversion of Ammonia into Nitrites:** The first phase involves converting NH3 (ammonia) to NO3- (nitrates). Nitrosomonas bacteria cause this. They oxidise soil ammonia and convert it to nitrites. The following chemical equation is used to represent the reaction:

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

(b) **Conversion of Nitrites to Nitrates:** Several microorganisms, including Penicillium species, Nitrobacter, Nitrocystis, and others, convert nitrites to nitrates. Nitrocystis oceanus is a common marine autotroph that uses nitrification to generate energy. The chemical equation of the reaction is given below.

$$2NO^-_2 + O_2 \longrightarrow 2NO_3^- + \text{energy}$$

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

(iv) Nitrogen assimilation: Green plants absorb inorganic nitrogen in the form of nitrates, nitrites, and ammonia, which is then transformed into nitrogenous organic molecules. Nitrates first convert to ammonia, which then reacts with organic acids to generate amino acids. Amino acids are necessary for the formation of proteins, enzymes, chlorophylls, nucleic acids, and other compounds. Plant proteins provide the nitrogen required by animals. Animals do not directly consume plant proteins. During digestion, they are broken down into amino acids, which are then absorbed and processed into animal proteins, nucleic acids, and so on. Plants can take nitrogen through their roots once it has been fixed in the soil. Assimilation is the term used to describe the process of absorption.

In the process of nitrogen assimilation, plants utilise the nitrates produced by soil bacteria to produce nucleotides, amino acids, and other essential molecules for life. Nitrates are absorbed by plants through their roots, where they are used for producing nucleic acids and amino acids. These amino acids and nucleic acids are then utilised by the animals that consume the plants in their own cells.

Plants obtain nitrogen molecules from the soil via their roots, which are available in the form of ammonia, nitrite ions, nitrate ions, or ammonium ions and are utilised to produce plant and animal proteins. Plants enter the food web in this way when they are consumed by primary consumers. It first becomes the nitrite ion, then the ammonium ion, which adds amino acids, nucleic acids, chlorophyll, and other compounds. Plants and rhizobia have a symbiotic relationship in which the plant provides nutrients to the bacteria and the bacteria provides nitrogen to the plant.

(v) Denitrification: Some nitrates are not absorbed by the plants. They are transformed into atmospheric nitrogen by pseudomonas and clostridium. It is a biological reduction process in which nitrogen molecules are released back into the environment in their gaseous state - nitrogen gas (N) - by the conversion of nitrate (NO3-). This is the final phase in which the nitrogen compounds in the soil return to the atmosphere. Denitrifying bacteria include Pseudomonas denitrificans, Bacillus licheniformis, Thiobacillus denitrificans, Hypomicrobium, and Chromobacterium etc.

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

(vi) Sedimentation: Soil nitrates are washed down to the sea or leached deep into the earth with percolating water. Nitrates lost from the soil surface are thus trapped up in the rocks. This is called nitrogen sedimentation. Rock nitrogen is only released when it is exposed and weathered. As a result, a significant amount of nitrogen gets fixed and stored in plants, animals, and microorganisms. Nitrogen leaves the biological system in the same proportion that it enters from the atmosphere, and nitrogen input and output are balanced throughout the ecosystem.

Human impacts on the Nitrogen Cycle

1. Human activities such as when fertilisers are used to raise ammonia levels in the soil, algae can overgrow, resulting in soil toxicity and ecosystem imbalance.
2. Nitrogen oxides are produced by automobiles and power plants and are one of the primary contributors to particulate matter, a type of air pollution.
3. Much of the nitrogen supplied to agricultural and urban areas eventually ends up in rivers and nearshore marine systems. Increases in nitrogen can frequently result in anoxia (no oxygen) or hypoxia (low oxygen), changed biodiversity, changes in food-web structure, and general habitat deterioration in nearshore marine systems.
4. Increased atmospheric concentrations of nitrous oxide (N_2O), a powerful greenhouse gas, as well as other nitrogen oxides (including nitric oxide, NO), which are responsible for the production of photochemical smog over large areas of the Earth.

5.4.3 Sedimentary cycle: Sedimentary cycling occurs for nutrients that exist in their elemental form, and the Earth's crust serves as a reservoir. It includes the phosphorus cycle, and the sulphur cycle, among others. Sedimentary cycles take a very long time to complete their circulation. The main reservoir in sedimentary cycles is soil; sedimentary and other types of rocks in the earth's crust. The sedimentary cycle has two phases: one water phase and one soil/sediment phase. The elements are weathered and dissolved in the water phase, then pass through the biotic components and return to the sediment phase.

5.4.3.1 Phosphorus cycle: Phosphorus is an essential nutrient for all biological processes. It is a significant part of phospholipids, which make up the majority of cell membranes as well as nucleic acids like DNA and RNA, and it also contributes to the structural elements of bones as calcium phosphate. It can be found in soil as rock phosphate, apatite or calcium phosphate, fluorapatite $Ca_{10}Fe_2\ (PO_4)_6$ iron phosphate, or aluminium phosphate. Phosphorus is abundant in soils derived from phosphate-rich rock beds. The phosphorus cycle describes how phosphorus moves through the hydrosphere, lithosphere, and biosphere. Phosphorous can be found in the soil in five different forms: P1 (Stable organic), P2 (labile organic), P3 (liable inorganic), P4 (Soluble), and P5 (mineral form), and of these forms, P3 and P4 are in equilibrium, and phosphorous entry into green plants is thought to occur via the liable inorganic pool.

Plant growth is frequently restricted by the low levels of phosphorous in soil. It is an essential component of molecules that store energy, including DNA, ATP (adenosine triphosphate), and lipids (fats and oils). It also plays a crucial role in cell development. Human bones and teeth contain 8% phosphorus. Phosphorous cycle is a very slow process, which involves following steps:

1. **Weathering:** The earth's crust, specifically sedimentary rocks containing phosphate (PO_4^{3-}) minerals. Because rocks are the primary source of phosphorous, the first step in the phosphorous cycle involves the extraction of phosphorous from rocks via weathering. Phosphorus is then carried to the soil by rain or acid produced by certain microbes. Actinomycetes, pseudomonas, bacillus, aspergillus, penicillium, and other microbes contribute to the production of phosphorus in soil, which is found in plants and other animals. Rain and weathering cause phosphate ions and other minerals to be released from rocks over time. This inorganic phosphate is then distributed in soils and water. Natural processes such as volcanic eruptions and asteroid impacts aid in the extraction of phosphorus from the soil.

2. **Absorption by plants:** Many different living species, including plants and microbes, can absorb the mineral phosphorus from the soil. Plants absorb the phosphate salts dissolved in water. However, because the soil contains very little phosphorus, phosphorus-containing fertilisers used to promote plant development and soil fertility. Aquatic plants absorb inorganic phosphorus from the bottom layers of bodies of water. Phosphate salts have an adverse effect on plant growth in aquatic ecosystems because they do not dissolve properly in water. Plants absorb inorganic phosphate from the soil, and symbiotic bacteria can help plants get phosphorus. The plants are then consumed by animals, and the phosphate is incorporated into organic molecules such as DNA. When an animal or plant dies, it continues decompose, returning organic phosphate to the soil.

3. **Absorption of animals:** Phosphorus is transferred from one species to the next when animals absorb it from plants or consume plant-eating animals. Animals consume phosphorus, which is used to produce biomolecule-like nucleotides and connective tissue-like bones. Plants and animals have a faster phosphorus cycle than rocks.

4. **Return to the environment via Decomposition:** Bacteria that break down organic matter to inorganic matter to inorganic forms of phosphorous in the soil can make organic forms of phosphate available to plants. This is referred to as mineralization. Phosphorus in soil can end up in rivers and, eventually, the oceans. Once there, it can gradually be incorporated into sediments. When plants and animals die, microorganisms such as fungi and bacteria decompose them. The organic form of phosphorous is converted during this process and recycled to soil and water. Soil and water will end up in sediments and rocks, which will then weather and release phosphorus. As a result, the phosphorus cycle is restarted.

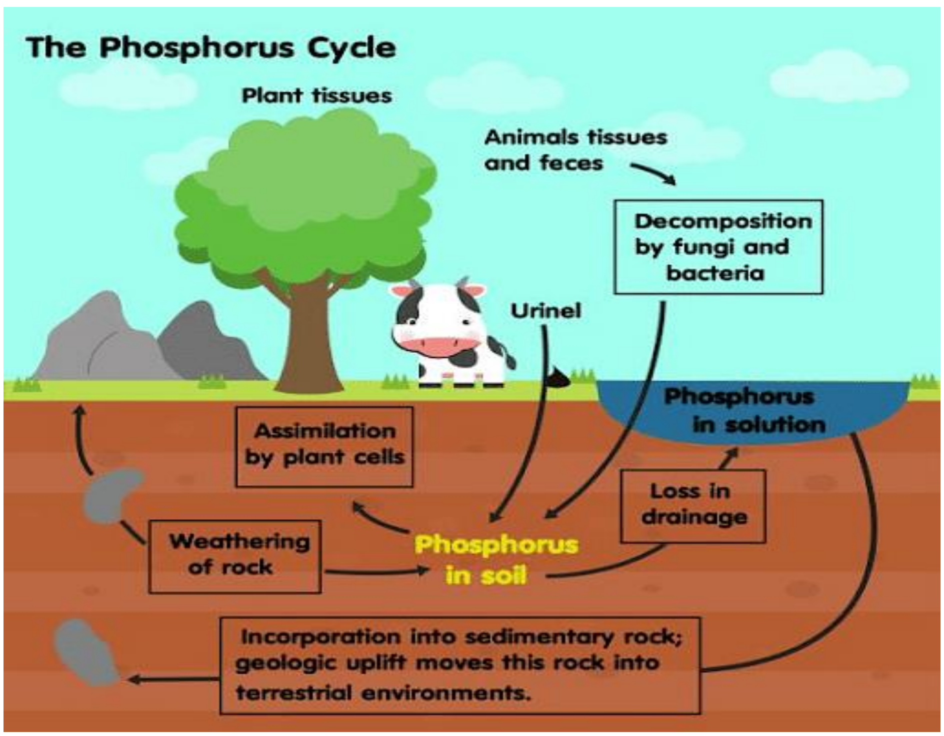

Fig.5.4 Phosphorous Cycle

(Source: https://prepp.in/news/e-492-biogeochemical-cycle-environment-notes#NutrientCycling)

Impacts of anthropogenic activities on phosphorous cycle

Phosphorous cycling is the slowest of all biogeochemical cycles. Human interventions, on the other hand, cause changes in the cycle.

1. Phosphorus is obtained through the mining of phosphate rocks and guano deposits, which is then used to produce a variety of products, including detergents, fertilisers, medicines, pesticides, and animal feed. This mining exposes phosphate deposits formed over millions of years.
2. Humans pollute aquatic systems with phosphates from animal waste runoff, fertilisers, and sewage treatment system discharges.
3. The phosphorous cycle is also disrupted by the discharge of sewage and other industrial effluents into bodies of water.
4. Humans have an impact on the phosphorus cycle by using synthetic fertilisers. Because phosphate in fertilisers is not completely utilised by plants, leftover phosphates remain in the plants' water supply. Water runoff contains residual phosphate.
5. When excessive amounts of phosphorus are leached into the water as a result of human activity, aquatic ecosystems suffer. Artificial or anthropogenic eutrophication is the term used to describe the significant amount of phosphorous that is drained into water systems. The excessive supply of plant nutrients promotes the excessive growth of algae when phosphorus levels are too high. However, these algae eventually die or produce toxic algae blooms that harm the ecosystem's plants and animals.

5.4.3.2 Sulphur Cycle: Sulphur is one of the earth's most abundant elements. It is a non-metal that is yellow, brittle, odourless, and tasteless. Sulphur can be found in all types of proteins. It is a vital component of vitamin and protein function in plants and animals. Sulfur-containing amino acids like cystine, methionine, and cysteine are directly absorbed by plants. Sulphur occurs naturally in the earth's crust, atmosphere, and bodies of water. Sulphur is found primarily in the earth's crust as pyrite (FeS_2, PbS, and HgS) and gypsum ($CaSO_4$). Another source of sulphur is the atmosphere (Sulphur dioxide, hydrogen sulphide gas, ammonium sulphate, and sulphate particles). The oceans are the largest sulphur reservoir. The oceans contain elemental sulphur, dissolved hydrogen sulphide gas, and about 2.6 g/L of sulphates.

Sulphur is released when rocks are exposed to the elements. When sulphur comes into contact with air, it undergoes a chemical reaction that converts it to sulphates. After absorbing sulphates, plants and microorganisms convert them into organic forms. The organic form of sulphur is then ingested by the animals via the food they consume, causing sulphur to move up the food chain. When the animals die, some of the sulphur is released as a byproduct of decomposition, and some of it is consumed by the bacteria that consume the dead animals. Sulphur is directly released into the atmosphere by a variety of natural processes, the most well-known of which are volcanic eruptions, water evaporation, and the decomposition of organic waste in swamps. Precipitation transports this sulphur to earth.

Steps of Sulphur Cycle: The following are the key steps in the Sulphur cycle:

1. **Decomposition of organic compounds:** Protein breakdown results in the release of sulphur-containing amino acids. The Desulfotomaculum bacteria convert sulphates to hydrogen sulphide (H_2S).
2. **Oxidation of Hydrogen Sulphide to Elemental Sulphur:** Elemental sulphur is produced when hydrogen sulphide oxidises. The oxidation process is initiated by photosynthetic bacteria from the chromatiaceae and chlorobiaceae families.
3. **Oxidation of elemental Sulphur:** The plants cannot directly use the elemental sulphur that is present in the soil. Therefore, chemolithotrophic bacteria transform it into sulphates.
4. **Reduction of Sulphates:** Desulfovibrio desulfuricans is responsible for converting sulphates to hydrogen sulphide. This occurs in two steps:
   (a) In the beginning, ATP is utilized in order to convert the sulphates into the sulfites.
   (b) Second, the reduction of sulphite to hydrogen sulphide.

The sulphur biogeochemical cycle has two components: atmospheric and terrestrial. The sulphur cycle connects soil, air, and water. It can be found in the atmosphere in the form of sulphur dioxide, which is produced by the combustion of fossil fuels or by volcanic eruptions. Another component of the atmosphere formed during the decomposition of organic sulphur under anaerobic conditions is hydrogen sulphide. The gaseous phase, on the other hand, does not form a large reservoir like nitrogen.

At high temperatures, sulphur dioxide is converted to sulphuric acid vapour, which then remains in the atmosphere. As the temperature drops, the vapours begin to condense gradually. The resulting condensate takes the form of aerosol droplets, which are black, acidic, and carbonaceous in nature due to the presence of unburned carbon particles. This substance, commonly known as "acid mist," has been found to spot or blister and corrode the substrates. Acid problems must become even more serious as it interacts with rain or snow in the atmosphere and returns to the earth's surface in the form of "acid rain" torrents. Acid rain can cause serious ecological imbalances by:

(i) Running fresh water lakes, rivers, and streams, killing fish and other marine life
(ii) Causing essential plant and crop nutrients to leach out of the soil, inhabiting the process of nitrogen fixation by microorganisms, affecting soil fertility and thus damaging crops
(iii) Posing major health risks by contaminating drinking water, as harmful sediments of metals such as calcium, aluminium, and lead are liberated from the affected fresh water lake or river bottom by the acid extraction process.

The soil-based component of the cycle involves microbial oxidation-reduction exchanges of sulphate, element sulphur, and sulphide. Under aerobic situation, heterotrophic organisms such as Escherichia, Aspergillus, Neurospora and others breakdown organic sulphur compounds and release sulphates. However, in anaerobic conditions, Desulphovibrio desulphuricans transforms sulphates to sulphide. When waterlogged soil drives and becomes aerobic, bacteria like Theobacilus thiooxidans oxidise H_2S to sulphate, resulting in high soil acidity.

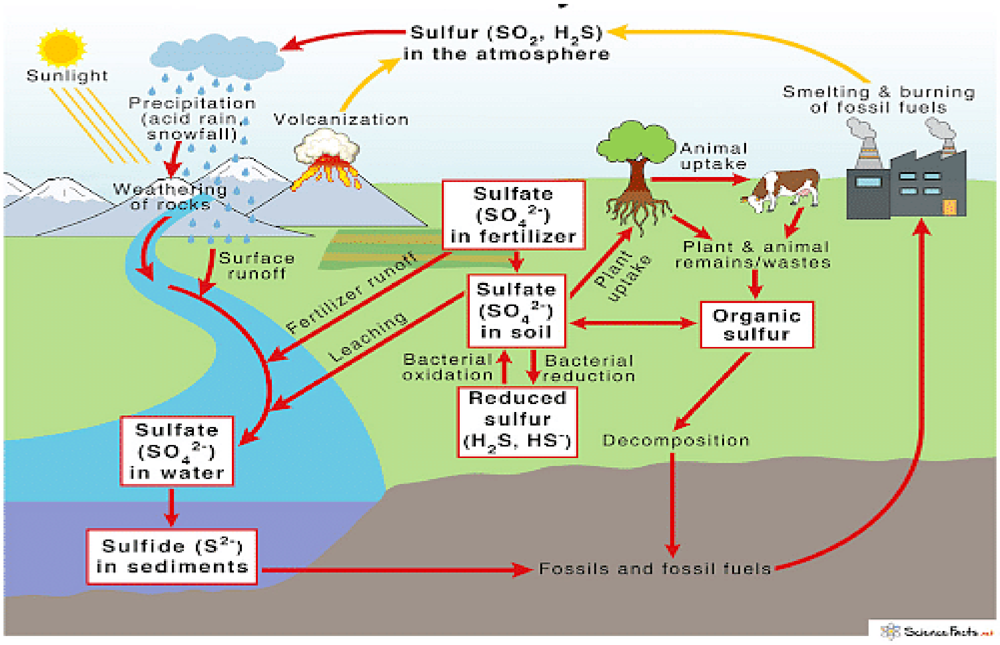

Fig.5.5 Sulphur Cycle

(Source: https://prepp.in/news/e-492-biogeochemical-cycle-environment-notes#NutrientCycling)

Human impacts on the sulphur cycle

1. Human activities has greatly influenced the global sulphur cycle. The use of fossil fuels such as coal, natural gas etc, has resulted in a rise in the amount of sulphur in the atmosphere and ocean, as well as a decrease in the amount of sedimentary rock that can absorb sulphur.
2. The combustion of fossil fuels and other forms of combustion raises the quantity of SO_2 in the atmosphere, causing an imbalance in the sulphur content on Earth. Sulphur dioxide raises Earth's temperature by increasing the particles in clouds. The rise in sulphur dioxide in clouds increases the area of acid rain on Earth.
3. In the absence of human intervention, sulphur would stay trapped in rocks for millions of years, only to be released after being uplifted by tectonic events and then subjected to erosion and weathering. Instead, the amount of drilling, pumping, and burning is increasing steadily. The amount of sulphate that has settled has increased thirtyfold in the most contaminated areas.
4. Industrial civilisation, together with a fast increasing global population and increasing mechanisation of agriculture and forestry, alters vast regions of previously undisturbed environment, altering the terrestrial ecosystem.

5. The addition of synthetic fertilisers to soil can have an impact on soil fertility, plant development, and microbiological activity.
6. Sulfuric acid and sulphur dioxide are released into the environment as a result of petroleum refining and industrial processes.

5.5 SUMMARY

A forest, like all ecosystems, is made up of living beings that need nutrients to survive. Nutrients are elements or compounds that are necessary for plant growth and survival. The nutrient cycle is a system in which energy and matter flow between living organisms and non-living components of the environment. This occurs when animals and plants use soil nutrients, which are then released back into the ecosystem through death and decomposition. Nutrient elements are exchanged among the soil, plants, and animals that live in forest ecosystems. Nutrient cycling is essential to the cyclic movement of nutrients in the forest environment. To maintain plant growth, all biochemical reactions required for plant growth are collected from the soil by the plant and returned to the soil directly or indirectly as organic matter. There are three types of nutrient cycles: hydrologic, gaseous, and sedimentary. The reservoir of the gaseous type of nutrient cycle, for example, carbon and nitrogen, is generally found in the atmosphere and the hydrosphere. The sedimentary type has reservoirs in the earth's crust, such as phosphorous and sulphur. Water, nitrogen, carbon, phosphorus, and sulphur are the major natural cycles. Many human actions, including deforestation, the use of fossil fuels, and the use of nitrogen-based fertilizers, have had a major effect on the natural cycle in recent years.

5.6 GLOSSARY

DNA: Deoxyribonucleic acid (DNA), a self-replicating substance found in almost all living species as the major component of chromosomes and a carrier of genetic information.

RNA: Ribonucleic acid, a nucleic acid found in all living cells, works as a messenger, transmitting DNA instructions.

Nitrogen fixation – It is the conversion of atmospheric nitrogen to ammonia. Nitrogen fixation takes place naturally by lightning, UV radiation. It is also produced by industrial processes and by living organisms.

Biological Nitrogen fixation: Biological nitrogen fixation refers to the conversion of nitrogen to ammonia by living organisms.

Ammonification: It is the process by which dead and decaying organic matter decomposes and produces ammonia.

Nitrification – Nitrification is the process by which bacteria in the soil convert ammonia to nitrite and nitrate. The bacteria *Nitrosomonas* and *Nitrococcus* first convert ammonia to nitrite, which is then oxidised to nitrate by the bacterium *Nitrobacter*.

Denitrification – Denitrification converts nitrate in soil back to nitrogen. Denitrification can be performed by bacteria such as Pseudomonas and Thiobacillus.
Assimilation – It is the conversion of nitrate and ammonia into organic molecules.
Biomass: The total number or weight of animals and plants in a given area or volume.
Oxidation: A chemical process that occurs when a material comes into touch with oxygen or another oxidising agent.

5.7 SELF ASSESSMENT QUESTION

5.7.1 Multiple Choice type Questions:

1-Which of the following is an example of sedimentary cycle?
(a) Carbon cycle (b) Oxygen cycle
(c) Phosphorous cycle (d) Nitrogen cycle
2- The most abundant source of phosphorous on the planet is:
(a) Water (b) Soil
(c) Rocks formed from the Earth's crust (d) None of the above
3-C: N ratio of normal soil is-
(a) 20:1 (b) 5:1
(c) 10:1 (d) 15:1
4- What happens to the nutrients in the ecosystems that are never lost?
(a) Exhaust (b) Deplete
(c) Newly formed (d) Recycle
5-What is the movement of nutrient elements through the various components of an ecosystem known as?
(a) Sedimentary cycling (b) Gaseous cycling
(c) Elemental cycling (d) Nutrient cycling
6- What occurs during the nutrient cycle?
(a) Storage and transfer of nutrients (b) Loss of nutrients
(c) Exhaustion of nutrients (d) Sedimentation of nutrients
7- How many different categories can a nutrient cycle are divided into?
(a) No type (b) One type
(c) Two type (d) Three type
8-Where is the gaseous type of nutrient cycle located?
(a) Atmosphere (b) Soil
(c) Earth's crust (d) Land surface
9-Where is the sedimentary type of nutrient cycle located?
(a) Earth's crust (b) Land surface
(c) Water (d) Atmosphere

10-Which one of the following biogeochemical cycles, the weathering of rocks is the main source of release of nutrient to enter the cycle?

(a) Carbon cycle
(b) Phosphorous cycle
(c) Sulphur cycle
(d) Nitrogen cycle

5.7.2 True or False

1. Nitrates are released back into the soil through dead organism.
2. Plants can absorb and use nitrogen gas out of the atmosphere.
3. The movement of nutrient elements through the various components of an ecosystem known as sedimentary cycling.
4. In through-fall rain water reaches the under-canopy soil by dripping, splashing, and freely penetrating a vegetative canopy.
5. Immobilization is the transformation of a nutrient from its organic (bound to carbon and hydrogen) form to its inorganic form.

Answer Key:

5.7.1: 1-(c), 2-(b), 3-(c), 4-(d), 5-(d), 6-(a), 7-(b), 8-(a), 9-(a), 10-(b)

5.7.2: 1-True, 2- False, 3-False, 4-True, 5-False

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5.9 SUGGESTED READINGS

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- Fundamentals of ecology by S.K. Agrawal, published by S.B. Nangia, APH Publishing Corporation.
- Ecology and environment by P.D. Sharma, published by Rastogi publication.
- A text book of Plant Ecology by R.S. Shukla and P.S. Chandel, published by S.Chand and company private limited

5.10 TERMINAL QUESTIONS

5.10.1 Short Answer Type Questions

1. What are nitrifying bacteria?
2. Define biogeochemical cycles. Name two types of them.
3. Briefly describe the process and products of decomposition.
4. Distinguish between wet deposition and dry deposition.
5. Give an account of factors affecting the rate of decomposition.
6. Write short notes on the following:
   (a) Biological Nitrogen fixation
   (b) Ammonification
   (c) Litter fall
   (d) Throughfall and Stem flow
7. Write a short note on nutrient pool in vegetation.

5.10.2 Long Answer Type Questions

1. What is meant by nutrient cycling? Explain nitrogen cycle.
2. What are sedimentary cycles? Depict phosphorous cycle with diagram.
3. Discuss water cycle in detail.
4. What is carbon cycle? Explain it in detail with diagram.
5. Define biogeochemical cycles. Discuss about any one of the gaseous cycle.

UNIT-6- ECOSYSTEM INPUTS OF NUTRIENTS

Contents:

6.1 OBJECTIVIES

The present topic provides an overview on nutrient inputs and outputs in an ecosystem. After reading this topic, the learners will be able to answer the:

- Nutrients inputs
- Nutrient outputs
- Losses of the nutrients

6.2 INTRODUCTION

Plants take nutrients elements from the atmosphere, water, soil and sediments. The inputs into an ecosystem are derived from meteorologic (nutrients in gases, precipitation, dust etc), geologic (dissolved or particulate matter carried in through water and soil movements) and biological (deposition of material gathered by animal elsewhere) sources. Within an ecosystem, the nutrients residing in five compartments, viz., plant biomass, animal biomass, detritus, soil and rock minerals, and available nutrients. Similarly, nutrients leave the ecosystem (output) through meteorologic (transport of gases and particulate matter), geologic (dissolve and particulated matter in moving water and soil), and biological (removal by animals and humans) pathways. These inputs and outputs constitute the extrasystem nutrient transfers or extrasystem nutrient cycling which effectively connect different ecosystem (Fig 6.1).

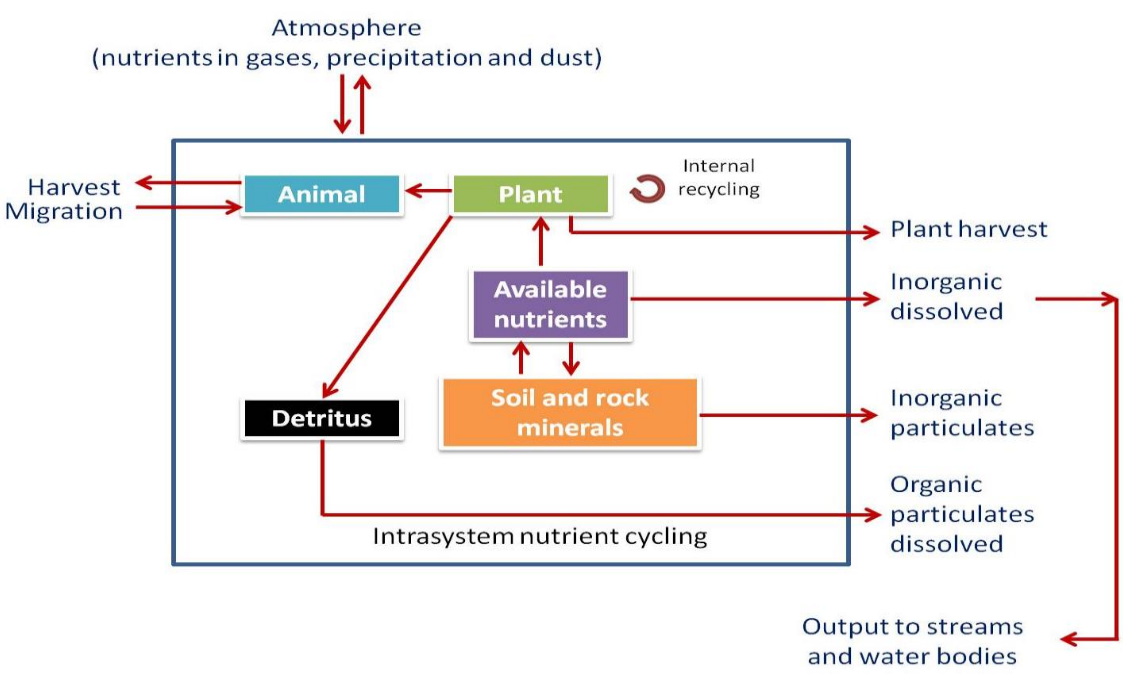

Fig 6.1: A compartment model of intrasystem cycling of nutrients and extrasystem nutrient transfer (Image is recreated by author, original source: Singh et al., 2015)

6.3 ATMOSPHERE

The term atmosphere includes only the thick gaseous mantle surrounding the earth. Up to height of about 300 km above the earth's surface, there is some sort of a thick gaseous mantle. With increasing height above sea level, the atmosphere pressure gradually decreases. In atmosphere , about 95% of the total air is present up to the height of about 20 km above earth's surface and remaining 5% in the rest about 280 km height. In the gaseous mantle, there is found a mixture of different gases in different proportions. Of these various gases, nitrogen, oxygen and carbon dioxide are the major components. Relative proportions of different gases, by volume, are shown in Fig 6.2.

Besides gases, some other constituents are water vapours, industrial gases, dust and smoke particles in suspended state, micro organisms, pollen grain, spores etc. Cycling of gases as carbon dioxide, nitrogen etc between the atmosphere, soil and organisms is the regular feature of nature.

Layers of the atmosphere

Earth's atmosphere has five major layers. From lowest to highest, the major layers are the troposphere, stratosphere, mesosphere, thermosphere and exosphere (Fig.6.2).

- **Layer 1: Troposphere:** The basal portion of atmosphere known as troposphere which extends from Earth's surface to, on average, about 12-20 kilometers in height, with its height lower at Earth's poles and higher at the equator. For organisms this is the most important zone. Yet this very shallow layer is tasked with holding all the air plants need for photosynthesis and animals need to breathe, and also contains about 99 percent of all water vapor and aerosols. In the troposphere, temperatures typically go down the higher you go, since most of the heat found in the troposphere is generated by the transfer of energy from Earth's surface. The troposphere is the densest atmospheric layer, compressed by the weight of the rest of the atmosphere above it. Most of Earth's weather happens here, and almost all clouds that are generated by weather are found here, with the exception of cumulonimbus thunder clouds, whose tops can rise into the lowest parts of the neighboring stratosphere. Most aviation takes place here, including in the transition region between the troposphere and the stratosphere.

- **Layer 2: Stratosphere.** Located between approximately 12 and 50 kilometers above Earth's surface, the stratosphere is perhaps best known as home to Earth's ozone layer, which protects us from the Sun's harmful ultraviolet radiation. Because of that UV radiation, the higher up you go into the stratosphere, the warmer temperatures become. The stratosphere is nearly cloud and weather-free, but polar stratospheric clouds are sometimes present in its lowest, coldest altitudes. It's also the highest part of the atmosphere that jet planes can reach.

- **Layer 3: Mesosphere.** Located between about 50 and 80 kilometers (31 and 50 miles) above Earth's surface, the mesosphere gets progressively colder with altitude. In fact, the top of this layer is the coldest place found within the Earth system, with an average temperature of about minus 85 degrees Celsius (minus 120 degrees Fahrenheit). The very scarce water vapor present at the top of the mesosphere forms noctilucent clouds, the highest clouds in Earth's atmosphere, which can be seen by the naked eye under certain conditions and at certain times of day. Most meteors burn up in this atmospheric layer. Sounding rockets and rocket-powered aircraft can reach the mesosphere.

Gas	Percent (by volume)
Nitrogen	78.08410
Oxygen	20.94860
Argon	0.934000
Carbon dioxide	0.031800
Neon	0.001820
Helium	0.000520
Crypton	0.000110
Xenon	0.000090
Hydrogen	0.000060
Methane	0.000200
Nitrous oxide	0.000050
Ozone	0.000004

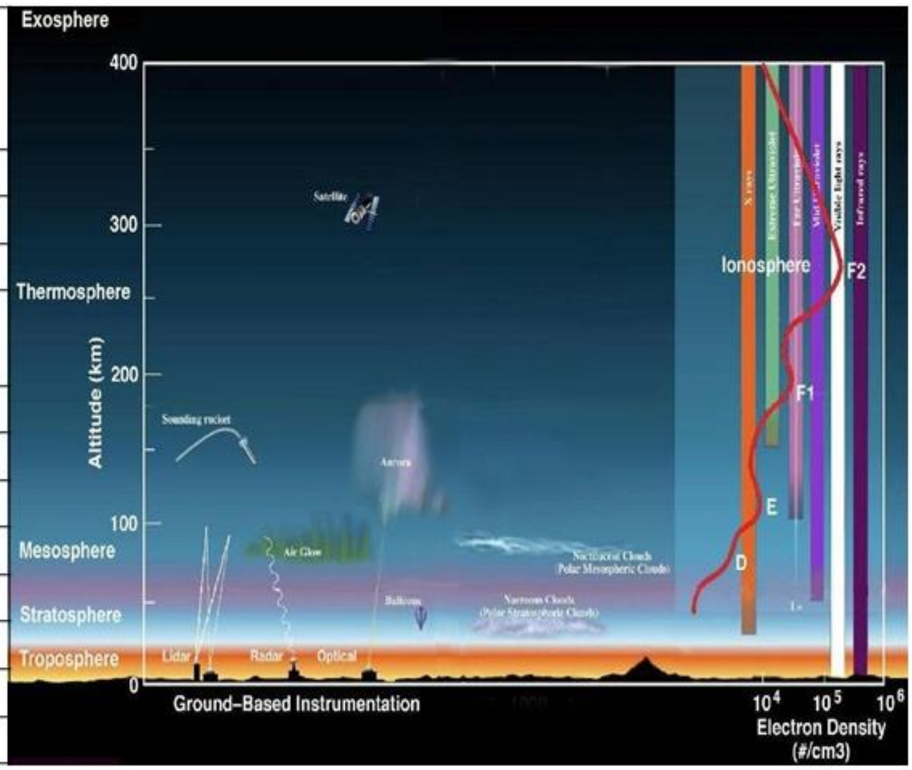

Fig 6.2: Diagram of the layers within Earth's atmosphere.
(Image is recreated by author; Credit: Sharma 2012 for table and NASA for image)

- **Layer 4: Thermosphere.** Located between about 80 and 700 kilometers (50 and 440 miles) above Earth's surface is the thermosphere, whose lowest part contains the ionosphere. In this layer, temperatures increase with altitude due to the very low density of molecules found here. It is both cloud- and water vapor-free. The aurora borealis and aurora australis are sometimes seen here. The International Space Station orbits in the thermosphere.

- **Layer 5: Exosphere.** Located between about 700 and 10,000 kilometers (440 and 6,200 miles) above Earth's surface, the exosphere is the highest layer of Earth's atmosphere and, at its top, merges with the solar wind. Molecules found here are of extremely low density, so this layer doesn't behave like a gas, and particles here escape into space. While there's no weather at all in the exosphere, the aurora borealis and aurora australis are sometimes seen in its lowest part. Most Earth satellites orbit in the exosphere.

Role of atmosphere in nutrients input

Nearly all of nitrogen and majority of sulphur and chlorine in terrestrial ecosystems are primarily derived from the atmosphere. Precipitation contains dissolved and particulate nutrients, including substantial amount of nitrogen. Leaves and branches of trees act as filters for atmospheric particles and gases which contain nutrients. Trace gases particularly oxidized forms of N and S are also a minor source of plant nutrients for land plants. These sources include direct addition of oxidized N (due to lightening) and S (from volcanic eruption). In recent years, industries have added large amount of NO_2 and SO_2, and other gases to the atmosphere, which in turn lead to increased deposition of N and S in the ecosystem (Singh et al. 2015).

Both oxidized and reduced forms of these gases are readily dissolved in rainwater and are transported to the ground as dissolved ion which is available for plant uptake. Rainfall also contains nutrients derived from the oceans. The aerosol originating from oceans contains important seawater constituents, especially Na, Mg, Cl, and SO_4. Similar aerosol may be transported over great distance from oceans to forest lands.

Dust in windstorms in dried region also contains atmospheric aerosols rich in Ca, K and SO_4. Volcanic eruptions and fires also inject gases and particulate matters, which can be transported to great distance. Dry deposition or dry falls is the result of gravitational sedimentation of particles during rainless periods and the rate of deposition depends on particle size.

Through wet fall is predominant process, dry fall can also be important. It contains more ions derived from continental sources than those derived from the ocean.

Apart from the wet and dry fall, the vegetation surface of forest and other natural vegetation also captures nutrients of fog droplets and aerosols from horizontal air streams. The interception may be sizeable in costal and montane forest ecosystem. Plants and soil can also directly absorb reactive gases such as SO_2 and NH_3.

6.4 WEATHERING OF ROCK MINERALS

The whole process of soil formation is generally divided into two stages (i). weathering: break down of bigger rocks into fine, smaller mineral particles. (ii). Soil development or pedogenesis: modification of the mineral matter through interaction between biological, topographic and climatic effects, which ultimately lead to the development of any of a great variety of potential soil types. In this unit we will briefly discuss about the weathering of rocks and mineral only.

Weathering describes the breaking down or dissolving of rocks and minerals on the surface of the Earth. Bare rock are exposed to various types of physical, chemical and biological processes which lead to physical and chemical disruption of their components. Physical processes of weathering include action of water, temperature, glaciers, gravity etc. which cause weathering of rocks through process as wetting-drying, heating, cooling, freezing, glaciations, solution and sand blast etc. The chemical processes of weathering include hydration, hydrolysis, oxidation-reduction, carbonation, chelation etc., which are due to chemical composition of rocks, chemicals in the atmosphere, as well as those produced as a result of living organisms, such as lichen, fungi, bacteria, blue green algae, bryophytes etc.

In biological processes lichens are able to extract nutrients from bare rocks. Lichens, fungi and bacteria on rock surface retain the water for a long period during which the chemical processes can proceed, splitting the rock alumino-silicates by hydrolysis and carbonation into the simpler clay alumino-silicates. Algal partner of lichen through photosynthesis, increases the amount of available organic matter at rock surface. Various exudates from these organisms and the respiratory carbon dioxide accelerate the process of weathering, as some of the lichen acids generally dissolve mineral components. Rock weathering is therefore, for a short time, a physic-chemical process but soon it becomes biogenic, increasing in its rate.

Types of weathering

The weathering processes are two types: Physical and chemical.

1. **Physical weathering:** This process is following types:

    a) Wetting-drying: It is the disruption of layer lattice minerals which swell on wetting.
    b) Heating-cooling: It is disruption of heterogeneous crystalline rocks in which inclusion have differential coefficients of thermal expansion. It occurs particularly in dry climates, where due to sun heating large boulders flake at surface.
    c) Freezing: This is the disruption of porous, lamellar or vesicular rocks by forest shatter due to expansion of water during freezing.
    d) Glaciation: Larger masses of snow and ice-glaciers, while falling may cause physical erosi rocks through grinding process.
    e) Solution: Some more mobile components of rocks such as calcium chloride, sulphates etc are simply removed by agents like water,
    f) Sand blast: In arid, desert conditions the rocks are disrupted by physical action of wind, sand etc.

2. **Chemical weathering:** It include the following:

a) Hydration: As a result of taking water due to reversible change of haematite to limonite, the rock swells. This swelling causes the disruption of sandstones etc.
b) Hydrolysis: In this process, components like alumino-silicates of rock breakdown during which elements such as potassium and surplus silicon are washed out which give rise to simpler mineral matter like clay alumino-silicates. For example: hydrolysis of orthoclase ($K_2Al_2Si_6O_{16}$) to kaolinite ($Al_2O_3.2SiO_2.2H_2O$).
c) Oxidation-reduction: Some oxidation-reduction chemical reactions, such as reversible change of Fe^{3+} to Fe^{2+} cause disruption of rocks, because Fe^{2+} is more soluble than Fe^{3+}.
d) Carbonation: Some produced in the atmosphere and those during the metabolism of microorganisms bring about carbonation. As for example reversible change of $CaCO_3$ to $Ca(HCO_3)_2$ leads to solution loss of limestone or disruption of $CaCO_3$ cemented rocks as the hydrogen carbonate is more soluble than the carbonate.
e) Chelation: Some chemical exudates, produced through biochemical activity of microorganisms like lichen, bacteria etc. are able to dissolve out mineral components of the rocks. These metals dissolved with organic products of microbial activity are known as chelates. For example acids produced by lichen and bacteria have strong chelating properties.

Importance of weathering

1. Topographical variations are the consequence of weathering of rocks.
2. It assists in soil formation.
3. Weathering is accountable for mass movement and erosion.
4. The level of bio-diversity and growth of vegetation are depending on the depth of weathered materials.
5. By the weathering and deposition of rocks, the concentration of valuable minerals like iron, manganese, aluminium, copper, etc takes place, by which their exploitation, processing and refinement become easy.

6.5 HYDROLOGIC INPUTS

Water does not leave the earth nor does it come from any other planet. There is a constant exchange of water between the oceans and the atmosphere and this phenomena is known as global hydrological cycle. It is a closed system so it does not require any input or output. The drainage basin hydrological cycle, even though it only has one river basin that is defined by its own watershed, is regarded as an open system. There are many types of inputs, outputs, stores, transfers and flows in this open system. Inputs include precipitation (including rain and snow) and solar energy for evaporation. Evaporation and transpiration from plants (together known as evapotranspiration), runoff into the sea, and percolation of water to underlying rock strata into underground reserves are examples of outputs that carry moisture out of the drainage basin. The outputs of precipitation from rain and snow, which deposit water on the surface of the oceans and land, balance out these atmospheric water inflows. Surface storage (lakes, puddles, rivers etc), glaciers, soil storage, groundwater storage, and water captured by vegetation after precipitation are all examples of stores. Percolation, overland flow, infiltration, stemflow, through flow, and overland flow are examples of transfers or fluxes. Here we will only discuss the hydrological inputs of the open cycle system in detail.

A simplified hydrologic cycle begins with heating brought by solar energy and progresses through stages of evaporation (or sublimation), condensation, precipitation (snow, rain, hail, glaze), groundwater and runoff. The primary sources of water include the oceans, glaciers, aquifers beneath the earth's surface, surface waters and the atmosphere. All of these compartments together contain a fixed, global amount of water. However, through the processes of precipitation, evaporation, and surface flow in addition to subsurface movement, water freely travels between its various compartments. Each of these compartments functions as a flow-through system by receiving water inputs and having corresponding outputs. If there is an imbalance between input and output, there can be significant changes in the quantity stored locally or globally. The drought that can develop in soil over a prolonged period without replenishing by rainwater is an example of a local alteration. The growing amount of continental ice that forms throughout glacial epochs is an illustration of a global change in hydrology. This phenomenon can cause the sea level to drop by more than 328 feet (100 metres), opening up huge tracts of the continental shelf for the emergence of terrestrial ecosystems.

Energy gradients drive the water motions in the hydrologic cycle. The incidence of gradients in water vapour concentration and heat energy cause evaporation. Most naturally occurring water evaporation on Earth is primarily facilitate by solar electromagnetic radiation. The heating that results from radioactive decay from deep inside the Earth's mantle and crust satisfies the additional thermal energy requirements. Surfaces absorb solar radiation, which raises their heat content and provides a source of energy for evaporation. On the other hand, surface and ground waters respond to gravitational potential gradients by moving. The presence of heat energy and gradients in water vapour concentration cause evaporation to happen. Solar electromagnetic radiation is the primary energy source for the majority of naturally occurring water evaporation on Earth. The additional thermal energy requirements are met by heating that occurs from inside the Earth's mantle and crust as a result of radioactive decay. Surfaces absorb solar radiation, which raises their heat content and provides a source of energy for evaporation. Contrarily, surface and ground waters move in reaction to gravitational potential gradients. In other words, water naturally flows downhill until it is impeded.

A defined region of landscape's hydrological cycle is a balance between water inputs from precipitation and upstream drainage, outputs from evaporation and drainage deep into the earth, and any internal storage that may happen as a result of input and output imbalances. A watershed, or the area of land from which water flows into a stream, river, or lake, is commonly used as a spatial scale for studying the hydrological budget of a landscape. The simplest watersheds are referred to as headwater systems, which do not receive any drainage from watersheds at higher altitudes. As a result, the sole hydrologic input is precipitation, primarily in the form of rain and snow. However, wind conditions can successfully push tiny air water vapour droplets into the forest canopy where fog is a frequent occurrence, and direct deposition of cloud water can be significant. The snow that is brought in as a result of precipitation has a tendency to build up as a persistent snow pack on the surface. A portion of the annual input is returned to the atmosphere by evapo-transpiration, and a portion is washed away by river movement.

The input and output dynamics of water are directly impacted by seasonal changes. Evapotranspiration occurs at its greatest rate during summer and hence the runoff is relatively less during this period. In fact, small streams can literally dry up because much of the rainfall input and soil water is used for evaporation, mostly by trees (Bargali et al. 2019). During the autumn and rainy seasons, the majority of rainfall input serves to recharge depleting groundwater storage, and once this is complete the stream flow rises again. Runoff is reduced during winter, as most of the precipitation input is in the form of snow, which accumulates on the ground surface due to prevailing subfreezing temperatures. Runoff is greatest during early spring and summer when warm temperatures cause snowflakes to melt over a short period of time, resulting in a clear stream of stream and river flows.

6.6 BIOLOGICAL INPUTS

A living organism or element of biological origin, as opposed to elements of synthetic or mineral chemical origin, is referred to as a biological input when it is added to a farm or livestock facility to help with production optimization. Several types of biological inputs are taken into consideration:

1. **Biofertilizers:** These are the living microbes that improve fertility of soil either by increasing nutrient availability or mobilizing of nutrients (Padalia et al. 2015). These microbes are known as biofertilisers (Table 6.1). Since several microbial taxa, including helpful bacteria and fungi, successfully colonise the rhizoplane, rhizosphere or root interior, therefore used as biofertilizers. Fertilizer components produced directly or indirectly by living organisms (manure, manure) favor crop growth and soil fertility (Padalia et al. 2021; Padalia et al. 2018). Some economical beneficial microbes such as algae, bacteria and fungi are capable to fix atmospheric nitrogen, mobilize potash or dissolve insoluble soil phosphate to making them available to plant roots. There are so many advantages of biofertilizers over the chemical substitutes. Some are listed below:

   - Renewable, environmentally friendly source of nutrients.
   - Affordable for the farmer.
   - Increases crop output by 10-20% compared to artificial fertilizers.

- Helps plants absorb macronutrients like nitrogen, phosphorus, and potassium.
- Provides the plant with biological nitrogen, phosphorus, and potassium.
- By releasing auxins, vitamins, and hormones, it promotes blooming, vegetative growth, and root development.
- Increases the productivity, health, and longevity of beneficial soil bacteria.
- Lessens the carbon footprint and significant profits from carbon credits

Table 6.1: *List of some biological control agents*

Biocontrol		Examples
Predators	:	Ladybugs, dragonflies, lacewings, pirate bugs, rove and ground beetles, aphidsmidge, centipedes
Parasitoids	:	Ichneumonid wasps, bracoind wasps, chalcid wasps, tachinid flies
Nematodes	:	*Heterorhaditidae* spp, *Mermithidae* spp., *Rhabditidae* spp., *Steinernematidae* spp.
Bacteria	:	*Bacillus thuringiensis, Bacillus popillae*
Viruses	:	Cytoplasmic polyhedrosis, granulosis and entomopox virus
Fungi	:	*Metarhizium anisopliae*, *Beauveria bassiana*, *Trichoderma viride*

(Source: Biological pest control. In: New World Encyclopedia (18)

Table 6.2: *Seed care chemical control vrs. biological control*

Crop	Disease	Conventional control	Biological control
Wheat	Loose smut/ false smut	Tebuconazole/ Carbendazim	Trichoderma
Barley	Loose smut/ false smut	Carboxin/ Thiram	Trichoderma/ Pseudomonas
Maize/ Millets	Charcoal rot/ root rot	Carbendazim/ Thiram	Trichoderma
Rice	Root rot/ sheath blight	Carbendazim/ Kitazin	Trichoderma/ Pseudomonas
Chillies	Damping off/ Wilt	Carbendazim/ captan	Trichoderma/ Pseudomonas
Potato	Blight	Mancozeb/ carbendazim	Trichoderma
Tomato	Damping off/ Wilt	Carbendazim/ Captan/ Thiram	Trichoderma/ Pseudomonas
Onion	Purple blotch	Mancozeb	Trichoderma/ Pseudomonas
Sunflower	Root and seedling rot	Carbendazim/ Captan	Trichoderma
Mustard	Stem rot	Carbendazim	Trichoderma/ Pseudomonas
Soybean	Root and seedling rot	Carbendazim/ Thiram	Trichoderma
Cruciferous	Damping off/ wilt	Carbendazim/ capton	Trichoderma/ Pseudomonas
Chickpea	Wilt/ Damping off	Carbendazim/ Thiram	Trichoderma
Groundnut	Aflatoxins	Thiram/ Mancozeb	Trichoderma

(Source: Biological pest control. In: New World Encyclopedia (18)

2. **Biological control:** Biological control, often known as biocontrol, is a technique for eradicating pests like weeds, insects, mites, and plant diseases by using other living things (Table 6.2). Predation, parasitism, herbivory or other natural mechanisms are used, although often active human management is also present. Living organisms, like microbes that can boost plant health and hydromineral feeding (like mycorrhizae), auxiliary insects when added to pest management, are necessary to maximize productivity.

3. **Crop protection:** Products used to preserve crops that are made from live organisms, such as liquid manure, powders, decoctions, and fermentations. They work in a variety of ways, either directly on the intended organisms or indirectly by enhancing the plant's inherent defences (Natural Defense Stimulators).

4. **Bioremediation:** In recent years, professional users and consumer organisations have recently developed an interest in a distinct class of cleaning solutions that contain active ingredients that are living microorganisms or spores. These products are sometimes referred to as bioremediation, biological cleaners or microbial cleaners. A biological process called bioremediation turns trash into a form that other species may use and reuse. Nowadays, the world is facing the problem of different environmental pollution, therefore, microorganisms are essential for a key alternative solution to overcome challenges (Table 6.3 & 6.4). A biological process called bioremediation turns trash into a form that other species may use and reuse. Environmental contamination is a problem that the globe is now dealing with. Microorganisms are necessary for a significant alternative approach to the problems.

Table 6.3: *Groups of microorganisms important for oil bioremediation.*

Compound	**Microorganisms**
Diesel oil	*Fusarium* sp., *Alcaligenes odorans, Bacillus subtilis, Bacillus cereus, Corynebacterium propinquum, Pseudomonas aeruginosa, Pseudomonas putida*, *Arthobacter* sp
Crude oil	*Aspergillus niger, Candida glabrata, Candida krusei, Saccharomyces cerevisiae, B. brevis, P. aeruginosa, Bacillus licheniformis* and *Bacillus sphaericus*
Diesel oil and crude oil	*Pseudomonas cepacia, Bacillus cereus, Bacillus coagulans, Citrobacter koseri and Serratia ficaria*

(Source: Abatenh et al., 2017)

Microorganisms are survive in all place on the biosphere because of their metabolic activity is astonishing; then come into existence in all over range of environmental conditions. Microorganisms have an incredibly diverse range of dietary requirements, making them ideal for use in the biotreatment of environmental contaminants. Through the ubiquitous active action of microorganisms, bioremediation is heavily involved in the degradation, removal, fixation or detoxification of many chemical wastes and physically hazardous elements from the environment. Pollutants such as hydrocarbons, oil, heavy metals, pesticides, dyes, and other substances are transformed and degraded as the basic principle. This is accomplished enzymatically by metabolising, hence it plays a significant role in the resolution of numerous environmental hazards.

Table 6.4: *Potential biological agents for pesticides*

Compound	**Microorganisms**
Endosulfan	*Bacillus, Staphylococcus*
Chlorpyrifos	*Enterobacter*
Ridomil MZ 68 MG, Fitoraz WP 76, Decis 2.5 EC, malation	*Pseudomonas putida, Acinetobacter* sp., *Arthrobacter* sp
Chlorpyrifos and methyl parathion	*Acenetobactor* sp., *Pseudomonas* sp., *Enterobacter* sp. *and Photobacterium* sp.

(Source: Abatenh et al., 2017)

The usage of organic inputs needs to be customized to the farm's cultural, financial constraints and educational. It is a part of a production system that upholds the principles of sustainable development and agricultural ecology

6.7 BIOMASS ACCUMULATION OR STORAGE OF NUTRIENTS IN PLANTS

Biomass accumulation is a primary aim of agriculturists, foresters, and ecologists. Many factors influence biomass production and use by plants. To enhance the biomass accumulation, the number and variety of these factors represent both opportunities and challenges. This topic considers some essential characteristics and information by which to estimate the biomass accumulation in plants.

Biomass accumulation is often confused with productivity. Hence it is important to make a distinction between the two processes. Productivity is the result of photosynthesis. It is measured by photosynthetic rate and by considering the factors that affect it. Whereas, biomass accumulation is the change in biomass over time per unit area. So, to calculate biomass accumulation, we have to consider the processes in the production, use, and distribution of biomass in plants. Researchers measure biomass accumulation on various scales, i.e.,

- The whole plant (above-ground and below-ground plant parts)

- Field or local scale
- Large ecosystem scale

The last two categories will include the “whole-plant” category while also considering additional large-scale factors–usually management practices, climate, geography, etc.

Factor affecting the biomass accumulation

Biomass accumulation can be influenced by the following factors: (1). Plant attributes (2). Environmental factors. (3). Soil conditions and (4) Management practices

1. Plant attributes: morphology, physiology and genetics

(A) Morphological Features: The morphological features that affect biomass accumulation are plant architecture, leaf area, and the root system.

- **Plant architecture:** Plant architecture shows the pattern in which plants grow to increase light interception. It is defined as the three-dimensional organization of above-ground plant organs, such as the branching pattern, arrangement, shape, and size of leaves, flowers, and fruits. Plant architecture directly determines the canopy of the entire plant, in turn affecting the plant’s light interception efficiency.

- **Leaf Area:** Leaves are the most vital parts of a plant for biomass production, as this is the site where photosynthesis occurs. In natural ecosystem, many abiotic and biotic factors that reduce leaf area will influence productivity, such as drought, lack of soil moisture, high temperatures, or pests and diseases.

- **Root System:** The root system has many functions, like anchoring the plant in the soil, absorbing water and nutrients, storing food, and vegetative propagation. There are various types of roots for these functions. Roots, especially fine roots, will also experience seasonal and yearly variations in growth due to water and nutrient availability. This plasticity is crucial in enhancing nutrient and water use efficiency to improve productivity.

(B) Physiological Processes: The physiological processes like photosynthesis, transpiration, stomatal conductance, and respiration are crucial in determining biomass accumulation in plants.

- **Photosynthesis:** Since 90% of plant biomass is composed of carbon, hydrogen, and oxygen, photosynthesis is the primary process that produces biomass. Therefore, it is important to include photosynthetic rate while estimating production.

- **Transpiration and stomatal conductance:** Transpiration and stomatal conductivity these two gaseous exchanges in leaves, are intricately connected to carbon uptake, carbon metabolism, and nutrient absorption. Since CO_2 from the air used in photosynthesis diffuses into the leaves through stomata, transpiration and stomatal conductance influence the rate of photosynthesis and determine plant productivity. The plants also take in oxygen through their stomata, which is required for carbon metabolism during respiration. Additionally, transpiration creates the pressure necessary for roots to absorb water and dissolved nutrients from the soil. These nutrients are required for the synthesis of bio molecules, which are essential to a number of fundamental physiological processes in plants. These nutrients are both components of the compounds in the dry matter of plants and aid in the production of biomass.

- **Carbohydrate metabolism:** Plants utilized the carbon dioxide to synthesize the food. In order to full fill the various physiological processes like development, maintain and reproduction, plants consume photosynthates (glucose and starch). Larger bio compounds including proteins, pigments, nutraceuticals and other substances are created when a portion of the photosynthates mixes with other minerals and substances. These could be used to produced new tissue, including new branches, leaves, flowers, etc. To boost the plant growth, these photoassimilates are also necessary. The remaining photosynthates are transferred to storage tissues in the stems that serve as sinks, fruits, seeds, root tubers, and bulbs.

(C) Genetics: The genotype of plants is crucial. It will determine the characteristics of shoot and root systems, leaf area, type of photosynthesis (C3 or C4 or CAM) and gas exchange rates.

2. Environmental factors: The environment has the direct impacts on the biomass accumulation. It includes the following factors:

- **Temperature:** The most crucial physiological process for plants, photosynthesis, is directly influenced by air temperature. For the majority of vegetative species, the ideal temperature for optimum photosynthetic activity is typically about 25°C. The temperature over 35°C inhibits photosynthesis, which could limit biomass output. Low temperatures have a deleterious impact on photosynthesis, which is redistributed and accumulates in roots and other organs sheltered from frost. Less than -12°C temperatures harm a tree's leaf canopy, shoot, and branches.

- **Light:** The two primary determinants of photosynthetic rate are light and concentration of CO_2. The greatest biomass production can be attained by raising light intensity up to an optimal limit, which will maximize photosynthetic rate.

- **Humidity:** Low atmospheric humidity accelerates leaf surface transpiration. The reduced water content in vegetative tissues results in increased transpiration, which slows plant growth and biomass accumulation.

Photoperiod: One of the most significant elements affecting vegetative growth is the amount of light present during each 24-hour period. Plant species with extended days have a major impact on their vegetative growth.

3. Soil Conditions: The availability of nutrients in the soil is one of the most crucial elements affecting biomass. Total biomass and fruit production are significantly impacted by both nutritional deficit and toxicity. So, it is possible to maximize the production of biomass by managing the optimal amounts of nutrient availability in soil. Toxicology of heavy metals (Cu, Zn, Ni, Pb, Mn, Cr, Cd) in soils is a major issue for plant growth and biomass production.

Soil moisture is a very crucial factor in root growth and development. Many plant species are more sensitive in soil humidity shortage during a particular (crucial) period of their growth. The effect of soil temperature on root development, nutrient and water intake, and biomass output is also significant. Because the majority of nutrients require energy to be absorbed (energetic uptake), low and extremely high soil temperatures have a detrimental effect on root development and nutrient uptake. Low soil temperatures also cause a water shortage.

4. Management Practices: To ensure the higher production of grains, fruits, vegetables, and forest plantations have the best possible circumstances to generate and accumulate biomass, people work hard to provide the appropriate amounts of nutrients and water. The major goal of management strategies in natural ecosystems is to maintain forests and other habitats by limiting or eliminating logging, grazing, or clearing so that the plants can stay standing and build up biomass. Biomass production in the food industry would benefit from larger-scale elements like forestry, silviculture, and ecosystem protection.

6.8 NUTRIENT OUTPUTS (ECOSYSTEM LOSSES)

Ecosystems need nutrients input from a variety of sources (biogeochemical cycles, gaseous cycle, weathering of rocks and minerals, routes, including lightning, nitrogen-fixing bacteria, atmospheric deposition, fertilizers, etc.) in order to produce food products and offer functions pertaining to food. In this procedure, many of the nutrients are lost to the environment during supply chains (Fig 6.3). This loss event in a ecosystem is referred to as nutrient output or ecosystem losses. The ratio of nutrient inputs to outputs at a given spatial scale or area should be the same (or be as close to equal as possible). If not managed properly, nutrient inputs (usually from fertilizers or organic amendments) can lead to a nutrient surplus within a given area (Shober et al. 2022).

The loss of nutrients is a natural phenomenon that occurs in both natural and artificial (man-made) ecosystems. For an example, the artificial ecosystem (farm land) produces food, fiber, or other renewable resources as outputs (Bisht et al. 2021). Agriculture, which differs more from natural ecosystems, requires greater amounts of human interference to keep them sustain and productive (Manral et al. 2022; Bargali et al. 2018). In this system, high inputs result in high outputs, such as high crop or animal production levels. Runoff from fields carrying agricultural waste, fertilizers, and pesticides can contaminate streams, rivers, and groundwater. Traditional agricultural ecosystems, on the other hand, closely resemble natural ecosystems since they grow a variety of crops in the same field, requiring less nutrient input than modern agriculture.

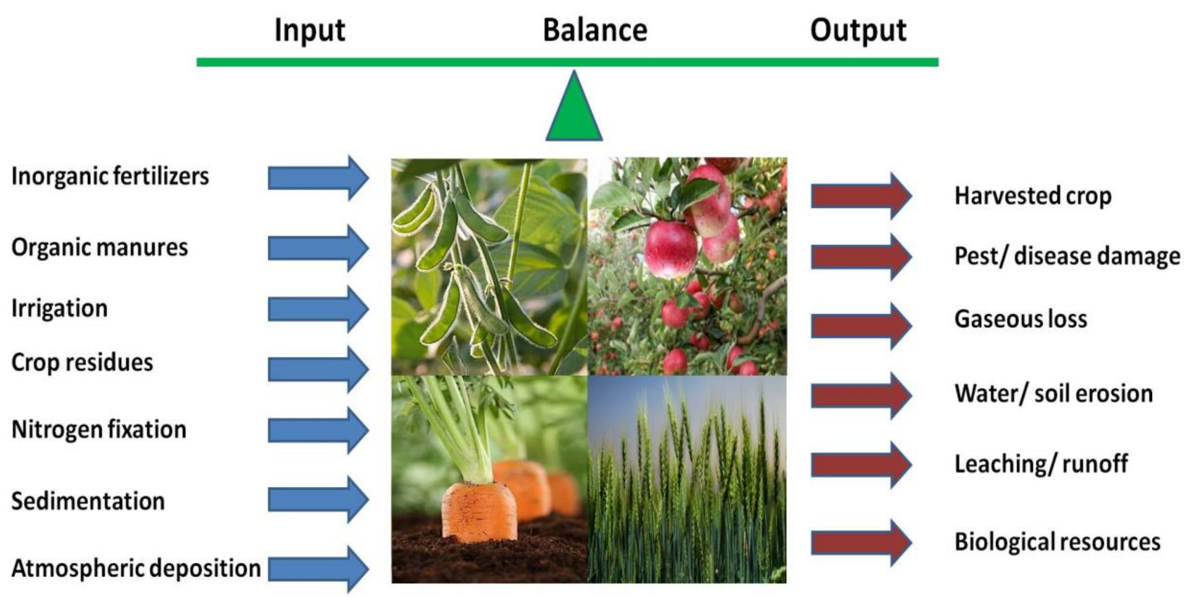

Fig. 6.3: Mean of nutrients for inputs and outputs, and the principles of integrated nutrient management systems. (Image is recreated by author, original source: Sharma et al. (2019)

Natural ecosystems are self-sufficient, self-organizing, and self-maintaining. They just need elements found in nature to survive including water and sunlight,. Most inputs and outputs of natural ecosystems are exchanges with adjacent ecosystems when materials which also contain energy and information are transported by wind, water, gravity or animals. Inputs and outputs are small because most natural ecosystems have evolved numerous mechanisms for holding onto materials. Natural ecosystems, for instance, protect soil from erosion brought on by rain or wind by covering it with grass or leaves. Ecosystems maintain mineral resources for plants inside the ecosystem when soil fertility is low by storing minerals in the bodies of plants, animals, and microbes.

Source of nutrient outputs

The output of nutrients from an ecosystem represents a loss. The output of nutrients from the ecosystems always takes place through the following processes.

1. **Surface flow and soil erosion:** Ecosystems may also release nutrients through soil erosion and water surface flow. However, nutrients lost from one environment may serve as an input for others. It is a primary method by which substantial amounts of nutrients are transferred from terrestrial to aquatic environments. Erosion is a normal process of soil rejuvenation, but in systems where farming, overgrazing, and vegetation clearing are practiced, erosion is frequently accelerated to several times over the long-term "natural" pace. C, N, P, and K are the key nutrients most impacted by erosion.

2. **Leaching:** Leaching is the process by which considerable amounts of nutrients in solution are moved from the soil system into groundwater and laterally to rivers, lakes, and oceans. Leaching occurs when water moves vertically through the soil profile. Nutrient losses from leaching are greatest in systems that have been altered or cultivated. Additionally, nitrogen is lost by soil leaching and ecosystem removal due to groundwater movement to streams. Leaching causes the export of nutrients like phosphorus, carbon, and other elements from ecosystems.

3. **Gaseous emissions:** Some gases, such as CO_2, CH_4, and CO (among other gases) are released into the atmosphere from the decomposition of organic matter, including digestion by animals, and the highly accelerated decomposition that occurs in fires. Processes related to the conversion between inorganic forms of N lead to emissions of N_2, N_2O, NO, and NH_3. Phosphorus has no significant gaseous forms in most ecosystems. Anthropogenic activities including the application of fertilizers, ploughing, fossil fuel burning, flooding, deforestation, drainage and changes to fire regimes, have tainted the amounts and proportions of emissions of nutrients to the atmosphere. This is the ultimate underlying cause of contemporary climate change and air quality deterioration. Through the process of respiration, which includes plants, animals, and microorganisms, ecosystems release carbon into the atmosphere in the form of carbon dioxide. Ammonia, nitrous oxide, and other gaseous forms of nitrogen are lost to the environment as byproducts of soil microbial activity.

4. **Emigration of species and harvesting:** Animal emigration, crop, forest, fish, or livestock harvesting are the four output sources. When biomass is directly removed from ecosystems through harvesting, particularly in farming and logging lands, significant amounts of nutrients are permanently lost from those ecosystems. Export from one ecosystem typically entails import into another, as was already mentioned. The majority of nutrients introduced into stream habitats come from terrestrial ecosystem's' output of organic matter. Herbivores can also move organic material between environments. For instance, deposition of nutrients in the form of excrement in nearby terrestrial ecosystems can occur when moose feeding on water plants transfer nutrients. Large amounts of nutrients are typically lost as a result of fire. In addition to destroying vegetation, fire also turns some biomass and organic soil matter into ash.

5. **Removal of nutrients:** The effective permanent removal of nutrients from the biosphere only occurs at a slow rate and through a small number of processes. For instance, for the atmospheric concentration of CO_2 to stabilize at levels that will not cause dangerous climate changes, anthropogenic carbon emissions must drop, within the next few centuries, to a level determined by the long-term sequestration sinks to a few teragrams (million tons) of carbon per year (Prentice et al. 2001). Fire causes loss of nutrients through volatilization and airborne particulate. Many minerals become easily accessible after a fire incident, and nutrients in the ash are amenable to quick mineralization. Nutrients may be lost from ecosystems through leaching and erosion if not absorbed by plants during vegetation recovery.

6.9 STREAM WATER LOSSES

Water loss from drainage basins is commonly caused by evaporation and transpiration. This loss can be divided into two categories: loss from canyon bottoms and loss from slopes. Since most of the water lost from the slopes is retained in the soil capillaries, therefore, it cannot be used to create stream flow. On the other hand, the water lost in the bottoms of canyons is typically lost through direct evaporation from streams, transpiration by plants with roots in streams, or in nearby groundwater. The following are some major reasons of stream water losses: (i) Transpiration (ii) Soil evaporation (iii) Evaporation from water surface. (iv) Infiltration (v) Seepage (vi) Watershed leakage (vii) Interception

1. **Transpiration**: The process of transpiration involves the movement of water through the structure of the plant and its eventual return to the atmosphere as vapour from the surfaces of leaves, tree trunks and tip of the branches. The rate of transpiration is influenced by so many factors including type of vegetation, soil moisture, wind, light, temperature, humidity etc.

2. **Soil evaporation:** Direct evaporation from the soil also contributes to the loss of soil moisture. The evaporation that occurs from water surfaces differs from this phenomenon. This is because moisture is present from the earth's surface to the ground water table in a decreasing proportion in the soil pores. Additionally, the soil pores retain water due to the force of attraction. With increasing dryness and temperature variations, soil evaporation increases. The flora that grows on the soil has an impact on it as well.

3. **Evaporation from open water surface:** Due to the sun's heat energy, water evaporates from the open surfaces of lakes, ponds, canals, rivers, reservoirs, etc. In semiarid and arid areas, water loss by evaporation is a highly important issue. The loss through evaporation is typically considered to be a direct consequence of the exposed area. The speed of

evaporation depends upon sun light, atmospheric temperature, relative humidity wind velocity and altitude of the place.

4. **Infiltration**: It is a process by which rainwater enters the top layer of the soil and travels to downward to join the groundwater reservoir. The water first fulfills the soil moisture deficiency before the remaining drains away portion goes down. If it encounters a relatively impervious base, only a part of absorbed water continues to flow downstream, with the remainder moving horizontally or laterally into the soil itself towards the stream channel. The infiltration affects run-off so its knowledge is necessary for a water resources engineer.

5. **Seepage**: The seepage of water from bodies of water like canals, reservoirs, and weir ponds is a major concern for water resources management. This is not only because water is wasted, but also because as it seeps through canal embankments, the main body of a dam or weir, as well as the bottoms of hydraulic structures, it strives to undermine the medium through which it travels. Additionally, seeping water puts pressure on the upward, jeopardizing the hydraulic structure's stability.

6. **Watershed Leakage**: A portion of the rainwater from a certain catchment region may find its way to an outlet through cracks, fissures, and discharges of water-holding layers depending on the geological structure of the subsurface underneath the location. This outflow could be in a different basin or the ocean. When this kind of loss happens in the storage reservoir, it is known as a "watershed leakage" and takes a serious significance. The following factors affect the actual quantity of loss in every drainage basin:

   - Type and development of vegetal cover.
   - Nature of precipitation
   - The climatic factors such as temperature of the area, humidity and wind velocity
   - The area covered by buildings, pavements and other permanent structures.

7. **Interception:** Due to the sun's heat, the surfaces of leaves, tree branches and trunks, and plant stems are held dry and made able to absorb more rainwater before the rain begins. When it starts to rain, a portion of the water is captured and stored by the vegetation.

6.10 LOSSES TO THE ATMOSPHERE

When planetary atmospheric gases escape into space, this phenomenon is referred to as atmospheric escape or losses to the atmosphere (Table 6.5). Escape takes place when kinetic energy of the molecular overcomes gravitational energy or when a molecule moving faster than the escape velocity of its planet. The relative importance of each loss process depends on the planet's escape velocity, its atmosphere composition, and its distance from its star. Categorizing the rate of atmospheric escape in exoplanets is necessary to determining whether an atmosphere persists, and so the exoplanet's habitability and likelihood of life. A number of different mechanisms can be accountable for atmospheric escape; these processes can be divided into (i). thermal escape, (ii) non-thermal (or suprathermal) escape, and (iii) impact erosion.

1. **Thermal escape mechanisms:** This phenomenon is take place if the molecular velocity due to thermal energy is adequately high. Thermal escape happens at all scales, from the molecular level (Jeans escape) to bulk atmospheric outflow (hydrodynamic escape).

    - **Jeans escape:** The classical thermal escape mechanism is the Jeans escape (Katling & Zhanle 2009), named after the British astronomer Sir James Jeans, who first described this process of atmospheric loss. The average velocity of any one molecule in a volume of gas is determined by the gas's temperature, but individual molecules' velocities fluctuate as they hit with one another, gaining and losing kinetic energy. The variation in kinetic energy among the molecules is described by the Maxwell distribution. The number of particles able to escape depends on the molecular concentration at the exobase, which is limited by diffusion through the thermosphere.

      The heavier molecules are less likely to escape because they move slower than lighter molecules at the same temperature. This is why hydrogen escapes from an atmosphere more easily than CO_2. Second, a planet with a larger mass tends to have more gravity, so the escape velocity tends to be greater, and fewer particles will gain the energy required to escape. This is why the gas giant planets still retain significant amounts of hydrogen, which escape more readily from Earth's atmosphere. Finally, the distance a planet orbits from a star also plays a part; a close planet has a hotter atmosphere, with higher velocities and hence, a greater likelihood of escape. A distant body has a cooler atmosphere, with lower velocities, and less chance of escape.

    - **Hydrodynamic escape:** Under the conditions of high temperature and pressure, an atmosphere can undergo in the state of escape and this phenomenon is described as hydrodynamic escape. In this occurrence, a large amount of thermal energy is absorbed by the atmosphere usually through extreme UV radiation. As molecules are heated, they expand upwards and are further accelerated until they reach escape velocity. In this process, lighter molecules can drag heavier molecules with them through collisions as a larger quantity of gas escapes.

2. **Non-thermal (suprathermal) escape:** Non-thermal interactions can also lead to escape. The majority of these activities are triggered by interactions between charged particles (ions) or photochemistry.

- **Photochemical escape:** In the upper atmosphere, high energy ultraviolet photons can react more readily with molecules. Photodissociation can break a molecule into smaller components and provide enough energy for those components to escape. Photoionization produces ions, which can get trapped in the planet's magnetosphere or undergo dissociative recombination. In the first case, these ions may undergo escape mechanisms described below. In the second case, the ion recombines with an electron, releases energy, and can escape (Shematovich and Marov 2018).

- **Sputtering escape:** Similar to sputtering from a solid surface, excess kinetic energy from the solar wind can provide enough energy to eject atmospheric particles. As the electrically charged solar wind is deflected by magnetic fields, reducing the loss of atmosphere, this form of interaction is more prominent in the absence of a planetary magnetosphere.

- **Charge exchange escape:** Ions in the solar wind or magnetosphere can charge exchange with molecules in the upper atmosphere. A fast-moving ion can capture the electron from a slow atmospheric neutral, creating a fast neutral and a slow ion. The slow ion is trapped on the magnetic field lines, but the fast neutral can escape (Shematovich and Marov 2018).

- **Polar wind escape:** Atmospheric molecules can also escape from the polar regions on a planet with a magnetosphere, due to the polar wind. Near the poles of a magnetosphere, the magnetic field lines are open, allowing a pathway for ions in the atmosphere to exhaust into space.

3. **Impact erosion:** The impact of a large meteoroid can lead to the loss of atmosphere. If a collision is sufficiently energetic, it is possible for ejecta, including atmospheric molecules, to reach escape velocity (Ahrens 1993). In order to have a significant effect on atmospheric escape, the radius of the impacting body must be larger than the scale height. The projectile can impart momentum, and thereby facilitate escape of the atmosphere, in three main ways: (a) the meteoroid heats and accelerates the gas it encounters as it travels through the atmosphere, (b) solid ejecta from the impact crater heat atmospheric particles through drag as they are ejected, and (c) the impact creates vapor which expands away from the surface. In the first case, the heated gas can escape in a manner similar to hydrodynamic escape, albeit on a more localized scale. Most of the escape from impact erosion occurs due to the third case (Ahrens 1993). The maximum atmosphere that can be ejected is above a plane tangent to the impact site.

Table 6.5: *Planets and the principal mechanisms by which they currently lose atmospheric gases. Also shown are the dominant loss mechanisms for early planetary atmospheres, which we take as before about 4 billion years ago (Source: Catling & Zahnle 2009)*

Planet	Key gases lost	Dominant mechanisms
Earth	Hydrogen	Charge exchange, Jeans, polar wind
	Helium	Polar wind, charge exchange
Early Earth	Hydrogen and moderately light gases, including neon	Hydrodynamic escape and drag
Venus	Hydrogen, helium	Charge exchange, sputtering
Early Venus	Hydrogen and moderately light gases, including oxygen	Hydrodynamic escape and drag
Mars	Hydrogen	Jeans
	Carbon, oxygen, nitrogen, argon	Sputtering, photochemical
Early Mars	All gases	Impact erosion
	Hydrogen and many heavier gases, including carbon dioxide	Hydrodynamic escape and drag
Early Callisto, Ganymede, and Europa	All gases	Impact erosion, hydrodynamic escape and drag
Titan	Hydrogen	Jeans, photochemical
	Methane, Nitrogen	Photochemical, sputtering
Early Titan	Hydrogen, methane, nitrogen	Hydrodynamic escape and drag
Pluto	Hydrogen, methane, nitrogen	Hydrodynamic escape
HD 209458b and similar ‘Hot Jupiters	Hydrogen and light gases, including carbon and oxygen atoms	Hydrodynamic escape and drag

In 1 billion years, the Sun will be 10% brighter than it is now, making it hot enough for Earth to lose enough hydrogen to space to cause it to lose all of its water. Atmospheric escape of hydrogen on Earth is due to Jeans escape (~10–40%), charge exchange escape (~ 60–90%), and polar wind escape (~ 10–15%), currently losing about 3 kg/s of hydrogen (David et al., 2009). The Earth additionally loses approximately 50 g/s of helium primarily through polar wind escape. Escape of other atmospheric constituents is much smaller (David et al., 2009). A Japanese research team in 2017 found evidence of a small number of oxygen ions on the moon that came from the Earth.

Consequences of atmospheric escape: Atmospheric escape has some significant consequences. Hydrogen escape is the ultimate reason of atmospheric escape that is why Mars and Venus are red, and probably also why much of Earth's continental crust is red. Initially, Mars was a gray-black color of volcanic rock. It turns red due to the oxidation of volcanic rocks to iron oxide, which requires that an amount of hydrogen from water has been lost to space to balance the oxygen left behind. In 2001, scientist suggested that Earth's accumulation of photosynthetic oxygen 2.4 billion years ago (when Earth's continental surface first turned red) was accelerated by the escape of hydrogen from an atmosphere rich in biogenic methane that preceded oxygenation. In Earth's case, we proposed that water molecules were broken microbially and the hydrogen passed like a baton from organic matter to methane, before reaching space. Cumulative hydrogen loss is consistent with a net excess of oxidized material now present in the overall inventory of Earth's crust, ocean and atmosphere (Catling & Zahnle 2009).

6.11 NUTRIENT LOSSES DUE TO FIRE

Fire has great influences on nutrients and their cycling in ecosystems by changing the form, distribution, amount, as well as by changing plant species composition. Although the relationship between fire and soil nutrients (Table 6.6) is complex because of the interactions among many factors, fire intensity is usually the most critical factor affecting post-fire nutrient dynamics, with greater nutrient losses occurring with higher fire intensity. Fire intensity both directly and indirectly impacts many of the mechanisms that affect nutrient pools and cycling.

Table 6.6: *Importance of various nutrients in plants metabolic activities*

Nutrients category	Elements	Function in plants
Primary macronutrients	Nitrogen (N)	Formation of proteins, amino acids
	Phosphorus (P)	Formation of nucleic acids, ATP
	Potassium (K)	Catalyst, iron transport
Secondary macronutrients	Calcium (Ca)	Cell wall component
	Magnesium (Mg)	Part of chlorophyll
	Sulfur (S)	Amino acids

The long-term effects of fire on soil physical properties range from a single season to many decades, depending on the fire severity, rate of recovery as influenced by natural conditions, post-fire use, and restoration and rehabilitation actions. Some of the most significant impacts of the fire are highlighted below (Fig. 6.4):

1. **Physical properties of soil:** Low intensity fires do not cause enough soil heating to produce significant changes to soil physical properties but repeatedly intense fire may alter several physical soil properties. Since soil organic matter holds sand, silt, and clay particles into aggregates, a loss of soil organic matter results in a loss of soil structure. By altering soil structure, severe fires can increase soil bulk density, and reduce soil porosity, mostly through the loss of macropores (>0.6 mm diameter). Soil porosity can also be reduced by the loss of soil invertebrates that channel in the soil. When fire exposes

mineral soils, the impact of raindrops on bare soil can disperse soil aggregates and clog pores, further reducing soil porosity and water holding capacity.

2. **Chemical properties of soil and nutrients:** The soil macronutrients are the elements considered essential for plant growth and nutrition needed in relatively large quantities (Padalia et al. 2021). The main functions of primary and secondary macronutrients are discussed below in brief. These nutrients play the important role of the metabolic activities of the plants.

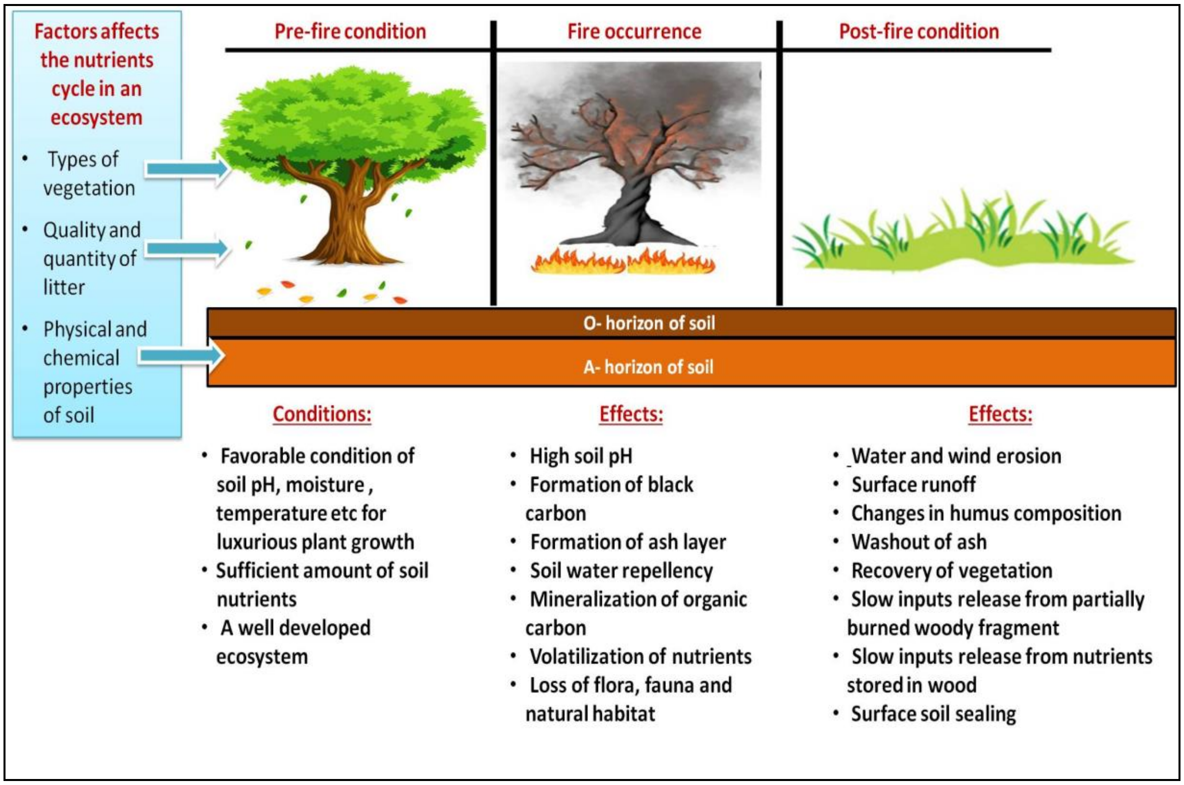

Fig. 6.4: The long-term effects of fire on soil properties range from a single season to many decades, depending on the fire severity, rate of recovery as influenced by natural conditions, post-fire effects, and restoration and rehabilitation actions.(Image is recreated by author; original source Caon et al. 2014)

Intense and frequently occur fire negatively destroy the soil organic matter or humus as it contains approximately 50% carbon (C) by mass and remaining percentage shared by the other nutrients (N, P and S), therefore, considered as the storehouse of plant nutrients (Stevenson 1994). Heating soil organic matter produces rapid losses of carbohydrates and proteins. N is the major limiting nutrient in most forests. Hydrophobic polymers are also formed upon heating, and these are probably responsible for the soil hydrophobicity that is observed after fire. The impact of fire on site productivity is also related to intensity which decreases site productivity.

3. **Nutrients uptake:** Plant uptake of nutrients and water is slowed in structurally degraded soils through the combined effects of lower soil moisture and lower soil porosity. Root growth can also be impeded by increased bulk density and soil strength.

4. **Plant roots:** The range of effects depends largely on the community of plants present in a forested, and on the intensity of the fire. Fire almost always results in the death of some plants in a given system, and the extent to which plants are killed has a strong relationship to the effects of fire on roots and also influence the process of decomposition as well as the entire soil food-web.

5. **Soil microbes and fire:** The effect of fire on soil microbes is dependent to a large extent upon fire intensity. The responses of soil microbes to fires range from no detectable effect in low intensity fires to total sterilization of the surface layers of soil in very hot wildfires (Renbuss et al. 1973). This is interesting because workers have observed that although there is a decrease in abundance of microbes following fire, the remaining microbes can have levels of activity that are greater than that of the microbial community prior to the fire (Poth et al. 1995). These authors found that the increased rates of microbial processes, such as denitrification and production of methane and carbon dioxide, persisted for one year following fire.

6. **Microinvertebrates and fire:** The negative effect of fire is mostly attributed to decreased habitat for mites and springtails, because many of these organisms live in decomposing leaf litter, and much of this litter is lost in fires. There is a general reduction of microarthropods with increasing fire frequency. One study showed that mites and springtails were reduced by a small amount (~25%) by periodic fires, but that the reduction was dramatic (75-80% fewer) when fires occurred annually.

7. **Macroinvertebrates and fire:** The general pattern of macroinvertebrate responses to fire is often driven by changes in habitat structure, or by changes in the amount or the quality of food resources. Whenever fire affects vegetation, temperature or moisture, or the nutrient status of a soil, there is potential for impact on the soil invertebrate community. Some arthropod groups increased in abundance but most decreased soon after fire. The reduction in the population of beetle larvae and earthworms is the example of impact forest fire.

6.12 NUTRIENT LOSSES IN FOREST HARVEST

Soil disturbance and nutrient removals are unavoidable consequences of forest harvesting. Displacement of surface organic layer and nutrient rich topsoil, soil compaction, exposure of unfavorable substrates and removal of nutrients in harvested material all occur to varying degrees in interior harvesting operation. Forest harvesting may also increase the risk of soil erosion and mass wasting. Some of the effects of deforestation or forest harvesting on nutrients are discussed below:

1. **Organic matter mineralization:** A major portion of the nutrients needed for tree growth are supplied through the mineralization or release of nutrients from organic sources by soil microbes. This is especially true of nitrogen, phosphorus, and sulphur. Changes in populations of soil microorganisms may have significant impacts on nutrient availability and consequent site productivity since the availability of most other soil nutrients depends at least partially on the activity of soil microflora.

   According to a number of researches on the release of nutrients from litter, the breakdown of the forest floor was accelerated when forest vegetation was removed. This enhanced nutrient availability is reportedly linked to increased soil microbial activity. After clear-cutting, both the amount of carbon dioxide in the soil and heterotrophic soil organisms rise. Increased nutrient flow through the profile and leaching would result from this increase in carbon dioxide generation by soil microorganisms. After logging, the soil temperature and moisture levels in the cleared area are higher, which is related with increased microorganism activity. In some cases, where timber cutting has increased ground water levels to the soil surface or near it, the decrease in soil oxygen levels might be so severe as to impede the decomposition of organic waste (Bell 1978).

2. **Nitrogen availability:** Almost all nitrogen in soil is found in organic forms, and it is typically the nutrient that restricts plant growth the most. Therefore, the effects of logging on the soil microbiota would probably have the most influence on nitrogen cycling. These impacts on soil nitrogen can be grouped generally into the following categories: biological "fixation" of atmospheric nitrogen into organic compounds through processes including nitrification (turning ammonium into nitrate) and denitrification (removing nitrate from soil).

3. **Nitrification:** The population of nitrifying bacteria will dramatically rise in some soils as a result of timber harvesting, especially clear cutting. Nitrate levels rose significantly as a result of clear-cutting, which encouraged bacterial populations (Likens et al. 1970). These harvesting-related impacts appear to be connected to stand-specific variations in organic matter buildup, soil temperature and moisture patterns, and soil texture (Stone 1973).

4. **Denitrification:** The denitrification rate may rise as a result of logging activities. Anaerobic bacteria are responsible for denitrification, hence the increases in soil water content during harvesting and the resulting decrease in oxygen levels would favour these species. The denitrifying microflora could potentially be stimulated by an increase in soil temperature or pH. (Broadbent and Clark 1965). The denitrifying bacteria are especially dependent on an appropriate supply of nitrate. As was mentioned before, removing the

overstory may increase nitrification rates in particular soils. These higher soil nitrate concentrations could promote more denitrification and consequent nitrogen loss.

5. **Dinitrogen fixation:** In natural ecosystems, the atmosphere provides nitrogen to the soil by fixing inert nitrogen gas into forms beneficial to plants. Growing the quantity of nitrogen delivered to the soil through biological fixation has garnered more attention as a result of recent rises in fertilizer costs. In some forest ecosystems, nitrogen fixation plays a significant role, especially in replenishing nitrogen losses brought on by harvesting and fire.

6. **Symbiotic organisms:** A higher plant and a microbe with the ability to fix atmospheric nitrogen form a symbiotic relationship, which results in nitrogen fixation. The leguminous plants and the bacterium genus *Rhizobium* have the most well-known connection of this kind. There are many different nonleguminous plants that exhibit additional symbiotic nitrogen-fixing connections. The nitrogen-fixing root nodules of over 100 plant species, such as Alnus and Ceanothus (Youngberg and Wollum 1970) may affect by the forest harvesting.

7. **Nonsymbiotic organisms:** The importance of free-living, nitrogen-fixing microorganisms in soil, in contrast to the symbiotic nitrogen-fixing plants, is not well understood. This group of organisms relies on organic materials in the soil as a source of energy and carbon, with the exception of autotrophic blue-green algae. The majority of the soil and stand modifications brought on by timber removal would favour non-symbiotic nitrogen-fixing plants. After logging, the soil's temperature, pH, and moisture level would all likely increase, which would tend to increase nitrogen-fixation rates. The blue-green algae that fix nitrogen would be more active if there was more light reaching the soil's surface. The nonsymbiotic nitrogen-fixing microorganisms, on the other hand, might be inhibited by observed increases in soil ammonium and nitrate concentrations after harvesting.

6.13 SUMMARY

The natural ecosystem is a self-governing and self-sustaining system. It has the ability to restore the damage and manage it properly without any human interference. The majority of the sulphur, chlorine and nearly all the nitrogen in terrestrial ecosystems derived from the atmosphere, while the main source of minerals input in an ecosystem is the weathering of rocks through diverse physical, chemical and biological processes. The constant exchange of water between the oceans and the atmosphere constitute the global hydrological cycle. Several types of biological inputs are also taken into consideration like biofertilizers, biological control, crop protection, bioremediation etc. Biomass accumulation is an example of storage of nutrients in plants.

Ecosystems need nutrient input from a variety of sources like biogeochemical cycles, gaseous cycle, weathering of rocks and minerals, many route including lightning, nitrogen-fixing bacteria, atmospheric deposition, fertilizers etc in order to produce food products and offer functions pertaining to food. In this procedure, many of the nutrients are lost to the environment during supply chains. This loss event in an ecosystem is referred to as nutrient output or ecosystem losses. The output of nutrients from the ecosystems always takes place through the several processes including leaching, removal of nutrients, gaseous emissions, atmospheric escape, emigration of species, surface flow, soil erosion etc.

The forest fire has also a great influence on nutrients and their cycling in ecosystems by changing the form, distribution, amount, as well as by changing plant species composition. Although the relationship between fire and soil nutrients is complex because of the interactions among many factors, fire intensity is usually the most critical factor affecting post-fire nutrient dynamics, with greater nutrient losses occurring with higher fire intensity. The long-term effects of fire on soil properties range from a single season to many decades, depending on the fire severity, rate of recovery as influenced by natural conditions, post-fire use, and restoration and rehabilitation actions.

The soil disturbance and nutrient removals are unavoidable consequences of forest harvesting. Forest harvesting may increase the risk of soil erosion and mass wasting. Some of the effects of deforestation or forest harvesting have significant impact on organic matter mineralization, nitrogen availability, nitrification, denitrification, activities of soil microorganisms etc.

6.14 GLOSSARY

Abiotic: Non-living. Abiotic resources comprise non-living things, for instance land, water, air and minerals.

Aerobic: Requiring oxygen.
Anaerobic: The absence of oxygen.
Anthropogenic: Effects which relate specifically to human activities.
Biological nitrogen fixation: A process where symbiotic (mutually beneficial) and nonsymbiotic organisms can incorporate atmospheric dinitrogen (N_2) gas into organic N forms
Biomass: The total weight of all the biological material or the combined mass of all the animals and plants inhabiting a defined area; usually expressed as dry weight per area.
Carbon cycle: The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide) through the atmosphere, ocean, terrestrial and marine biosphere, and lithosphere.
Denitrification: An anaerobic process where nitrate (NO_3^-) is converted by into nitrogen gas (N_2) specialized bacteria. The conversion of nitrate to dinitrogen is often incomplete and results in the production of nitrous oxide, a potent greenhouse gas. Denitrificiation occurs in the soil only in low oxygen environments, often associated with flooding or soils nearly saturated with water.

Ecosystem: A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.

Ecosystem service: Ecological processes or functions having monetary or non-monetary value to individuals or society at large.

Immobilize: The incorporation of compounds (such as reactive nitrogen) into soil microbial biomass, rendering it unavailable for plant uptake.

Leaching: The washing out of soluble ions and compounds by water draining through soil

Mineralization: During decomposition of plant or animal material, specialized bacteria transform nitrogen to ammonia (NH_3) or ammonium ($NH4^+$); the latter can be taken up by plants

Nitrate: A naturally occurring, negatively charged ion that is the primary form of nitrogen used by plants.

Nitrite: A naturally occurring negatively charged ion. Nitrite can be produced by the oxidation of Ammonium (NH4+), which is the first step in the nitrification process. Accumulation of nitrite is usually rare in agricultural soils.

Nitrification: An aerobic process where ammonium (NH_4^+) is converted to nitrite (NO_2^-) and nitrite to nitrate (NO_3^-) by specific types of bacteria. Nitrous oxide, a potent greenhouse gas, can be produces as an intermediary biproduct during this process.

Nitrogen cycle: The circulation of nitrogen among the atmosphere, plants, animals, and microorganisms that live in soil and water.

Transpiration: The process by which water is drawn through plants and returned to the air as water vapor. Evapotranspiration is combined loss of water to the atmosphere via the processes of evaporation and transpiration.

6.15 SELF ASSESSMENT QUESTIONS

6.15.1 Multiple choice questions

1. Plants take nutrients elements from the
    a. Atmosphere b. Water
    c. Soil and sediments d. All of these
2. The inputs into an ecosystem are derived from
    a. Meteorologic b. Geologic
    c. Biological d. All of these
3. Physical processes of weathering of rocks include
    a. Action of water b. Temperature
    c. Glaciers d. All of these
4. The chemical processes of weathering include
    a. Hydrolysis b. Oxidation-reduction
    c. Carbonation and chelation d. All of these
5. The primary sources of water include
    a. Oceans b. Glaciers
    c. Surface waters and the atmosphere d. All of these
6. Researchers measure biomass accumulation through
    a. The whole plant b. Field or local scale
    c. Large ecosystem scale d. All of these

7. Biomass accumulation can be influenced by
    a. Plant attributes
    b. Environmental factors
    c. Soil conditions and management practices
    d. All of these
8. The functions of root system are
    a. Anchoring
    b. Storage
    c. Vegetative propagation.
    d. All of these
9. The genotype of plants determine
    a. Characteristics of shoot and root systems
    b. Leaf area and gas exchange rates
    c. Type of photosynthesis (C3 or C4 or CAM)
    d. All of these
10. In an artificial ecosystem, which of the following is not considered as outputs?
    a. Produces food
    b. Fiber
    c. Other renewable resources
    d. Chemical fertilizers

6.15.2 True and false

1. The availability of nutrients in the soil is one of the most crucial elements affecting biomass.
2. Since 90% of plant biomass is composed of carbon, hydrogen, and oxygen, photosynthesis is the primary process that produces biomass.
3. Total biomass and fruit production are significantly impacted by both nutritional deficit and toxicity.
4. The loss of nutrients is occurring only in natural ecosystem but not in artificial ecosystems.
5. Agriculture does not requires greater amounts of human interference as to keep them sustain and productive.
6. Leaching is the process by which considerable amounts of nutrients in solution are moved from the soil system.
7. Phosphorus has no significant gaseous forms in most ecosystems.
8. Fire causes loss of nutrients through volatilization and airborne particulate.
9. When planetary atmospheric gases escape into space, this phenomenon is referred to as atmospheric escape or losses to the atmosphere.
10. The classical thermal escape mechanism is the Jeans escape, named after the British astronomer Sir James Jeans.

6.15.3 Fill in the blanks

1. Nearly all of nitrogen and majority of sulphur and chlorine in terrestrial ecosystems are primarily derived from the ______
2. In biological processes ______ are able to extract nutrients from bare rocks.
3. The ______ partner of lichen through photosynthesis, increases the amount of available organic matter at rock surface.
4. The ______ occurs at its greatest rate during summer.

5. The ______ are the living microbes that improve fertility of soil either by increasing nutrient availability or mobilizing of nutrients.
6. Productivity is the result of ______
7. The ______ accumulation is the change in biomass over time per unit area.
8. ______ and ______ these two gaseous exchanges in leaves, are intricately connected to carbon uptake, carbon metabolism, and nutrient absorption.
9. Plants utilized the ______ to synthesize the food.
10. ______ are self-sufficient, self-organizing, and self-maintaining.

Answer Key:

6.15.1: 1. (d); 2. (d); 3. (d); 4. (d); 5. (d); 6. (d); 7. (d); 8. (d); 9. (d); 10. (d)

6.15.2: 1. True; 2. True; 3. True; 4. False; 5. False; 6. True; 7. True; 8. True; 9. True; 10. True

6.15.3: 1. Atmosphere; 2. Lichens; 3. Algal; 4. Evapotranspiration; 5. Biofertilizers; 6. Photosynthesis; 7. Biomass; 8. Transpiration and stomatal conductivity; 9. carbon dioxide; 10. Natural ecosystems

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6.18 TERMINAL QUESTIONS

6.18.1 Short answer type questions

1. Discuss the role of atmosphere in nutrients input.
2. What do you understand by weathering of rocks?
3. Briefly describe the biofertilizers.
4. What are the roles of microorganisms in bioremediation?
5. What do you understand by biomass accumulation in plants?
6. What are ecosystem losses? Discuss in brief.
7. Write a short note on stream water losses.
8. Discuss the Jeans escape theory.
9. Write the consequences of atmospheric escape.
10. Discuss the role of fire on Physical and chemical properties of the soil.

6.18.2 Long answer type questions

1. Discuss the weathering of rock minerals in detail. What are the types of weathering?

2. Describe the biological inputs in detail.
3. What do you understand by biomass accumulation in plants? Discuss the various factors which affect the biomass accumulation.
4. What do you understand by nutrient outputs? What are the source of nutrient outputs?
5. Discuss a detailed note on nutrient losses due to fire.
6. What do you understand by atmospheric losses? What are the consequences of it?
7. Write a detail note on nutrient losses in forest harvest.

UNIT -7-INTRA SYSTEM CYCLE

Contents:

7.1 OBJECTIVES

After reading this unit the learners will be able to understand

- Nutrient uptake by plants and its allocation to different plant parts.
- Role of mycorrhizae in nutrient cycling
- Nutrient use efficiency of plants
- Effects if Nitrogen and Phophorus enrichment in biodiversity.

7.2 INTRODUCTION

Nutrient uptake from the soil solution by plants, nutrient allocation to different plant components (e.g., foliage, stem, branch and root) and nutrient return to soil are the major processes of intra system nutrient cycles. These processes involve rather large movements of nutrients compared to the amount of inputs and outputs from intersystem transfers. Sollins et al. (1980) demonstrated that the circulation of N and P within the forest stand in an old-growth Douglas fir forest was 6.5 and 18.2 times greater than the nutrients acquired from the atmosphere and rock weathering. Similar to this, in forest ecosystems, nutrient transfers through the biotic component outweigh nutrient losses to stream water.

7.3 AVAILABILITY OF NUTRIENTS IN SOIL SOLUTION

The soil is a very dynamic system that may support complicated chemical processes. The soil solution serves as the medium for complex chemical reactions in this heterogeneous system. Clay and humus, two soil colloidal components, bind the exchange cations on the surfaces. One of the most significant soil reactions is cation exchange. Humus and clay, two types of colloidal soil particles, typically have an electronegative charge. The charge may be caused by the adsorption of too many anions or by an imbalance in the atomic charges within the clay micelle's crystal lattice. The particles have a tendency to absorb cations on their surface to counteract the negative charges. Exchangeable cations, the balancing ions, are in kinetic equilibrium with the soil solution. Several variables affect the nutrients that are available to plants in the soil solution. Which are as follows:

1. The exchange reactions are the dominant chemical processes that occur in soils. These silicate clay minerals have surface negative charges that attract and hold soluble nutrient cations from the soil solution. The negative charges possessed by silicate clay minerals contribute to soil cation-exchange capacity (CEC), expressed as milliequivalents per 100g of soil. At the majority of the typical soil pH levels, iron and aluminium hydroxides, on the

other hand, have a surface positive charge. These particles hold nutrient anions, in particular PO_4^{-3} and SO_4^{-2}. Additionally to clay particles, organic stuff raises soil CEC. The CEC and base saturation, which measure the proportion of exchange sites that are really occupied by nutrient cations, rises during the early stages of soil development on freshly exposed parent materials and falls in an extensively weathered soil, such as soils of tropical forests. Nutrient losses to runoff water are minimal in soils with high CEC, such as rich soils. Low CEC is found in iron- and aluminum-oxide-dominated tropical forest soils.

2. More than 95% of the nitrogen in soil is present as organic compounds. Insoluble organic nitrogen is transformed into soluble organic nitrogen, which is mineralized to form NH_4- N and, under specific circumstances, to NO_3- N (Fig. 17.5). Both NH_4^+ and NO_3^- nitrogen are freely available for plant absorption. Due to its location on cation exchange sites, NH_4-N is slightly immobile in soil compared to NO_3-N, which is highly mobile.

   'Cation exchange' refers to the adsorption of a cation by a colloid nucleus or colloid clay micelle and the subsequent release of one or more ions retained by the micelle. Ca^{2+}, Mg^{2+}, K^+,Na^+ and NH_4^+ are the main cations. The soil also contains traces of other cations including Cu^{2+}, Mn^{2+} and Zn^{2+}.

3. Numerous nutritional components are known to be influenced by soil pH. As in low pH conditions in soils, PO_4^{-3} is tightly bound by Fe and Al, lowering its availability to plants. The chelates (such as citrate) that some plants' roots secrete into the soil solubilize phosphate by tying up the Fe in insoluble iron phosphates (Lambers et al. 1998). Clay surfaces also effectively bind PO_4 at low pH levels. When PO_4 and Ca interact at high pH, they produce insoluble phosphates.

   Thus, pH 6.5 has the highest level of P availability. Over 50% of the total phosphorus in surface soils found in forest soils is present in organic form. As a result, the competition between biological and geological sinks for the phosphate anions restricts the availability of phosphorus as defined by the mineralization of organic P (i.e., cleaving of the ester bond, C-O-P, by the phosphatases produced by plant roots and mycorrhizae) (Attiwill and Adams 1993). The pH of a soil solution also affects how soluble other ions are. For example, when the pH is in the acidic range (below 5.5), the availability of N and K decreases.

4. Since positive ions predominate over negative ions in soil nutrients, a charge imbalance would result from ion uptake by plant roots. According to Nye (1981), plants that use NH_4+ as a source of nitrogen are known to acidify the immediate area around their roots. Because plants emit HCO^{3-} and organic acids to counteract the negative charge, the intake of NO_3 has the opposite effect (Waring and Schlesinger, 1985).

7.4 NUTRIENT SUPPLY AND UPTAKE

The majority of nutrients dissolved in water are absorbed by plants like *Elodea*, *Lemna* and *Vallisneria* through their submerged leaves in aquatic settings. The leaves of terrestrial plants can also take up nutrients that are available as gas or dissolved in rainwater. However, in terrestrial ecosystems, soil is the primary source of all nutrients for plants. Plant roots absorb nutrients from the soil solution as cations of nitrogen (NH_4^+ and NO^{3-}), phosphorus (H_2PO_4- and HPO_4^{2-}), sulphur (SO_4^{-2}), and metals. The principal exchangeable cations in soils are Ca, Mg, K, and Na. Both biological and inorganic colloids have a negatively charged surface that holds an exchangeable cation adsorbed. Although cations in the exchangeable form are not soluble, protons from plant roots can be used to exchange them, bringing them into solution for plant absorption.

The rates of nutrient supply and absorption are frequently correlated. The following methods distribute nutrients to plant roots: (i) Roots extending into the soil capture exchangeable nutrients; this is crucial for Ca and NH_4 -N. (ii) The movement of soil water in response to transpiration causes ions to flow in large quantities; this is significant for Mg, SO_4^{-2} , Fe, and Ca. (iii) Ions diffuse towards the root surface; this happens when absorption lowers the concentration of nutrients at the root surface and mineralization raises the concentration of nutrients elsewhere in the soil solution. Along this gradient of concentration, nutrients like N, P, and K flow to the root surface. Phosphate ion diffusion rates in most soils are significantly lower than those for K^+ and NO_3^-

How does the plant absorb nutrients? However, the majority of nutrient uptake is primarily an energy-dependent active activity. Some nutrients reach the plant passively with the flow of water. At root cell membranes, nutrient uptake is regulated; not all elements are allowed in, and poisonous, unnecessary, and excess elements are frequently blocked from entering or given restricted access. It has been proposed that nutrient uptake involves enzyme-mediated processes and the presence of particular ion carriers in root cell membranes (Ingstead, 1982). In order to get the nutrients to the vascular tissues of the roots, the ion carriers identify nutritional ions in the soil solution. Active absorption becomes higher as ion concentrations in soil solution increase, with the maximum rate being reached when all carriers are saturated. Competition between groups of ions with the same charge for the ion carrier may have a significant impact on how well an ion is taken up. For example, a high K^+ concentration in the soil solution may inhibit the uptake of NH_4^+.

The N uptake needs special consideration because demand frequently exceeds supply. different kinds of plants have different preferences for absorbing the various types of nitrogen, including ammonium (NH_4^+), nitrate (NO_3^-), and dissolved organic nitrogen. The nitrogen cycle is quite conservative since older forests litter may contain nitrogen that has been immobilised, preventing nitrogen loss into stream water. Species from areas where microbial nitrification is hindered or slowed frequently exhibit better development with NH_4^+. The intake of NO_3^- seems to be favoured by fast nitrification. For instance, chir pine (*Pinus roxburghii*) uses both NO_3^- and NH_4+ equally, whereas banj oak (*Quercus leucotrichophora*), one of the two main species that create forests in the central Himalaya, prefers NO_3^-. Plant energy is needed more when converting NO_3- to amino groups (-NH_2) than when converting NH_4^+ to amino groups. The following are a few reasons why there is not preferential NH_4^+ uptake. (i) For more mobile NO_3^- than NH_4^+, the rate of supply to the root by diffusion or mass flow is higher. (ii) NH_4^+ and other positively charged nutrient ions do not compete with NO_3^- for uptake by plants (iii) NH_4^+ may be hazardous to plants. However, Aerts and Chapin (2000) analysed numerous research to demonstrate that (i) species that occur in habitats rich in NO_3-N preferentially absorb nitrate, (ii) those that occur in habitats rich in NH_4-N preferentially absorb ammonium, and (iii) that species that occur in habitats rich in NH_4-N preferentially absorb nitrate and (iii) in a number of terrestrial habitats, plants can take up soluble organic N from both mycorrhizal and non-mycorrhizal sources.

7.5 ROLE OF MYCORRHIZAE IN NUTRIENT CYCLING

Trees and other higher plants frequently form symbiotic relationships with mycorrhizal fungi, which is vital to the transfer of nutrients, particularly for P. Mycorrhizae also aid in the absorption of N and other nutrients with slow diffusion rates. The presence of mycorrhizae enables the root to search a larger area of the soil for nutrients since the absorption surface grows significantly as a result of the fungal hyphae. Mycorrhizal association is responsible for the effective establishment of many species on nutrient-poor environments including mine ruins and rocky surfaces with minimal soil. Mycorrhizae absorb nutrients at a lower carbon cost than roots because of their smaller diameter and higher surface-to-volume ratio (Aerts and Chapin, 2000). It's interesting to note that P uptake is increased in the presence of N-fixing bacteria, demonstrating a relationship between N, P, and C in the nutrition of higher plants.

The annual growth of mycorrhizae accounted for about 15% of the annual net primary production in a research on the Pacific silver fir (*Abies amabilis*) stands in Washington (Vogt et al., 1982). However, in the presence of mycorrhizae, the tree may reduce allocation to the roots, leading to improved overall development. Now a question arises that why is a nutrient-poor environment more likely to have mycorrhizal infection? According to one theory, plants that are experiencing inadequate nutrition typically experience slowed development but persistently high levels of photosynthesis (Chapin, 1980). According to Hobbie (1992), plants from nutrient-poor environments allocate C to the roots. In nutrient-poor areas, the resulting rise in the concentration of carbohydrates in roots may encourage mycorrhizal infection.

7.6 NUTRIENT CONCENTRATIONS AND STORAGE IN VEGETATION

Between plants and in various parts of the same plant, nutrient concentrations vary greatly. The concentrations in the aboveground components of the majority of trees are found in the following sequence: leaf > twig > branch > bole, and in the belowground components: fine root > lateral root > stump root. Deciduous species have the highest N concentrations among the various growth forms, while evergreen species leaves have lower concentrations than those of forbs and graminoids (Aerts and Chapin, 2000). For optimal plant growth, the foliar N: P mass ratio (Redfield ratio) should be 10: 1. According to Aerts and Chapin (2000), plant growth is N-limited at N: P ratios under 14:1 and P-limited at ratios over 16, with intermediate ratios co-limiting N and P. The amounts of various nutrients stored in plant biomass and litter compartments vary greatly between ecosystems (Table 7.1). The quantities typically follow the following order: N ≥ Ca>K>P. The dry matter accumulation and the nutritional concentration of the accumulated biomass account for the variance amongst ecosystems.

Table 7.1. Nutrient content (g/m²) in vegetation and litter in certain forest ecosystems

Forest	**Component**	**N**	**P**	**K**	**Ca**	**Reference**
Pines banksiana Canada	Vegetation	16.5	1.4	8.2	11.2	Foster and Morrison (1976)
	Litter	32.8	4.3	38.8	50.0	
Pinus roxburghii India	Vegetation	114.5	14.8	37.8	54.0	Chaturvedi and Singh (1987)
	Litter	13.1	1.1	2.4	8.3	
Post oak black jack Vegetation oak, USA	Vegetation	107.1	9.5	119.6	433.3	Johnson and Risser (1974)
	Litter	8.6	0.6	6.2	21.6	
Oak forest, India	Vegetation	336.6	14.0	99.7	452.6	Rawat and Singh (19886)
	Litter	9.4	0.4	1.2	10.2	
Tropical dry deciduous, India	Vegetation	53.4	3.5	24.2	26.8	Singh and Singh (1991b)
	Litter	3.3	0.2	1.3	1.1	

Source : Singh et.al., (2014)

7.7 SEASONAL CHANGES IN FOLIAGE NUTRIENTS AND NUTRIENT RESORPTION

From bud break until leaf senescence, the concentration of N, P, and K in woody plants gradually decreases. With very few exceptions, the concentrations of calcium, magnesium, and iron do not follow the aforementioned pattern; instead, they often grow constantly until leaf abscission. The increase in photosynthetic product accumulation and cell thickening as leaves grow and mature (the dilution effect) and the retranslocation of nutrients to other regions of trees during leaf senescence are the causes of the fall in N. P. and concentrations. Nutrient concentration times leaf dry mass equals the mass of N, P, and K in leaves, which rises throughout the growth phase as leaves expand and gain mass and then declines as leaves start to senesce (Fig. 7.1). Across woody species from various settings, the percentage of nutrients (N, P, and K) removed from leaves typically ranges between 20% and 80%. Different nutrients are reabsorbed at varying rates depending on the species. For instance, the chestnut oak *Quercus prinus* retranslocates 78% of its N mass and 59% of its P during leaf fall. In mid-August, there was 53% K and 8% Ca (Ostman and Weaver, 1979).

In some species, the mass of calcium increases rather than decreases during leaf senescence. An intraplant or internal nutrient recycling process is represented by the absorption of nutrients from leaves. Resorption of nutrients creates an internal nutrient reserve that is easily accessible for future development, reducing the need to absorb nutrients from the soil. According to Lal et al. (2001a), the N-mass resorbed in the previous year was enough to enable the full development of the leaf area and more than 50% of the maximum leaf weight in the subsequent growing season in numerous dry tropical species. Resorption is not just a feature of senescent tissues. Resorption is not specifically associated with tissues that are senescent. New leaf development takes place in trees with leaves that have a lifespan of several years by using nutrients resorbed from leaves that developed the year before, in some species nutrient are resorbed from leaves that are less than six months old (Nambiar and Fife, 1987).

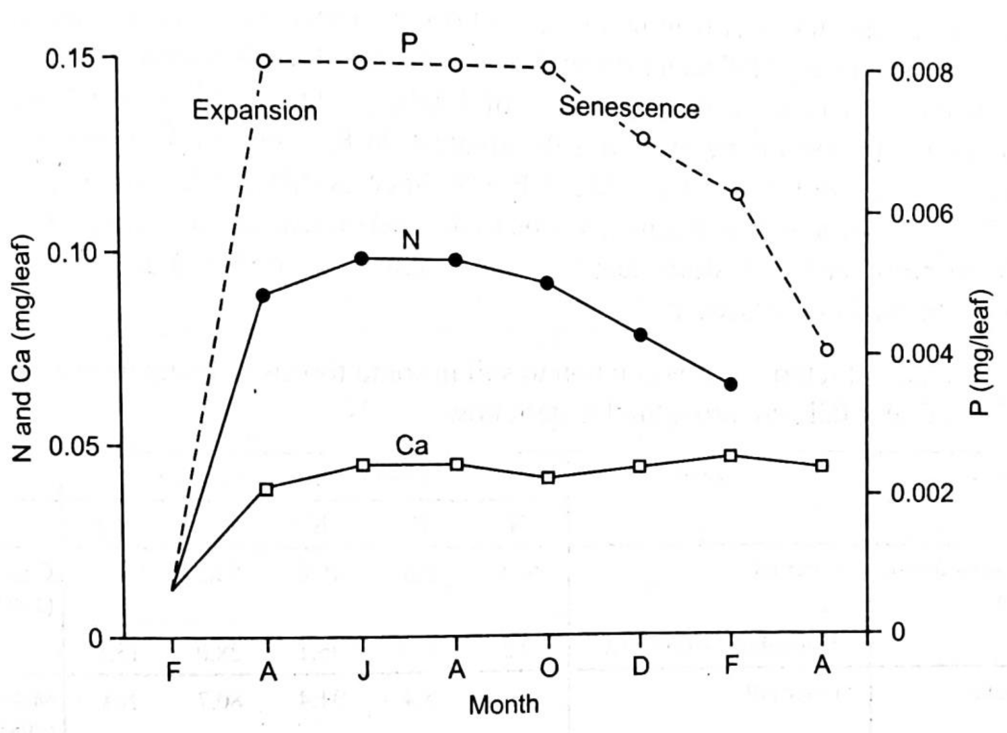

Figure 7.1 Nutrient mass (expressed as mg/leaf dry weight) changes in Pinus roxburghii (Central Himalaya) leaves within an annual cycle (data from Ralhan and Singh, 1987)

According to recent assumptions, species from nutrient-poor settings have ahigher nutrient usage efficiency than those from nutrient-rich environments, and evergreen species are less efficient than deciduous species at reabsorbing nitrogen (Eckstein et al., 1999). In a nutrient-rich site, deciduous species resorbed larger amounts of N and P than evergreen species, according to data gathered from a large number of tree species living in a dry tropical environment. However, the deciduous species at the nutrient-rich site showed significantly higher resorption efficiency for N and P than the deciduous species at the nutrient-poor site. Resorption efficiency doesn't follow a predictable pattern across gradients of nutrient availability, indicating that organisms adopt an individualistic adaptational approach with regard to nutrient cycling. However, nutrient resorption is a conservation strategy since nutrients left in litter may be lost to runoff and other processes.

7.8 NUTRIENT RETURN FROM VEGETATION TO SOIL

The aboveground vegetation returns nutrients to the soil in two ways: (i) litterfall (of leaves, twigs, reproductive structures, etc.); and (ii) leaching from canopy by rainwater through stemflow and throughfall. Throughfall contains nutrients that have been washed off of leaf surfaces and stemflow fluids, with the majority of those nutrients coming from bark surfaces. Although there are significantly more nutrients in stemflow waters than in throughfall waters, throughfall accounts for the majority of the water that reaches the forest floor. Thus, 90% of the nutrients that seep into soil from vegetation through evaporation are found in the throughfall water. For most minerals, leaching (throughfall plus stemflow) contributes significantly to nutrient return, with K having the highest levels. K > Ca > Mg > P > N is typically the sequence in which nutrients leach. Leaching appears to depend on leaf nutrient concentration, area-to-volume ratio, surface texture, leaf age, and amount of rainfall. Species differ in leaching-induced nutrient transfer from canopy to soil. Senescence is a phase when leaching is most noticeable.

Resorption of nutrients prior to leaf abscission has a significant impact on the amounts of nutrients that return from canopy to soil since leaf fall accounts for the majority of the nutrient return through litter fall. Calcium is absorbed into the cell walls of plants where it is very mobile. Litterfall thereby mediates 80% of the whole annual aboveground cycle of calcium. Since potassium is extremely mobile, around 30% of the yearly aboveground cycle of K is accounted for by leaching from canopies.

Information on the return of nutrients through root litter fall is very limited since it is challenging to assess the growth and demise of fine roots. However, the fact that in some forest ecosystems the output of fine roots can exceed that of leaves suggests the substantial importance of this nutrient return pathway. As an example, in Tennessee's yellow poplar (*Liriodendron tulipifera)* forest, root death produced twice as much N and seven times as much K as the aboveground processes did (Cox et al., 1978). Similar to this, in an Amazonian tropical forest, fine root turnover added 343 kg and 11 kg/ha/yr of N and P to the soil, respectively. These contrast with the 61 and 0.8 kg/ha/yr added by fine aboveground litter, respectively.

7.9 DECOMPOSITION AND NUTRIENT RELEASE

The intrasystem nutrition cycle is completed when organic matter in the soil and litter decomposes, releasing nutrients for use by plants and microorganisms. The warm and humid climate in the tropics contributes to the quick decomposition of litter, yet the rates are very varied and overlap with temperate forest decomposition rates at the lower end. According to Vitousek and Sanford (1986), the litter turnover (k), which is determined by dividing the yearly litter fall by the amount of litter that is at present developing on the soil surface, ranges from 0.34 to 1.1 for diverse tropical forests? On the opposite extreme, k might be as low as 0.001 in very cold boreal peatlands (Olson, 1963). Mineral release decreases from tropical to temperate to boreal forest environments in accordance with the rate of decomposition. The nutrient turnover time is reciprocal of k, or (1/k), for the world's largest forests and some Indian forests (Pine forest, Oak forest, and Dry Deciduous Forest). Evergreen plants decompose leaf litter at a slower rate than deciduous ones, according to research by Aerts and Chapin (2000), both in temperate and tropical climates.

The soil microbial biomass, which serves as both a source and a sink of nutrients available to plants, is where the majority of N and P available to plants pass through. When the C: N ratio exceeds 25:1, soil bacteria are known to immobilise nitrogen and excrete it below this level. As a result, the microbial community in high C: N ratio decomposing litter immobilises any available N from the soil solution. As a result, the pattern of nutrient release from decaying litter includes early immobilisation of nutrients in the microbial biomass, followed by a net nutrient release as a result of death, decay, and cell lysis of microbial organisms. When absorbing material with a high C: N ratio, the soil microbes in barren soils may immobilise N and P, severely reducing the amount of nutrients that are available to plants, perhaps temporally. In certain environmental conditions, the lysis of microbial biomass may cause a periodic release of nutrients that may be timed with active plant growth (Singh et al. 1989). However, the ecosystem may lose nutrients if this periodic release is not timed with plant uptake (Lodge et al. 1994).

7.10 NUTRIENT USE EFFICIENCY

Nutrient utilisation efficiency (NUE) is calculated as net primary production divided by net intake of nutrients. Thus,

$$NUE = \frac{\text{Net primary production}}{\text{Net nutrient uptake (ie, adjusted for resorption)}}$$

We can alternatively compute NUE by dividing net primary output by nutrient losses from litter fall and leaching, keeping in mind that annual nutrient loss must be compensated by absorption. For convenience, the following expression is frequently used.

$$NUE = \frac{\text{Dry mass of litter fall}}{\text{Nutrient content of litter fall}}$$

The parameters utilised in this formula can be easily studied for data. Photosynthesis and leaf N content are positively associated across a wide variety of species. It may be possible to raise NUE by making adjustments to reduce nutrient losses through leaching and to boost internal nutrient utilisation (retranslocation from senescing leaves and other similar components). It is frequently claimed that communities on low-fertility sites use nutrients more effectively than those on high-fertility sites (high biomass production per unit of nutrient taken up from the soil). Contrary to deciduous forests, which are frequently connected to nutrient-rich places, coniferous forests, which occupy relatively nutrient-poor sites, exhibit higher NUE (Table 7.2).

Table 7.2. Comparison of nutrient use efficiency (NUE) of coniferous and deciduous forests. NUE is calculated by dividing net primary production (kg/ha/yr) by net nutrient intake (kg/ha/yr) (data from Cole and Rapp, 1981).

Forest type	**NUE**			
	N	**P**	**K**	**Ca**
Deciduous	143	1859	216	130
Coniferous	194	1519	354	217

This might not always be the case, though. Because wood has significantly lower nutrient concentrations than leaves, trees on nutrient-rich sites typically grow taller and produce more wood than trees on nutrient-poor areas. The nutrient usage efficiency on fertile sites may not be lower than that for the communities on nutrient-poor sites as a result of a relatively higher wood production per unit nutrient used (Grubb, 1989). Due to the proportional increase in wood output and the removal of some nutrients, particularly P and K, from older wood in some species, NUE increases as trees age.

7.11 NUTRIENT CONSERVING ADAPTATIONS IN OLIGOTROPHIC SOILS

Because of variations in weathering, soil characteristics and detritus breakdown, the ecosystems of temperate and tropical forests exhibit different patterns of nutrient cycling. Tropical forest soils have low clay concentration, deep weathering, and low cation exchange capacity (ability to hold nutrients). As a result, living biomass contains the majority of the nutrients in many tropical forests. The rapid recovery of nutrients from the debris supports the high productivity of tropical forests. Following are some observations of the many nutrient-conserving strategies seen in oligotrophic soils.

1. **Large root mass:** Some species adapted to barren locations have large root mass and a high root: shoot ratio. Large root masses fill the space in the soil where nutrients are stored when they are released during decomposition, increasing the amount of surface area available for robust nutrient absorption. Root length per unit root mass, or higher specific root length, might compensate compensate for lower allocation to root mass.
2. **Root concentration near the soil surface:** Roots may be heavily concentrated at the top layer in nutrient-poor soils in order to capture the nutrients before they are washed down the soil profile. Infertile tropical wet forests frequently exhibit the development of a dense root mat on the upper surface. The species has an extra benefit when it comes to acquiring nutrients because of the concentration of roots at the soil surface, where nutrients are released by decaying litter. The advantage these species receive in their struggle with decomposers for the available nutrients is equally significant. As a result, nutrients from decaying matter can reach roots directly in the "root mat" without first needing to be stored in mineral soil.
3. **Nutrient absorption by aerial roots:** Numerous trees in tropical damp forests have adventitious tree roots. The presence of endomycorrhizae, numerous root hairs, and unsuberized root tips indicate that these roots are involved in the transfer of nutrients from the dead portions of mats that bryophytes, lichens, ferns, bromeliads, orchids, and other plants form on the stems and branches of trees.
4. **Mycorrhizal association:** Mycorrhizae typically have a close relationship with terrestrial ecosystems like forests and other communities on nutrient-poor areas. Mycorrhizae are supported by the majority of the C that is allocated below ground in low-nutrient situations (Hobbie, 1992). In tropical forests, arbusculur endomycorrhizae (AM) are more prevalent and can actually reach the cortex of feeder roots. Bypassing the known decomposers, mycorrhizae may offer a "direct" route for nutrients from decomposing litter to roots. In some tropical forests, mycorrhizae can be seen attached to decomposing litter. By drawing nutrients from dead roots and perhaps establishing an interspecific transfer of nutrients, mycorrhizae appear to completely close down nutrient cycling in tropical rain

forests. Water component appears to have an impact on the spread of organisms with symbiotic associations for nutrient delivery. In savannas, trees with sheathing mycorrhizae lack significance as precipitation declines, but nodule-bearing species (N-fixers) gain significance as water availability declines (Grubb, 1989).

5. **Evergreen, sclerophyllous leaves:** Species of nutrient-deficient soils typically develop scleromorphic (tough, typically thin) evergreen leaves. As a whole, their leaf P concentration is less than 0.3%. The hard, evergreen leaves are resistant to herbivory and have low nutritional contents. Because it costs a lot to replace leaves frequently, plants in barren soils may benefit from having leaves with a long lifespan. Sclerophilly is more prevalent in tropical evergreen forests with broadleaved species than in temperate forests. In contrast to the low cost, quick profit strategy of short-lived deciduous leaves, long-lived leaves with high specific leaf mass (leaf dry weight per unit area) have potentially high production costs, low but long periods of photosynthesis, and are therefore referred to as having a high cost, slow profit strategy.
6. **Nutrient scavenging epiphylls:** On tree leaves, particularly in the wet tropics, you can find epiphylls, which are plants like mosses, lichens, and algae. They can scavenge nutrients from rainfall flowing over leaves, while some lichens and algae may also fix nitrogen.
7. **Secondary compounds as chemical defense:** In tropical trees and other plants, secondary plant chemicals like phenols serve as defences against herbivory by mammals, insects, and diseases. There is an idea that growing new leaves costs more than growing secondary compounds. By preventing bacteria from degrading and denitrifying, secondary chemicals can also have an impact on nutrient cycle.
8. **High silica levels:** In contrast to the high quantities of silica found in many types of plants and grass, tropical soils frequently have poor phosphate availability. It may serve two purposes. (i) Silicon partially replaces phosphorus (P) when it is deficient. (ii) Silicates take the place of soil phosphates that were previously bonded to iron and aluminium, releasing the phosphates in soluble form.
9. **High nutrient storage in biomass:** Some humid tropical forests are thought to have a large buildup of nutrients in the wood and overall biomass in comparison to the soil. It is hypothesised that nutrient leakages from the environment would be reduced by increased biomass accumulation of nutrients. There are also indications that the biomass of tropical forests does not store nutrients as effectively as that of temperate forests.
10. **Nutrient retranslocation during senescence:** It has not yet been determined whether nutrient resorption is more prevalent on infertile sites than on fertile sites, but it does reduce nutrient leakages from the ecosystem when it occurs before leaf abscission. Studies suggest that plants growing in fertile soils may even have higher rates of resorption.

7.12 EFFECTS OF N- AND P-ENRICHMENT ON BIODIVERSITY

Since the start of the Industrial Revolution, there has been an extraordinary increase in human-made N and P inputs into the biosphere (from 15 3 to 259 Tg N/year and from 03 to 16 Tg P/year, according to Penuelas et al., 2011). According to Tillman et al. (2001), this extensive nutrient enrichment is currently regarded as one of the biggest challenges to the preservation of biodiversity. Toxic effects, increased sensitivity to pests and environmental pressures, changed mutualistic connections, soil acidification, and eutrophication are some of the mechanisms responsible for species loss (Bobbink et al., 2010). A lot of focus has been placed on eutrophication, or higher primary productivity brought about by an increased supply of nutrients that limit production and the competitive exclusion of species with low productivity (Hautier et al., 2009). There is an urgent need to comprehend the relative impact of rising N and P to biodiversity loss, especially in light of the estimate that agriculturally driven eutrophication with N and P will grow by 2.4 to 2.7-fold by the year 2050 (Tilman et al., 2001).

The higher species richness in P-limited grasslands has been demonstrated by Ceulemans et al. (2013) using data on soil, productivity, and plant species from 132 seminatural grasslands located along a gradient of nutrient availability and atmospheric N deposition in north-east England and southern Scotland, central France, and Belgium. In contrast to N enrichment, their work demonstrates the detrimental effects of P enrichment on biodiversity in at least some terrestrial habitats. The relationship between soil nutrients, acidity, limiting, productivity, and indicators for plant species richness has been investigated using linear mixed models. With regard to overall species count, forbs, and endangered species, soil P had a substantial negative correlation. Only the amount of forbs and endangered species had a substantial negative relationship with soil N. Additionally, according to new research by these researchers, P-limited grasslands have a higher species richness than N-limited grasslands (Ceulemans et al., 2013).

SUMMARY

Biogeochemical cycles, also known as nutrient cycles, are ongoing cycles in which nutrients move continuously from the environment to organisms and back to the environment. You must have learned from this study of the nutrient cycles the significance of the function played by green plants, which serve as abiotic components by absorbing nutrients from the soil and the atmosphere, and by decomposers, which return the nutrients to the abiotic pools for re-use by the plants.

In tropical forests, a significant fraction of the available nutrients are stored in the biomass rather than the soil, but in temperate areas, a significant portion of the organic matter and nutrients are always present in the soil and sediments. It's interesting that while both ecosystems have the same quantity of organic carbon, the tropical forest has more than three-quarters of it in the form of plants. Numerous nutrient-conserving biological adaptations contribute in the recycling of nutrients in the organic structure of tropical forests.

Some of these adaptations, which are particularly well-developed in tropical rain forests, depend on the geology and basic fertility of the area which are: (i) the nutrients from leaf fall and rain are promptly retrieved by root mats made up of several fine feeder roots that penetrate the surface of the litter before being leached away. Additionally, root mats stop the action of bacteria that break down nitrogen, preventing nitrogen loss. (ii) As nutrient traps, mycorrhizal fungi connected to root systems aid in the recovery and storage of nutrients. This symbiosis can also be found in temperate forests, which are generally deficient in nutrients. (iii) Evergreen leaves comprise thick, waxy cuticles that prevent the loss of water and nutrients. Additionally, evergreen leaves have pointed tips, or "drip tips," that quickly drain water, preventing the loss of leaf nutrients. (iv) the diffusion of nutrients out of the phloem and subsequent loss by stem flow, or rain running down tree trunks, are inhibited by thick bark. (v) Many leaves have algae and lichens on their surfaces, which absorb nutrients from rainfall, some of which are readily available to the leaves. Also, lichens fix nitrogen.

Due to these nutrient-conserving processes, tropical forest soils which are often low in nutrients are able to retain high production under natural conditions. These systems essentially skip the soil by having a plant to plant cycling. These systems are destroyed when such woods are cut down or cleared for farming, and productivity decreases quickly. The potential of the land to store nutrients and to fight off pests in an environment of consistently high temperatures is lost when forests are cut down. Crop production falls off, and the land is eventually abandoned after a few years.

Soils in temperate forest have relatively large nutrient pools and when these forests are cleared, the soil retains nutrients and may be cultivated for many years by ploughing one or more times a year, planting short season annual plants and applying inorganic fertilizers. During winter, freezing temperatures help hold in nutrients and combat disease and pest.

Due to these factors, agricultural techniques that work well in temperate climates may not be effective in tropical ones and shouldn't be used unchanged there. Nutrient cycling is facilitated by the uptake of nutrients by green plants and the release of nutrients for re-use by decomposers. The ecosystems are continually adding and removing nutrients. The nutrient budget of an ecosystem is a measurement of input and outflow.

A significant amount of the nutrients in tropical forests are stored in the biomass rather than the soil. This is a result of nutrient recycling between plants, which is facilitated by a number of biological adaptations. As a result, clearing tropical forests reduces the soil's capacity to hold nutrients, rendering it unsuitable for extensive agriculture. The soil as compared to plant biomass contains the majority of the nutrients in temperate woods. As a result, even after these the soil still contains nutrients and is suitable for farming.

7.14 GLOSSARY

Bromeliads: Bromeliads are relatively slow-growing plants that take one to three years to mature into flowering plants.
Cation: a positively charged ion, i.e. one that would be attracted to the cathode in electrolysis.
Cation exchange capacity: a measure of the total amount of exchangeable cations that a soil can hold, expressed in m.eq/100 g.
Clay: soil particles less than 0.002 mm in diameter.
Eutrophication: It is the process when the environment becomes enriched with nutrients, increasing the amount of plant and algae growth to estuaries and coastal waters.
Forbs: These are herbaceous flowering plant species.
Graminoids: herbaceous plant with a grass-like morphology i.e. elongated culms with long, blade-like leaves.
Leaching: the process of downward movement of soluble nutrients and other salts with Envimment and its moving water through soil profile.
Micelle: a complex soil particle with negative electric charges at its surface
Mycorrhizae : Fungi that have a symbiotic relationship with the roots of many plants.
Nitrogen Fixation: It is a biological process in which the nitrogen gas is converted into a usable form for plants and other microbes. In this process, nitrogen gas present in the atmosphere is converted into ammonia and other nitrogenous compounds.
pH : measure of acidity and alkanity on a 0-14 scale, with pH being neutral at 7. Numbers greater than seven, i.e., 8-14 pH being alkaline (basic), and less than seven, i.e., 6 pH being acidic.
Productivity: amount of organic matter accumulated in the living component of an ecosystem in unit time, i.e., the rate of conversion of sunlight by plants into chemical bond energy.
Resorption: the process or action by which something is reabsorbed.
Retranslocation: Nutrient removal from plant tissue into the perennial part of the plant prior to senescence.
Photosynthesis : the process by which chlorophyll containing cells of plants utilize energy of the sun to synthesise simple carbohydrates from carbon dioxide and water. Oxygen is a by-product
Soil : the upper portion of earth's crust in which plants grow. It is composed of mineral matter, air, water, organic matter and various kinds of living organisms.
Soil profile : a vertical section of soil extending through all its horizons from the surface to Bedrock.

7.15 SELF ASSESSMENT QUESTIONS

7.15.1 Multiple choice questions

1. The cation-exchange capacity (CEC), is expressed as
a. Milliequivalents per 10g of soil
b. Milliequivalents per 100g of soil
c. Milliequivalents per 1000g of soil
d. None of them
2. Nutrient losses to runoff water are minimal in soils with
a. High CEC
b. Low CEC
c. Does not affected by CEC
d. None of the above
3. Low CEC is found in
a. Iron- and aluminum-oxide-dominated temperate forest soils.
b. Iron- and aluminum-oxide-deficient tropical forest soils.
c. Iron- and aluminum-oxide-dominated tropical forest soils.
d. Iron- and aluminum-oxide-dominated temperate forest soils.
4. When the pH is in the acidic range (below 5.5), the availability of N and K
a. Decreases
b. Increases
c. Remains unchanged
d. None of the above
5. Many leaves have _____algae and ______lichens on their surfaces, which absorb nutrients from rainfall.
a. Fungi and pteridophytes
b. Algae and lichens
c. Fungi and bryophytes
d. All of the above
6. Clay and humus, two soil colloidal components, bind the exchange cations on the surfaces.
a. Soil and silt
b. Clay and humus
c. Clay and soil
d. All of the above
7. When PO_4 and Ca interact at high pH, they produce.
a. carbonates
b. Both a and b
c. insoluble phosphates

d. None of the above
8. Phosphate ion diffusion rates in most soils are significantly lower than those for K^+ and NO_3^-
a. Na+ and NH_4
b. Mg^{2+} and K^+
c. SO_4^{-2} and NO_3^-
d. K^+ and NO_3^-
9. Across woody species from various settings, the percentage of nutrients (N, P, and K) removed from leaves typically ranges between 20% and 80%.
a. 20% and 80%.
b. 30% and 70%
c. 40% and 60%
d. 25% and 75%
10. The concentrations in the aboveground components of the majority of trees are found in the following sequence: leaf > twig > branch > bole,
a. Leaf > branch >twig > bole
b. Twig >leaf > branch > bole
c. Bole >leaf > twig > branch
d. Leaf > twig > branch > bole

7.15.2 Fill in the blanks

1. The nutrient turnover time is reciprocal of _______________.
2. The majority of nutrients dissolved in water are absorbed by aquatic plants like *Elodea*, *Lemna* and *Vallisneria* through their _______.
3. These silicate clay minerals have ____surface charges that attract and hold soluble nutrient ______ from the soil solution.
4. Plants that use NH_4+ as a source of nitrogen are known to _______ the immediate area around their roots.
5. Banj oak (*Quercus leucotrichophora*), one of the two main species that create forests in the central Himalaya, prefers _____ ion.
6. Mycorrhizae_______ absorb nutrients at a lower carbon cost than roots because of their smaller diameter and higher surface-to-volume ratio.
7. The principal exchangeable cations in soils are _______.
8. For optimal plant growth, the foliar N: P mass ratio (Redfield ratio) should be ____.
9. The concentrations in the belowground components of the majority of trees are found in the sequence-
10. The movement of soil water in response to causes ions to flow in large quantities; this is significant for Mg, SO_4^{-2}, Fe, and Ca.

7.15.3 True and false

1. The rates of nutrient supply and absorption are not correlated.
2. Plants emit HCO^{3-} and organic acids to counteract the negative charge.
3. Roots extending into the soil capture exchangeable nutrients like Ca and NH_4 -N.
4. Evergreen leaves comprise thick, waxy cuticles that prevent the loss of water and nutrients.
5. Litter contains the majority of the nutrients in many tropical forests.

Answer Key:

7.15.1: 1. b, 2. a, 3. c, 4. a, 5. b, 6. b, 7. c, 8. d, 9. a, 10. d.

7.15.2: 1. Litter turnover (k), 2. submerged leaves, 3. negative; cations, 4. acidify, 5. NO_3^- , 6. mycorrhizae, 7. Ca, Mg, K, and Na., 8. 10: 1, 9. fine root > lateral root > stump root, 10. transpiration.

7.15.3: 1. False 2. True, 3. True, 4. True, 5. False.

7.16 REFERENCES

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7.18 TERMINAL QUESTIONS

1. Write a short Nutrient supply and uptake.
2. Write a short note on role of mycorrhizae in nutrient cycling.

3. Write about Nutrient concentration and storage in vegetation.
4. Write a detailed note on seasonal changes in foliage nutrients and nutrient reabsorption.
5. Write about Nutrient return from vegetation to soil.
6. Write briefly about decomposition and nutrient release.
7. Write a short note on Nutrient use efficiency.
8. Nutrient conserving adaption in oligotrophic soil.
9. Effects if N and P enrichment in biodiversity.

UNIT-8- FOREST HYDROLOGY

Contents

8.1 OBJECTIVES

The present topic provides an overview on forest hydrology. After reading this topic, learners will be able to answer the:

- Impact of forest on precipitation apportionment
- Water discharge from watersheds
- Role of water in nutrients cycling

8.2 INTRODUCTION

Hydrology and forestry are two distinct fields that are combined in forest hydrology. The study of the available water of the Earth is known as hydrology. The study of hydrology aims to comprehend where and how water occurs, how and why water distribution varies over time, as well as its chemical and physical characteristics and relationship to living things.

The study of forestry aims to comprehend the nature of forests and the interactions between the various components that make up a forest. Consequently, forests are essential to both the water cycle and the quality of the water. Ecologists consider the water as a crucial component of every ecosystem, including the forest ecosystem. The physical landscape is shaped by water through erosion and deposition. Additionally, it affects the biological components of the ecosystem by influencing their occurrence, distribution, quantity and quality (Manral et al. 2018). Ecosystem activities and functions are significantly influenced by the water cycle.

The watershed protection has been an integral part of forest management since its origins. The forest reserves secure the favorable conditions of water flow, reduce flooding, protect and enhance water supplies, reduce the chance of forest fire and provide other ecosystem services (Padalia et al. 2015; Padalia 2015). In essence, the forest acts like a giant sponge, recycling and filtering water. The leaves of trees absorb water from snow, rain, and fog while also releasing water through evapotranspiration back into the atmosphere. Tree roots help keep the soil in place by drawing water from the ground (Padalia et al. 2022; Manral et al. 2022). By intercepting and delaying the arrival of water at the surface, forested terrain lessens the impact of rain on its surface. Additionally, forestland reduces the quantity and rate of storm runoff across the land surface. As a result, more water percolates into the earth, some of which may eventually recharge underlying aquifers.

Different scales of hydrological processes are crucial for preserving landscape variability, biodiversity, and the availability of fresh water for people and animals. Watershed management benefits from research on forest hydrology, which is essential to understanding the physical, biological, and chemical processes in a watershed. As a result, hydrology and water management have focused heavily on the effects of forests on sediment and water cycle. The forest hydrology and its different components will be covered in detail in this chapter.

8.3 IMPACT OF FOREST ON PRECIPITATION APPORTIONMENT

A stable supply of clean, fresh water as well as many other ecosystem functions related to water, such as preventing floods and erosion and regulating the climate, depend heavily on forests. The recycling and transportation of precious water resources toward the interior of the continent is another key function of forests. (Ellison et al. 2019; Sheil and Daniel 2009).

The basis for these many water-related services provided by forests can be found in the structure and function of forest ecosystems and a better understanding of plant-plant water relationships. Forests affect the water regime of a region by their consumptive use of water (i.e., transpiration) and by their consequence on the energy balance of the region. Trees, whether they are found alone, in a tiny patch, or in a large stand of forest have an impact on the amount of precipitation that falls on the earth's surface by utilizing:

1. Interception
2. Affecting the flow of air over the surrounding area, as would any physical obstruction, and therefore the deposition pattern of rain and even more snow.

Trees as multi-tasking water engineers

According to Verstraeten et al. (2005) trees have a greater leaf area index than other types of vegetation. This suggests that their canopies are better at catching rain, and when combined with their deeper roots, they lessen the erosive forces of rain. Additionally, trees offer a microclimate that is more shaded and humid, which lessens the consequences of climate change (Zellweger et al. 2020). Trees have deeper root system than other plants (Jackson et al. 1996), therefore, they are capable to reach and pump larger volumes of soil water for transport to leaves for transpiration and growth. It is roughly estimated that a mature oak tree during their growing season evaporates up to 1600 liters of water per day. Trees combine this high transpiration rate with relatively high water productivity (the amount of biomass produced per liter of water in g/L), which entitle them an efficient and fast producers of biomass.

Trees have higher evapotranspiration than other vegetation types due to higher rates of transpiration and interception (Verstraeten et al. 2005). The energy needed to completely evaporate the water is taken from the environment and exits the system as latent heat. Thus trees and forests have a pronounced cooling effect on their environment that can easily decrease surface temperatures by 5–10 °C (Hesslerova et al. 2013). In addition, the increased amount of litter produced by trees and forests leads in more soil carbon (Bargali et al. 2019; Padalia et al. 2018; Bargali et al. 2018; Padalia et al. 2017), which enhances both soil water retention and groundwater recharge.

Forests balancing blue and green water

There has been much debate over the exact role of forests in the water cycle. Forests were described in older literature as "sponges", emphasizing the water absorption and buffering capacity of their roots, crown and soil, balancing river flows and controlling floods. Green water is that portion of precipitation that evaporates back into the atmosphere through plant absorption and transpiration, or through evaporation from leaf surfaces, soil, and water surfaces.

Managing for water-related forest ecosystem services

The fundamentals of managing forests in a way that conserves water are fairly well understood. Avoiding deforestation is crucial, especially in areas vulnerable to erosion (Bruijnzeel 2004). The size of a clearcut in the forest should be kept to a minimum, especially on steep slopes, to minimize surface runoff and sediment loss. Increased water harvest in aquifers and river catchments results from strategically placing fast-growing tree species in intensive plantation forests since this reduces evapotranspiration (Muys et al. 2014). Significant deforestation frequently affects cloud formation and rainfall and emphasises seasonality (Bonan 2008). Forest clearings can result in a distinct, convection-driven "vegetation breeze" as moist air is sucked out of the forest (Laurance 2005). The localised increase in rainfall that is occasionally linked to fragmented forest cover is believed to be caused by atmospheric turbulence caused by canopy roughness and temperature-driven convection (Bonan 2008).

Water quality may be improved by restoring the forests near riverbanks. Broadleaved forest is preferable over conifer forest in locations where drinking water is produced because of its lower average leaf area, which provides more water in the aquifer and because this water is also less contaminated because conifers intercept more air pollutants.

The protection of forest’s hydrological ecosystem services is one of the new problems arise by climate change to which they must adapt. According to Allen et al. (2015), "hot droughts," or droughts that occur during hot summers with a high atmospheric water demand, are becoming more common for forests to deal with. Under these circumstances, increased thinning intensity promotes the health and growth of the forest (Sohn et al. 2016). However, little is known about the long-term impacts of increased canopy openness on biodiversity, which is dependent on a robust forest microclimate during climate change. Greening cities with trees cools urban heat islands (Moss et al. 2019), and mitigates peak discharges.

Combining different tree species frequently encourages roots to explore different types of soil, which may improve a tree's ability to withstand drought (Sousa-Soilva et al. 2018). Loss of soil carbon content, infiltration, water retention, and groundwater recharge due to land degradation and loss of tree, forest, and vegetation cover globally have significant impacts on these processes, making arid landscapes more vulnerable to drought and wildfire.

An atmospheric moisture pump

Conventional meteorological research regards pressure gradients caused by temperature and convection as the primary causes of air movements. The partial pressure of water vapour near the earth's surface, under ordinary atmospheric circumstances, is much more than the weight of the water retained in the atmosphere above it. Powerful airflows may be produced by the imbalance. Force consequences from the way pressure and temperature both turn down with altitude in the lower atmosphere (troposphere). The atmospheric water can remain static and in a gaseous state when the vertical temperature decline (the "lapse rate") is less than the critical value of 1.2°C per km. But the global average lapse rate is more than 6°C per km. These faster speeds cause water vapour to ascend and condense. Air pressure decreases as a result of the drop in atmospheric volume that occurs during this gas to liquid phase change. Wherever the pressure is lowest, air currents near Earth's surface move in that direction, so, these are the areas that possess the highest evaporation rates (Makarieva and Gorshkov), forests maintain higher evaporation rates in equatorial climates than other cover types, including open water. Thus, forests draw in moist air from elsewhere; the larger the forest area, the greater the volumes of moist air drawn. In turn, this additional moisture rises and condenses, creating a positive feedback in which a significant amount of the water condensing as clouds over wet places is brought in from elsewhere.

Evaporation and forests

In evaporation, there are two different types. The evaporation flux occurring inside of plants is known as transpiration. By managing their stomata, the plants regulate this flow. Another significant process is evaporation from moist areas like soils and open water. Conditions determine which mechanism contributes most to overall evapotranspiration (Sevenidge 2004). Forests evaporate more moisture than other vegetation, typically exceeding flux from herbaceous cover (Calder 2005). Closed tropical forests typically evaporate more than a meter of water per year (Gordon et al. 2005).

Both height and roughness of the canopy causes turbulent airflows, are advantageous for forest evaporation. This phenomenon, known as the "clothesline effect," as it is the same reason why clothing dries more quickly on a line than when it is spread out flat on the ground (Calder 2005). Forest evaporation is mostly limited by sun radiation and climatic conditions if moisture levels are adequate (Savenije 2004).

Water reserves in plant and soil is crucial. Plants with high stem volumes permit transpiration to exceed root uptake, as stem water reserves are exhausted by day and refilled at night (Sheil 2003). Forest lianas and trees have typically deeper root system, therefore, can easily access subterranean moisture during droughts (Nepstad et al. 1994). Many forest soils possess good water infiltration and storage- properties often lost with deforestation (Bruijnzeel 2004). Vertical translocation of soil water through the forest soil profile by roots at night may also be important (Lee et al. 2005). The forests and cloud forests subjected to coastal fogs abundant bryophytes and dense foliage contribute to efficient mist and dew interception (Dietz et al. 2007).

Makarieva and Gorshkov suggest that forests can influence precipitation. Rain takes place when condensed moisture gets accumulated and the resilience generated by rising humid air is low enough. To reduce moisture stress, plants frequently close their stomata in the afternoon. This lowers the rate of evaporation (Pons and Welschen 2004).

Recycling

Oceanic and terrestrial evaporation are the sources of atmospheric moisture. Recyclable precipitation refers to precipitation that comes from terrestrial sources and adds to local precipitation. The percentage of recycled precipitation is a measurement based on the size of the area under consideration.

Rainfall transects

The two sorts of rainfall trends from the coast to the continental interior are predicted by Makarieva and Gorshkov's hypothesis. They suggest and prove that well-forested transects exhibit no yearly rainfall reduction with increasing distance from the coast, whereas forest-free transects exhibit one regardless of location or seasonality.

Seasonal rainfall

The monsoon climate alternates between two phases: wet and dry. This switch is driven by the annual rhythm of solar energy outside the equatorial regions and its different effects on land and sea. This switching is dependent on the relative evaporative flux. During seasons of low solar energy, land evaporates less moisture than open water (oceanic evaporation remains substantial even in winter) and the seas draw air from land, causing dry weather. When the sun shines brighter again, there will be enough solar energy for the land to once more drain more moisture than the nearby oceans, which will result in the change in air currents that characterizes the traditional monsoons. The rain-evaporation system's positive feedbacks are which control the switching. As a result, the duration of the rainy season can be shortened and the penetration of monsoon rains can be decreased.

8.4 WATER DISCHARGE FROM WATERSHEDS

Every body of water, including ponds, streams, lakes, rivers, and estuaries, has a watershed. A watershed is a region of land that drains or drains water into a particular receiving body of water, like a lake or river. In the watershed, as rainwater or melted snow flows downstream, sediments and other materials are collected, transported, and deposited into the receiving reservoir. Watershed discharge conveys information about how water interacts with human activities and natural processes on land. In addition to supplying necessary nutrients and water, watershed discharges also influence downstream aquatic life by introducing harmful pollutants into it. Excessive fluxes of nitrogen and phosphate can give the luxurious growth of the alga which causes large algal blooms that block light and drain oxygen from the water, creating "dead zones."Sediment deposition can also veil the water, making it impossible for anything, including algae, to photosynthesize.

Because of the three elements of the ecosystem—abiotic (soil, water), biotic (vegetation), and cultural (people and their social relationships)—water is often used as a unit of analysis in efforts to manage natural resources. Water is the most obvious aspect of an ecosystem's movement and its territory. Watershed morphometry includes the density of river flows, shape and area influences the water storage, infiltration system and surface runoff, including sediment transported in the runoff (Antoko and Sukmana 2007). A watershed with a larger area likely to received a more amount of rainfall, leading to a greater amount of runoff from the watershed. A circular watershed has a stronger flood flow because precipitation falling in the watershed will travel more swiftly to the outlet. Similar to this, watersheds with numerous river branches will have larger peak flows as a result of water entering the river more rapidly and easily (Suprayogi et al. 2014).

Some scientists investigate watershed discharge to learn what regulates the movement of materials from the land to the water and how those materials impact aquatic ecosystems. In order to determine how much water, sediment, nutrients (nitrogen, phosphorus, and carbon) and other substances are leaving the watershed, researchers have analysed stream monitoring stations. The climate, land use, geology, and land management are all linked to variations in discharge between watersheds. To understand why watershed outputs vary over time, researchers also considered weather, land use changes and climate change. Some important regulating water usage and water discharges are discussed below in brief:

1. **Stream water:** A water body that flows along the surface of the Earth is called a stream. Although rivers typically refer to bigger streams, the words stream and river are frequently used synonymously. Streams require both gravity and water to function. When precipitation falls to the earth, some water trickles into the groundwater, but the majority

of it runs off the surface as runoff and gathers in streams. Rock is eroded by streams as they move it and other debris downstream and this process is known as erosion. Streams take on a variety of shapes depending on the terrain they traverse. One channel of a meandering creek traverses the surrounding area. Oxbow lakes can be formed when these curves eventually meet and separate the bend from the rest of the stream. Braided rivers resemble braided hair because they have numerous channels that split and converge.

The streams sweep away waste, offer irrigation for crops, provide drinking water, and even generate electricity through hydropower. Streams support a vital habitat for several plants and animals. Various plants and animals have developed specifically to flourish in streams. Plants frequently have long, flexible branches that can move with the current and well established roots that serve as anchors. The health of a stream can be harmed by numerous things. Dams obstruct the natural flow of water and sediment and limit the free movement of water, nutrients, and species through the stream system. Urban areas occasionally discharge untreated sewage into waterways, resulting in algal blooms that suffocate wildlife. Farms and factories can discharge pollutants into streams, endangering wildlife and human depended on fresh and clean water.

2. **Stormwater:** Storm water is the amount of water that drips off of paved surfaces like parking lots, roads and rooftops after it rains or melts snow. Along the route, contaminants such as soil sediments, motor oils, gasoline, antifreeze, and brake dust (often found on pavements), as well as fertilizers and pesticides (often found in landscaped areas), may be picked up and transported by from one place to another by the stormwater (from farms and construction sites). The water eventually travels through storm drains and streams, rivers, and lakes in the area before being released untreated into a nearby body of water. Stormwater significantly contaminates surface waters, which negatively impacts activities like swimming and the sustaining of aquatic life.

3. **Sewage water:** Wastewater produced by residents of a community is referred to as sewage water. Wastewater is the term for the water that is discharged from homes after being used for a variety of tasks like cleaning dishes, doing laundry, and flushing the toilet. The used water transport to the adjacent water bodies from the houses through pipes installed during plumbing. The sewage water then moves into sewers, either constructed by the house owner, or into a sewer facility set up by the municipality. Grey water and black water make up the majority of sewage water. Grey water is the used water that is left over after cleaning clothes, dishes, or the bathroom. The waste water from toilets is known as black water. Due to the chemical makeup of the various waste items, it is distinguished by detritus including paper wrappings, sanitary products, soap residues, and grime. The problem is that inadequate planning for urban overcrowding has

led to sewage contamination, which endangers not just the environment but also human health. Additionally, it has an impact on agriculture, aquatic life, biodiversity, and is a significant cause of eutrophication and an increase in biological oxygen demand (BOD).

4. **Municipal wastewater:** The term "municipal wastewater" refers to both precipitation water and wastewater from houses or a combination of both. Domestic waste is the primary source of pollution in municipal water. If we look at the source, it could be a combination of liquid and water-carried wastes from households, industrial plants, factories, institutions, as well as any groundwater, surface water, and storm water that may have unintentionally entered the municipality's sewerage system. Industrial wastewater may contain contaminations, which cannot be ejected by conventional treatment. If the environment is overburdened with consumption of organic contaminants, then it can diminish the levels of dissolve oxygen in the water. Waste water treatment plant can reduce this problem. The primary function of a wastewater treatment facility is to enhance the natural processes that can purify water. The natural processes in lakes and rivers used to be adequate for meeting our fundamental needs, but as populations have grown and pollution levels have risen, unnatural solutions are being used to address the problem. The secondary treatment stage of municipal wastewater treatment is designed to lessen the biological pollutants produced by food, detergents, and soaps as well as human waste. Municipal plants use an aerobic biological process to clean up the foul fluids.

5. **Industrial wastewater:** Manufacturered goods and services are provided by industry and are sold globally. Pollutants found in wastewater produced by industrial processes include oils and greases, suspended particles, BOD (biochemical oxygen demand), nutrients, heavy metals, and other harmful inorganic and organic compounds. These contaminants have the potential to seriously damage the ecosystem if left untreated. The Government bodies regulate the discharge of industrial wastewater to the ground water, surface water, and to sewage treatment plants through permitting programs. All licences include discharge limitations and guidelines for treatment, monitoring, and reporting that are intended to prevent pollution of the waters. For industrial wastewater releases, there are usually two different types of permits are available:

    a. Individual permits: It is concerned straight to an applicant and is customized to according to the company's activities based on flow and the pollutants restricted in the discharge.
    b. General permits: It is given to allow one or more applicants to engage in similar minor activities within a defined category of discharge.

6. **Agricultural wastewater:** The agriculture is a vibrant sector of the economy that contributes significantly each year around the world. Animal rearing and crop cultivation both fall under the category of agriculture (Bisht et al. 2021; Padalia et al. 2018 and 2017). If agricultural wastewater is not adequately handled, it can contaminate surface as well as ground water. Agricultural wastewater is produced by a range of farm activities, including the processing of agricultural goods and animal feeding operations. Manure, wash water from milking parlours, slaughterhouse wastewaters, barnyard and feedlot runoff, egg washing and processing, horse wash waters, and runoff from composting are a few examples of agricultural wastewater. Additionally, pesticides, fertilizers and silt may enter surface rivers by runoff from croplands.

8.4.1 Variables influence a watershed

The watersheds and the streams that flow through them are persuaded by many factors including geology, terrain, climate, soils, hydrology, vegetation, type and size of stream etc. Before we can protect these systems, we must first comprehend how these influences affect watersheds and streams.

1. **Geology:** The geology of watershed is significant because it affects topography, water quality and biological productivity, the geometry of the drainage basin, the direction of water flow, the materials of the stream bed, etc. The topography of the watershed is determined by weathering and geologic forces that cause the earth's surface to rise or sink. Watershed movement patterns are influenced by geology. For instance, limestone or dolomite in karst places like the Ozark region has geology that has opened up as a result of water dissolving the rock along fractures and between layers. These access points serve as efficient funnels that quickly channel water to the water table. These channels can swiftly contaminate groundwater and streams with contaminants from the land surface, in addition to affecting the amount of water in streams and groundwater.

   The parent materials, or bedrock formation types, and the corresponding soils of the watershed are determined by the geology. A stream's water quality, biological productivity, and aquatic life are all influenced by the parent materials and the soils that are created from them. Parent material and soils also influence how susceptible a stream is to erosion by giving the components that make up the banks and bottoms of channels. Parental materials also offer restrictions on the growth of stream channels. The depth to which a stream may easily dig its channel is constrained by bedrock. The lateral, or sideways, movement of the stream can also be influenced by bedrock.

2. **Topography:** The topography of land is refers to its physical characteristics and shape. The watershed's geology is reflected in the topography of a stream channel and its

watershed. The design and distribution of stream channels are in turn influenced by the geography of the watershed. The steepness of the land surface and stream channels depends on the topography of the watershed. This steepness is also referred to as a slope, grade, or gradient. The erosive power of water in a watershed and its stream channels is influenced by the height and steepness of the hills, floodplains, and channels. Gravity may quickly increase the flow rate of water on steep slopes. The more quickly water moves, the more energy or force it has to erode and carry away soil, sand, gravel, rocks, and other debris. Stream sinuosity is also impacted by topography. Low gradient channels frequently meander back and forth, while steeper channels do not wind back and forth as much but frequently contain more riffles.

3. **Climate:** The main factor influencing the land and streamflow is the climate. The climate of an area's is influenced by its topography, elevation, latitude, vegetation cover and proximity to the ocean or other major water bodies. Temperatures, humidity, wind, precipitation, and evaporation in a watershed are all determined by these variables taken together. The temperature, wind, rainfall, snow, glaciers and other weathering elements erode soil and rock formations and alter the topography of watershed. Streamflow is deeply affected by climate and as a result new stream channels form and change.

4. **Soil:** On the surface of the ground, soil is made up of loose mineral materials. Due to the physical, chemical and biological changes in the soil can support plants growth. The soil is influenced by vegetation cover and their roots (Padalia et al. 2022). The most imperative characteristics of soils are their ability to nourish plants, cycle nutrients, and absorb, store and transmit water. The types of flora that can flourish in a watershed, on floodplains, and along streams are directly influenced by the soils. By absorbing agricultural pesticides, industrial pollutants, and organic waste, soils can lessen pollution of the water and air.

   Infiltration capacity is the measure of how quickly soil can absorb rainwater. Runoff occurs when more rainfall reaches the ground than the ground can soak up. The texture and structure of surface soils, vegetation cover, and land use all affect infiltration rates. The quantity of subsurface flow is governed by the infiltration capability as well as the texture, type and depth of soil. Water can go underground and downwards to a channel in highly permeable soil, such as tilled soils or forest litter. Water begins to accumulate in surface depressions once the infiltration capacity is achieved. Water begins to flow downhill as runoff as the depressions are filled. Water flow with more velocity and energy as it descends slopes, eroding more soil. Some of the soil the water is carrying will be deposited when it reaches a smoother slope since the water's velocity slows down.

Soils, together with geography and geology, influence the path that water will take after it hits the ground.

The regions of plane topography and deep soils allow the rain and the nutrients and chemicals it carries to slowly infiltrate and percolate down into the water table. More of the infiltrating water travels to channels as subsurface flow in locations with mountainous terrain and shallow soils. Gravel-filled streambank soils drain swiftly. However, the low cohesiveness of gravelly streambanks renders them extremely vulnerable to erosion by flowing water, which can remove gravel and soil fragments off the bank. On the other hand, clay streambanks are more cohesive and more resilient to the erosive energy of running water. Unfortunately, clay banks are prone to collapse due to a slide or slump. For instance, when there is a flood, the clay banks slowly absorb water but after the flood subsides, the clay banks slowly let the water drain away. Low shear strength boon the weight of the water in the clay bank can cause the bank to collapse. However, one type of soil rarely constitutes the entirety of a streambank. A streambank frequently has multiple soil layers. Soil stratification refers to this process. The number, order, and types of soil strata have a significant impact on how a bank erodes, together with bank height and the depth to which bank and riparian vegetation are rooted. It can be challenging to forecast how a stratified bank would erode because the rate of rise, peak, duration and rate of fall of each flood will determine which strata are more likely to erode.

5. **Hydrology:** The hydrology is the branch of science that examines the characteristics, distribution, and movement of water in the atmosphere, on the surface of the land, and underground. The primary events in the hydrologic cycle included precipitation, evapotranspiration, storage and runoff. How much precipitation is available to form and develop a watershed's features depends on both the short and long term climate. The amount, type and timing of precipitation directly affect erosion and deposition in a watershed. Through the transpiration of plants and the evaporation of surface water, evapotranspiration recycles water vapour from the atmosphere. The precipitation is stopped by depressions or vegetation and returned to the atmosphere by evaporation or transpiration. Storage refers to the retention of water in wetlands and lakes as well as groundwater infiltration through soil.

Water that falls on the ground and runs across land and into channels is known as runoff or overland flow. Runoff patterns and erosion rates vary from watershed to watershed and are influenced by geology, vegetation, land use, and terrain. The erosion and sedimentation of the land surface can be accelerated by changes in runoff. Flooding and rapid soil erosion can result from excessive runoff. Streambed and streambank erosion can become harmful as a result of excessive runoff as channels change over time to carry more water. The amount of soil, sand, gravel, nutrients, and contaminants that are flushed into streams can also rise during periods of high runoff. The precipitation that percolates down into the soil and is gradually discharged over the course of weeks or months into a stream channel or spring is known as the base flow or groundwater flow. Many streams and springs are maintained by base flows during protracted dry spells.

6. **Vegetation and land use pattern:** In a watershed, runoff will be reduced by the amount of flora that can absorb and transpire water. In a watershed runoff and erosion rates are influenced by the quantity and type of vegetation cover. Vegetation buffer the effect of raindrops on soil and delay the rate at which water flows across the land's surface, allowing more water to permeate the ground. A watershed with native grass or a forested backdrop often releases its runoff slowly, resulting in minimal soil and channel erosion. Watersheds with row cropping, too much logging grazing, urbanization, paving and other kinds of development typically have excessive runoff rates and volumes. Because less water is allowed to percolate into the ground or return to the atmosphere through transpiration, runoff increases in these circumstances. Unnaturally high runoff rates result in floods that are more frequent, bigger, and rise faster. Similarly, increased runoff can hasten surface erosion. As floodwaters recede and channels adapt to the new channel-forming flows, more flooding may accelerate streambed and streambank erosion.

   Many conditions and activities in a watershed can influence a stream. Uncontrolled erosion and runoff from construction sites; row cropping of highly erodible land; construction of houses, buildings and parking lots that prevent infiltration and speed runoff of precipitation; removal of riparian vegetation; improper disposal or excessive application of industrial, agricultural or household chemicals; point and nonpoint sources of nutrients and runoff from strip mines are some ways receiving streams can be degraded. These and other factors collectively contribute the unhealthy biological communities, poor water quality and unstable stream channels. Important steps can be taken to minimise the harm that human land use causes to streams, including installing erosion control measures on farmland and construction sites, limiting the amount of impervious area associated with urban development and maintaining or establishing areas of vegetation.

7. **Size and shapes of watershed:** Watersheds can range in size from large to tiny. Flood levels in the mainstem stream in small watersheds primarily depend on how quickly water drains from the ground. In small watersheds, flood flow experiences short peaks and quick decreases. The length of time it takes for water to move through the system of channels determines the flood levels in the mainstem streams of major watersheds. Floods with large watersheds persist longer but do not peak as rapidly. The size of the watershed affects the delivery of sediment eroded from the land and channels in a manner similar to how it influences runoff. The size of surface watershed is based on the

geometry of the land surface. Unless a water drop infiltrates to a stream's recharge region within the specified surface watershed, it will flow into another watershed if it falls outside the line, which is known as the watershed split. A subterranean stream recharge is harder to locate than its surface watershed since it is underground.

The shapes of watersheds vary greatly. Similar to watershed size, watershed shape also has an impact on how rapidly precipitation and silt reach the mouth of the mainstem. A watershed with a round shape produces fast, high flood peaks because water has a shorter distance to travel from headwaters to mouth. Long, narrow watersheds have longer distances for water to travel and will have more moderate flood peaks (Fig 8.1).

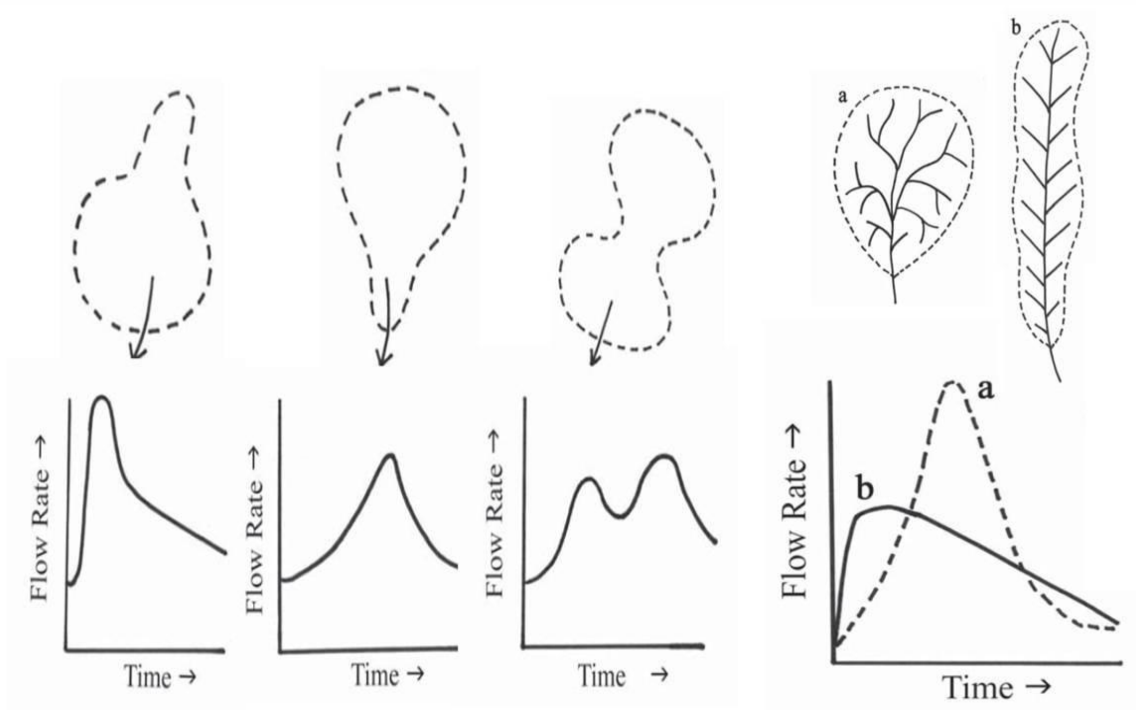

Fig. 8.1: Different size and shapes of watershed and its relative water flow rate (image is modified by the author; original Source: Lobb and Femmer 2018)

8. **Stream order:** The more superficial watersheds of a geographical area usually result in larger watershed sequences. However, the form of the drainage basin can affect the order of the streams. For example, long, narrow watersheds with many first and second order streams can hold much amount of water and give rise to large streams that are only second or third order streams.

9. **Drainage network patterns:** The whole system of land-surface channels used to transport water, sediment and other natural and artificial materials from a surface watershed is known as a drainage network. There is a distinct network of channels in every watershed. Streams in drainage networks can range in size from narrow, meandering streams to small, high gradient headwater channels. The timing and transport of floodwaters and sediment to each portion of the network will be influenced by drainage patterns and the structure of the watershed. The geology and topography of the watershed determine the shape or structure of a drainage network. As water flows along the lines of least resistance, a network of streams develops. As the channels are formed by the flowing water, the network steadily expands. The main channels and tributaries erode their beds and climb slopes over time, expanding the network. The stream system must constantly transport and accumulate sediment as a result of this upstream expansion. As tributaries join and the topography's relief is gradually diminished by ongoing weathering, the number of tributaries eventually declines.

8.4.2 Importance of watershed management

The considerable amounts of pollutants enter into a lake or river or adjacent waterbodies through the runoff, rain and melted snow. Watershed management identifies the types of pollutants present in the watershed, how those pollutants are carried, and make recommendations for ways to minimise or remove those pollution sources. This helps to regulate pollution of the water and other natural resources in the watershed. The natural characteristics and water quality of a watershed are impacted by all activities that take place within it. The quality of the resources in a watershed may be impacted many factors including runoff from already developed regions, new land development, agricultural operations, household activities including gardening and lawn care, septic system use and maintenance, water diversion, and vehicle maintenance, as well as other factors.

Comprehensive watershed management planning analyses the activities that have an impact on the watershed's health and offers suggestions on how to effectively handle them in order to lessen the negative effects of pollution. The planning process culminates in cooperation between all parties affected by the watershed, which makes watershed management crucial as well. That partnership is necessary to the thriving management of the water and land resources in the watershed since all partners have a stake in the health of the watershed. The implementation of watershed management plans can be prioritised effectively in situations where resources may be scarce. Following are the key steps in watershed management:

1. **Familiarize with local watershed:** Prior to developing a comprehensive watershed plan, the watershed's characteristics and natural resources should be listed. In order to adequately plan for the improvement of the resources in the watershed and to actually

quantify such improvements, it is crucial to establish a baseline of the general character and quality of the watershed. The first steps in watershed management planning are to:

- Inventory and map the natural and manmade drainage systems in the watershed
- Inventory and map the resources in the watershed
- Identify the quality of water resources in the watershed as a baseline
- Inventory and map land use, land cover and soil
- Outline and map the watershed's boundaries and the smaller drainage basins within the watershed
- Identify areas of erosion, including stream banks and construction sites
- Inventory and map pollution sources, both point sources (such as industrial discharge pipes) and nonpoint sources (such as municipal stormwater systems, failing septic systems, illicit discharges).

2. **Local partnerships:** The partners, or "stakeholders," in the watershed should also be identified and included in the planning process. The creation of local alliances may also result in increased public awareness and support. When people learn about and become interested in their watershed, they frequently get more active in both hands-on preservation and restoration work and decision-making. Such involvement promotes commitment to the measures required to achieve environmental goals, creates a sense of community, lessens conflicts and ultimately increases the possibility that the watershed management plan will be successful. Residents, landowners, federal, state, and municipal government representatives, watershed associations, environmental and community organisations, local business and industry leaders, agricultural users, developers, educators, and recreational users can all participate in local partnerships.

3. **Determine priorities for action:** Additionally, pollution reduction possibilities and other urgent environmental challenges should be prioritised in watershed management planning, along with an agenda for achieving pollution reduction and resource and habitat enhancements. The highest priority for control and reduction may be given to those problems that pose the biggest threat to human health, specific resources, or preferred uses of resources (such as bathing beaches). Clear objectives, visions and suggested courses of action should be outlined in watershed plans. There are many opportunities to reduce pollution and take care of other complex environmental challenges.

4. **Infrastructure improvements:** Following steps should be taken to enhance the quality and maintenance of watershed:

- Identifying resource and wildlife habitat restoration priorities.

- Reducing paved areas and other impermeable surfaces, particularly those near wetlands and water sources.
- Municipal stormwater systems should be maintained more frequently, and insufficient stormwater treatment systems should be improved or replaced. Illegal connections to municipal stormwater systems should also be found and removed.
- Locating suitable places for greenway planning, the construction of vegetated buffers alongside waterbodies, and the acquisition of open space.
- Establishing sewer avoidance areas to limit development.
- Identifying additional good housekeeping practises for landowners and homeowners, such as minimising lawn areas and the quantity of chemical fertilisers used in agricultural areas, advising washing cars on lawns rather than driveways so that rinse water can drain into the lawn rather than into storm drains, promoting the use of vegetated buffers next to waterbodies and wetlands, etc.
- Increasing inspections and maintenance of existing septic system and encouraging repairs to failing systems.
- Enhancing recycling, pollution prevention and waste management programmes at public buildings and commercial establishments within the watershed.
- Increasing and promoting public access and greenways and identifying areas where it is appropriate to do so.

5. **Educational programs:** The level of public education and involvement in the planning process can have a significant impact on how successfully a watershed is managed. Public involvement in and education on watershed management can be accomplished in a variety of ways. A successful, community-based, and locally managed endeavour requires the creation of citizen review groups and advisory committees, which can build support from the watershed's population. These community-based groups and committees can also provide the means to keep the project going once the plan has been finalized to make sure that recommended actions are taken. It might also be helpful to identify a watershed coordinator to help in this effort. Outreach and education efforts can include:
    1. Newsletters and other printed materials to provide status and progress reports.
    2. Organized storm drain stenciling projects.
    3. Periodic informational meetings
    4. Stream walk assessments
    5. Celebrate watershed clean-up days and riparian planting/habitat restoration days
    6. Coordination with school systems within the watershed.
    7. Promotional videos to enhance and restoration of watershed.

6. **Ensure implementation and follow-up:** It is important to establish a schedule with milestones and some sort of committee to ensure that projects proceed in a timely manner regarding the watershed management. It is also important to set up a monitoring programme so that data can be gathered to assess success. It's crucial to figure out how to support landowners in making the modifications they need, whether through low-interest loans or technical outreach. Last but not least, it is crucial to make sure that the suggestions made in the watershed plan, particularly the design criteria, are included into local land use legislation (zoning, subdivision, inland wetlands).

8.5 ROLE OF WATER IN NUTRIENTS CYCLING

The energy and matter are transferred between living and non-living elements of the environment through a system called the nutrient cycle. This happens as a result of soil nutrients being consumed by plants and animals, which are subsequently released back into the environment as a result of death, decaying and decomposition (Padalia et al. 2015). In forest ecosystems, there is an exchange of nutrient elements such as carbon, hydrogen, oxygen, nitrogen etc among the soil, plants and animals that inhabit within the environment.

The movement of essential components including carbon, nitrogen, phosphorus, and sulphur as well as their biogeochemical cycles is controlled by the water. These vital nutrients are carried by water as it flows through and across soils. A landscape absorbs water and many of the nutrients that are dissolved in the water are also absorbed simultaneously. The hydrologic cycle and the nutritional cycle therefore depend heavily on water as a connecting factor.

Ecosystems experience a directionally flowing flow of energy that enters as sunlight and exits as heat during the numerous transitions between trophic levels. However, the material that makes up living things is preserved and recycled. The six most frequent elements found in organic molecules are carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulphur. These elements can persist for extended periods of time in the atmosphere, on land, in water, or below the surface of the Earth in a variety of chemical forms. This material recycling is influenced by a number of geologic processes, including weathering, erosion, water drainage, and the subduction of continental plates. A biogeochemical cycle is the term used to describe the recycling of inorganic matter between living organisms and their environment. Geology and chemistry play significant roles in the study of this process.

All biological functions depend on hydrogen and oxygen, both of which are present in water. The hydrosphere is the region of the planet where water is moved around and stored in various forms, including as liquid on the surface and below it, frozen (in rivers, lakes, seas, groundwater, polar ice caps, and glaciers), and as water vapour in the atmosphere. All organic macromolecules contain carbon, which also plays a significant role in fossil fuels.

Our nucleic acids and proteins include a significant amount of nitrogen, which is also essential to human agriculture. One of the key components of artificial fertilisers used in agriculture and their accompanying environmental effects on our surface water is phosphorus, which, along with nitrogen, is a significant component of nucleic acid. The combustion of fossil fuels, such as coal, releases the sulphur into the atmosphere, which is necessary for the 3-D folding of proteins (such as in disulfide binding).

The cycling of these aforementioned elements is connected. For instance, the leaching of nitrogen and phosphate into rivers, lakes, and seas depends on the flow of water. The all life on Earth requires carbon to survive, the carbon cycle is, therefore, crucial for all life. There is proof that during volcanic eruptions, the element carbon is reintroduced to the atmosphere in order to balance carbon that has been buried due to sedimentation. Furthermore, the ocean itself serves as a significant carbon sink. Mineral nutrients are thus cycled, either quickly or slowly, between the biotic and abiotic worlds, from one living thing to the next.

The dynamics of an ecosystem depend greatly on water cycle. Water has a major influence on climate and thus on the environments of an ecosystems. A large amount of the Earth's water is locked in place in these reservoirs as ice, beneath the ground, and in the ocean, and, thus, is unavailable for short-term cycling (only surface water can evaporate). Many essential elements including carbon, nitrogen, phosphorus, and sulphur are frequently cycled from land to water through rainfall and surface runoff.

8.5.1 Role of water in carbon cycle

Carbon moves through the air, water, and soil in a complex manner that frequently happens much more slowly geologically than it does between living organisms. Long-term storage of carbon is known as carbon reservoirs which includes the atmosphere, liquid water bodies (primarily oceans), ocean sediment, soil, terrestrial sediments (containing fossil fuels), and the interior of the Earth. As previously discussed carbon dioxide in the atmosphere serves as a significant reservoir of carbon and is crucial to photosynthesis. The oceanic carbon reserve has a significant impact on the atmospheric carbon dioxide concentration. The amount of carbon present in each place is influenced by the interchange of carbon between the atmosphere and water reservoirs, and each one affects the other in a reciprocal manner. When atmospheric carbon dioxide (CO_2) is dissolved in water, it reacts with the water molecules to form carbonic acid, which subsequently ionises to form carbonate and bicarbonate ions.

The equilibrium coefficients are such that more than 90 percent of the carbon in the ocean is found as bicarbonate ions. Some of these ions interact with the calcium in saltwater to create calcium carbonate ($CaCO_3$), a crucial part of the shells of marine organisms. On the ocean floor, these organisms eventually create sediments. The greatest carbon store on Earth is limestone, which is created over the course of geologic time from calcium carbonate.

The decomposition of living organisms (by decomposers) or weathering of terrestrial rock and minerals both result in the storage of carbon in soil on land. Surface runoff may leach this carbon into the water storage reservoirs. Fossil fuels are the leftovers of anaerobically decomposing plants that took millions of years to develop and can be found deeper underground, on land, and in the ocean. Subduction (the movement of one tectonic plate beneath another) is a geological process that pulls carbon-rich sediments from the ocean floor deep inside the Earth.

8.5.2 Role of water in nitrogen cycle

It's challenging for nitrogen to enter the living world. Despite the fact that about 78% of the atmosphere is made up of this molecule (which is strongly bound, triple covalent N_2), plants and phytoplankton are not able to absorb nitrogen from the atmosphere. Free-living and symbiotic bacteria introduce nitrogen into the living world by nitrogen fixating it into their macromolecules (conversion of N_2). Most aquatic environments with sunshine support cyanobacteria, which are essential for nitrogen fixation. Cyanobacteria have the ability to "fix" nitrogen using inorganic sources. Legumes (including peas, beans, and peanuts) rely on rhizobium bacteria, which coexist symbiotically in their root nodules and supply them with the organic nitrogen they require. Azotobacter is one of many free-living bacteria that fix nitrogen.

There are two main methods that human activity can release nitrogen into the environment: burning fossil fuels, which produces various nitrogen oxides, and using artificial fertilisers in agriculture, which are subsequently washed into lakes, streams, and rivers through surface runoff. Numerous effects of atmospheric nitrogen on Earth's ecosystems are linked to it, including the formation of acid rain (as nitric acid, HNO_3) and greenhouse gases (as nitrous oxide, N_2O), which may contribute to climate change. Freshwater and saltwater eutrophication, a process where nutrient runoff causes the excess development of microorganisms, depletes dissolved oxygen levels, and kills ecosystem species, is one of the main effects of fertiliser runoff.

Similar activities take place in the marine nitrogen cycle, where marine microorganisms carry out the ammonification, nitrification and denitrification processes. Some of this nitrogen is lost to the ocean floor as sediment, which over the course of geologic time can be transported to land by uplift of the Earth's surface and then integrated into terrestrial rock.

8.5.3 Role of water in phosphorus cycle

A vital nutrient for the functions of living things is phosphorus. It is a crucial part of calcium phosphate, phospholipids, and nucleic acid. In aquatic environments, phosphorus is frequently the limiting nutrient (required for growth). In nature, phosphorus is found as the phosphate ion (PO_4^{3-}). In addition to phosphate runoff caused by human activity, phosphates can also be released into rivers, lakes, and the ocean naturally when they are weathered from phosphate-containing rock. This rock has its origins in the ocean. The bodies of ocean animals and their excretions are the main sources of phosphate-containing ocean sediments. Volcanic ash, aerosols and mineral dust, however, may potentially be important phosphate sources in isolated areas. As parts of the Earth's surface are raised during geologic time, this silt is subsequently transported to land. Additionally, marine ecosystems and phosphate that has been dissolved in the ocean exchange phosphorus reciprocally. Phosphate moves very slowly from the ocean to the land and via the soil, with the typical phosphate ion having an oceanic residence time of 20,000–100,000 years.

The excessive proliferation of microbes and the depletion of dissolved oxygen caused by excess phosphorus and nitrogen that enters these ecosystems from fertiliser runoff and sewage cause the mortality of numerous ecosystem species, including shellfish and fish. Dead zones in lakes and at the mouths of many significant rivers are the result of this phenomenon. A dead zone is a region of a freshwater or marine environment where substantial areas of the typical flora and fauna have been eliminated; these regions can be brought on by eutrophication, oil spills, the dumping of hazardous chemicals, and other human activities.

8.5.4 Role of water in sulphur cycle

For the macromolecules that make up living things, sulphur is a crucial component. It acts to help establish the 3-D folding patterns and consequently the functions of proteins by assisting in the creation of disulfide bonds inside proteins, which is a component of the amino acid cysteine. Sulphur dioxide (SO_2), the chemical form of atmospheric sulphur, is released into the atmosphere by three different processes: human combustion of fossil fuels, volcanic eruptions, and geothermal vents.

Precipitation, direct fallout from the sky, rock weathering, and geothermal vents are the four major processes through which sulphur is deposited on land. Sulphur is present in the environment as sulphur dioxide (SO_2) and dissolves as weak sulfuric acid as rain falls through the atmosphere (H_2SO_4). In a process known as fallout, sulphur can also fall directly from the atmosphere. Additionally, sulphur is released into the soil during the weathering of sulphur containing rocks. These rocks are made of ocean sediments that have been geologically elevated and transported to land. The sulphur from these soil sulphates ($SO4^-$) can then be used by terrestrial ecosystems, which release the sulphur back into the atmosphere as hydrogen sulphide (H_2S) gas once the organisms die and decompose. Through air fallout, oceanic geothermal vents, and runoff from the land, sulphur enters the ocean. Chemoautotrophs, which use sulphur as a source of biological energy, are important in several environments. The sulphates that result from this sulphur then sustain marine life.

The global sulphur cycle's balance has been significantly altered as a result of human activity. Large-scale fossil fuel combustion, particularly which derived from coal, results in greater atmospheric emissions of hydrogen sulphide gas. As rain falls through this gas, it creates the phenomenon known as acid rain. Acid rain is corrosive rain that harms aquatic habitats by converting rainfall into weak sulfuric acid as it falls to the ground through sulphur dioxide gas. Acid rain harms both the natural and built environments. It lowers the pH of lakes, which destroy a lot of the local fauna, and it causes buildings to deteriorate chemically. For instance, acid rain has over time caused considerable harm to numerous marble monuments. These illustrations highlight the extensive impacts of human activity on the ecosystem as well as the obstacles we still face today.

8.6 SUMMARY

The present topic provides an overview on forest hydrology, water discharge from watershed and role of water in nutrients cycling. Hydrology and forestry are two distinct fields that are combined in forest hydrology. The study of the available water of the Earth is known as hydrology. The study of hydrology aims to comprehend where and how water occurs, how and why water distribution varies over time, as well as its chemical and physical characteristics and relationship to living things. Different scales of hydrological processes are crucial for preserving landscape variability, biodiversity and the availability of fresh water for people and animals.

Forests help to maintain the ecosystem and have the direct impact on precipitation apportionment. Trees, whether they are found alone, in a tiny patch, or in a large stand of forest have an impact on the amount of precipitation that falls on the earth's surface by utilizing: Interception and a by effecting the flow of air over the surrounding area, as would any physical obstruction, and therefore the deposition pattern of rain and even more snow. Forest also serve as the multi-tasking water engineers, balancing blue and green water, managing for water-related forest ecosystem services, an atmospheric moisture pump, recycling of water, rainfall transects and seasonal rainfall.

This chapter also covers the brief description of watershed. A watershed is a region of land that drains or drains water into a particular receiving body of water, like a lake or river. Watershed discharge conveys information about how water interacts with human activities and natural processes on land. The climate, land use, geology, soil management, size and shapes of watershed, drainage network patterns etc are all linked to variations in discharge between watersheds.

In this chapter we also study about how water is necessary components in regulation the nutrient cycle in the ecosystem. The movement of essential components including carbon, nitrogen, phosphorus, and sulphur as well as their biogeochemical cycles is controlled by the water.

8.7 GLOSSARY

Afforestation: Artificial establishment of forest on lands, which previously not covered with forest vegetation.

Biomass: The amount of living matter expressed interms of weight per unit area or unit volume of water. It is a total mass of life in an ecosystem at any given time. It is an indicator of the productivity of the ecosystem.

Biotic factor: The influence exerted on a habitat by the plant and animal organisms that inhabit an area. Biotic influence includes grazing, tramping, manuring, predation, parasitism, migration and territorial behavior patterns of animals.

Canopy: The uppermost level of foliage formed by the branches and leaves of a tree.

Carbon dioxide (CO_2): A molecule made up of one carbon atom joined to two oxygen atoms. It is a major gas in the Earth's atmosphere. Also see greenhouse gases.

Conservation: Protection of plant and animal habitat including the management of renewable natural resource with the objective of sustaining its productivity in perpetuity while providing for human use compatible with sustainability of the resource.

Crown: The top of a tree or group of trees. The leaves and living branches of a tree.

Deforestation: Clearing of forested areas. Also see clearing, reforestation.

Density: Mass of wood per unit volume.

Ecosystem: Any biological community and its non-living environment, including all the plants and animals in an area together with the air, land and water with which they interact.

Fire: The active principle of burning or combustion.

Forest: An area of land greater than 0.5ha in size, with trees higher than 2 metres and a canopy cover of more than 20 percent; or where trees will mature to these thresholds.

Habitat: The native environment where an animal or plant naturally lives or grows.

Land use conservation: The process of changing the current use of a piece of land into other use(s).

Natural resource: These are materials that are obtained from the earth for use by man. For example minerals and forests.

Nutrient cycle: The exchange or transformation of elements among the living (organic and biotic) and nonliving (inorganic and abiotic) components of an ecosystem

Rainforest: Type of forest that grows in higher rainfall regions and in fertile soils. There are both tropical and temperate rainforest in Australia and tend to be protected from harvesting.
Reforestation: Replanting of a forest on cleared, degraded or destroyed forest areas.
Resource: Material required or needed, where stock that can be drawn on. Anything for which there is a perceived present or future use. Can be either renewable or non-renewable.
Runoff: The proportion of rain falling in a catchment which flows across the surface rather than infiltrating the soil. A major cause of soil erosion by water.
Soil erosion: Detachment and movement of soil materials, by the action of wind or running water, brought about by natural process or human activity.
Subtropical: A type of rainforest occurring between the tropics and temperate geographic regions; found between tropic and temperate conditions.
Sustainable use: The use of components of biological diversity in a way and at a rate that does not lead to a long-term decline of biological diversity, thereby maintaining its potential
Tree: Perennial plant having a self-supporting woody trunk that develops woody branches.
Watershed: A watershed is a region of land that drains or drains water into a particular receiving body of water, like a lake or river.
Wood: The hard, fibrous inner part of tree trunks, branches and stems. Tissue that lies underneath the bark of a plant. A source of timber.

8.8 SELF ASSESSMENT QUESTIONS

8.8.1 Multiple choice questions

1. When precipitation comes down to the earth in liquid form, it is called:
   (a). Cloud (b). Rain
   (c). Snow (d). Water vapour
2. What is considered as lungs of nature?
   (a). Rock (b). Tree
   (c). Water (d). All of the above
3. How erosion controlled by forest?
   (a). By reducing the rainfalls force on the soil surface
   (b). By reducing the sunlight penetration
   (c). By reducing the atmospheric pressure
   (d). None of the above
4. How forests increase the atmospheric humidity?
   (a). By transpiration (b). By reduction
   (c). By oxidation (d). All of the above
5. What is drainage coefficient?
   (a). Depth of water (cm) to be drained in 24 hrs period from the entire drainage area.
   (b). It is the drainage capacity of a canal.

(c). Drainage of water from a water body within 12 hours.
(d). Drainage of water from a crop field before the symptoms of wilting appear in plants.

6. Objective of watershed development programme are:
(a). To mitigate the adverse effects of drought on crops and livestock.
(b). To encourage restoration of ecological balance.
(c). To promote economic development of village community.
(d). All of the above.
7. Which of the following is the most essential component of the ecosystem
(a). Fish (b). Sea
(c). Money (d). Water
8. Tree are:
(a). Water engineers (b). Balancing blue and green water
(c). Recycling the nutrients (d). All of the above
9. Which of the following nutrient(s) is recycled by the water:
(a). Carbon (b). Nitrogen
(c). Phosphorus (d). All of the above
10. What is seepage?
(a). Horizontal flow of water in water channel.
(b). Vertical flow of water in water channel.
(c). Zigzag flow of water in water channel.
(d). None of the above.

8.8.2 True and False

1. The study of the available water of the Earth is known as hydrology.
2. Forests have no effect on water regime of a region.
3. Trees, only in a large stand of forest have the impact on the amount of precipitation.
4. Forests were described in older literature as "sponges", emphasizing the water absorption and buffering capacity of their roots, crown and soil, balancing river flows and controlling floods.
5. A watershed with a larger area likely to received a less amount of rainfall, therefore a greater amount of runoff from the watershed.
6. The climate of an area's is influenced by its topography, elevation, latitude, vegetation cover and proximity to the ocean or other major water bodies.
7. Watersheds can range in size from large to tiny.
8. All organic macromolecules contain carbon plays a significant role in fossil fuels.
9. The movement of essential components including carbon, nitrogen, phosphorus, and sulphur as well as their biogeochemical cycles has no impact of water.
10. Volcanic ash, aerosols and mineral dust, however, may potentially be important phosphate sources in isolated areas.

8.8.3 Fill in the blanks

1. Hydrology and forestry are two distinct fields that are combined in forest _______.
2. _______ have higher evapotranspiration rate than other types of vegetation.
3. Avoiding _______ is crucial, especially in areas vulnerable to erosion.
4. _______ refers to precipitation that comes from terrestrial sources and adds to local precipitation.
5. The monsoon climate alternates between two phases: _______.
6. A _______ is a region of land that drains or drains water into a particular receiving body of water, like a lake or river.
7. The energy and matter are transferred between living and non-living elements of the environment through a system called the _______.
8. Ecosystems experience a directionally flowing flow of energy that enters as _______ and exits as heat during the numerous transitions between trophic levels.
9. _______ is the basic component of our nucleic acids and proteins and also is key components of artificial fertilisers used.
10. Long-term storage of carbon is known as _______.

Answer Key:

8.8.1: 1. (b); 2. (b); 3. (a); 4. (a); 5. (a); 6. (d); 7. (d); 8. (d); 9. (d); 10. (a).
8.8.2: 1. True; 2. False; 3. False; 4. True; 5. False; 6. True; 7. True; 8. True; 9. False; 10. True
8.2.3: 1. Hydrology; 2. Trees; 3. Deforestation; 4. Recyclable precipitation; 5. Wet and dry; 6. Watershed; 7. Nutrient cycle; 8. Sunlight; 9. Nitrogen; 10. Carbon reservoirs

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8.11 TERMINAL QUESTIONS

8.11.1 Short answer type questions

1. Briefly describe the importance of watershed management.
2. Describe the role of water in nitrogen cycle.
3. Justify the statement that "trees as multi-tasking water engineers".
4. Write a short note on:
    a. Stream water
    b. Stormwater
    c. Sewage water
    d. Municipal wastewater

8.11.2 Long answer type questions

1. Write a detail note on the impact of forest on precipitation apportionment.
2. What do you understand by watersheds? Discuss the different methods of drainage of water from watersheds.
3. Discuss the variables that influence a watershed.
4. Describe the role of water in nutrients cycling.

BLOCK-3- SUCCESSION,
GLOBAL CLIMATE CHANGE

UNIT-9- SUCCESSION

Contents:

9.1 OBJECTIVES

After reading this unit the learners will be able to:

- Understand the types of Ecological Succession
- Understand Mechanism/Models of Ecological Succession
- Understand Structural and Functional changes during Succession

9.2 INTRODUCTION

All ecosystems change in structure and function with time. Some changes are seasonal, e.g., rise or fall of a river and its effects on vegetation adjacent floodplain, seasonal growth and disappearance of plants in a forest, effects of stratification and mixing of water on plants in lakes and so on. Some other changes are long-term, progressive and non-cyclical which may result in a process "**Ecological Succession**." It is a fundamental concept in ecology and refers to orderly and predictable changes in the community structure and function with time.

Environment is always changing with time by variations in climatic, physiographic factors or by interactions with existing species in an area. Each species in ecosystem has set of environmental conditions for its optimal growth and reproduction. As long as these conditions remain favorable, the particular species flourish in the environment. As the environmental conditions changes, they become optimal for other species and subsequently, first species may fail to flourish. In this way, a given community of organisms in an area is not permanently stable over time; rather it keeps on given community of organisms in an area is not permanently stable over time; rather it keeps on changing with the replacement of one community with another. The process of change continues keeps on increasing in number by reproduction. All these changes are very orderly and predictable with time; the overall process is named as ecological succession. Thus, Ecological Succession may be defined as "**the orderly changes in community structure and function in an ecosystem with time mediated through the modifications in physical environment ultimately leading to a stable community over that area.**" Cowles (1899), Clements (1905, 1916) and many other early twentieth century botanists made significant contributions to establish the concept of succession.

Clements (1916) while studying plant communities defined succession as "*the natural process by which the same locality becomes successively colonized by different groups or communities of plants.*" As the process of succession proceeds, changes occur not only in the biotic community but also in physical environment and overall characteristics of the ecosystems changes in a holistic manner. Therefore, Odum (1969) preferred to designate the term as "**Ecosystem Development**" rather than ecological succession and elaborated the process of ecological succession in terms of the following parameters:

1. It is an orderly process of changes in species structure and function with time within a community. It is a directional and continuous process and thus, predictable.
2. It is a natural process and results from modifications in physical environment by the community species. These modifications may be brought by continuing struggle among species for physical factors (light and space) and resources for survival (energy and nutrients). Thus, the succession is a community controlled process even though the modifications in physical environment determine the patterns, rate of changes and development during the process.
3. It involves either change in abundance of dominant species or a complete replacement of species from immature to more mature and stable communities over a period of time.
4. It culminates in a stable ecosystem with a dominant species known as **climax** which is in more or less equilibrium with the surrounding environment.
5. The entire sequence of communities that replace one another in a given area is called as **sere** and the transitory communities are called as **seral stages** such as grass stage, herb sage, shrub stage, etc. The initial stage is called **pioneer** stage and is characterized by early successional pioneer plant community. The last or terminal stage is known as **climax**. The pioneer community may be replaced more easily by the next seral stage where as climax community is considered as more mature and stabilized stage of ecosystem.

Succession is a series of complex processes. There are three main causes of succession:

a) **Initiating causes:** these are climatic as well as biotic factors. The former includes landslide, volcanic activity, wind, soil erosion, etc. and the latter includes various activities of organisms. The process of ecological succession is usually initiated by the formation of a bare area or habitat without any life form (e.g. by a landslide or lava flow) or formed from disturbance of an existing community (e.g. fires or land clearance).

b) **Ecesis or continuing causes:** these involve different processes like dispersal, migration, establishment, aggregation, competition, co-action, reaction, etc. which keep the pace of changes in community structure.

c) **Stabilizing causes:** According to Clements, climate is usually considered as one of the significant factor that causes stabilization of ecosystem.

9.3 TYPES OF SUCCESSION

Various types of succession have been grouped differently on the basis of different aspects as below:

Primary and Secondary Succession: On the basis of nutrient availability in the soil, succession is of two types: Primary and Secondary succession. Primary Succession starts in a newly formed area where environmental conditions are elementary, such as a bare area formed by lava flow, a new pond created by a landslide, sand dunes formation or bare rock surface formed by the retreating glaciers. The primary area contains no biological legacy, i.e., no vegetation, seed bank or organic matter. The area is not initially occupied by any community and the seeds or propagules for the first organism should arrive by immigration. For example, xerarch succession, beginning on a bare and dry land, imply a directional development from first stage “lichen” towards a mature and stable ecosystem, usually a “forest”. Another example is formation of island from volcanic activity in ocean with pioneer species like bacteria, fungi and moss and followed by grasses, shrubs and trees in later stages (Fig 9.1)

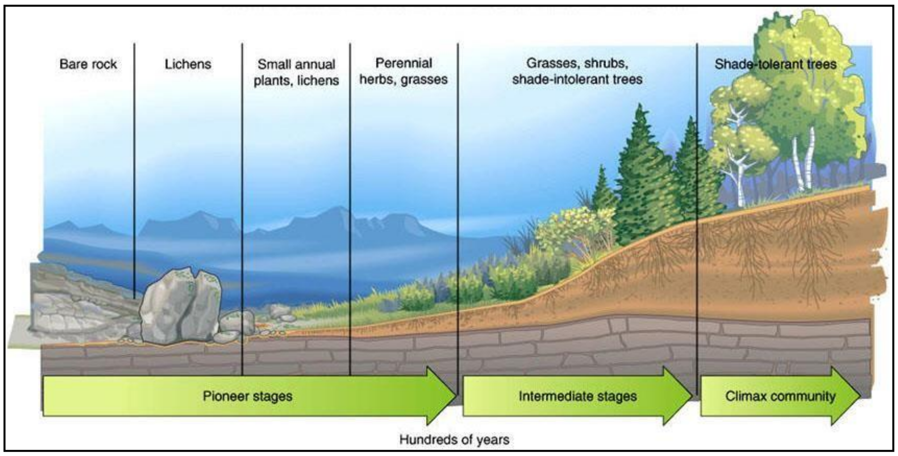

Fig. 9.1: Primary Succession (Source: http://www.sciencescene.com/Environmental%20Science/02TheEnvironment&Ecosystems/02-Application.htm

Secondary succession starts in an area previously occupied by a community, but now devegetated by some natural or human activities like fire, storms, tree cutting, disease outbreak, cultivation, biotic interventions, etc. After several years, some new community again occupies that area. It is called secondary succession (Fig. 9.2). The area is not having living matter above ground, but its substratum is built up with the nutrients, organic matter or propagules deposited by previously occupied community. Thus, the process of secondary succession is comparatively rapid than primary succession.

Autogenic and Allogenic Succession

After the succession has begun, sometimes the community itself modifies its own environment which becomes unsuitable for that community, and its own replacement by new community takes place. This type of succession is known as autogenic succession, as it is self-made succession. In some cases, the replacement of existing community takes place due to some external force (e.g., fire or human activities) and not by the existing community. This is called as allogenic succession.

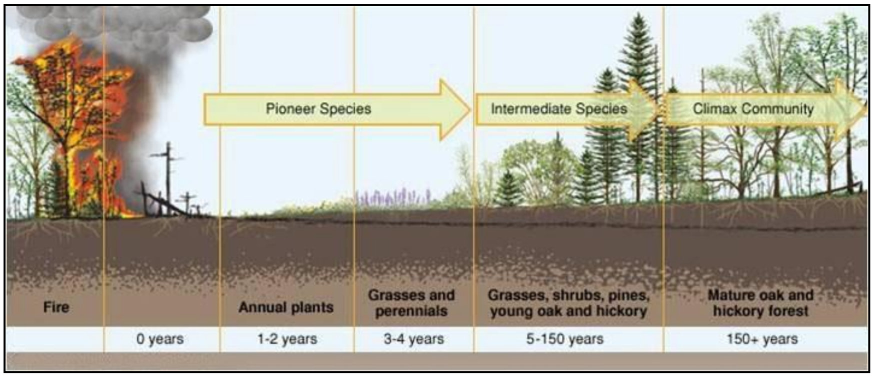

Figure 9.2: Secondary Succession (Source: http://www.sciencescene.com/Environmental%20Science/02TheEnvironment&Ecosystems/02-Application.htm)

Autotrophic and Heterotrophic Succession

On the basis of successive changes in nutritional and energy requirements, succession is classified as autotrophic and heterotrophic succession. **Autotrophic succession** is characterized by the dominance of green plants and trees. It starts in a predominantly inorganic environment and energy flow is maintained indefinitely followed by increase in the organic matter content in the ecosystem. In this type of succession, rate of production (P) is more than rate of respiration (R)**.** Initially primary producers are in majority but later on biomass of organisms increases and ratio of production and respiration remains one. The diversity of species increases with increase in organic matter content. In **heterotrophic succession**, heterotrophs dominate such as bacteria, actinomycetes, fungi and other consumers. It starts in a predominantly organic environment followed by progressive decline in energy content of ecosystem. Initially the rate of respiration is greater than production**.** For example, small areas of rivers and streams, which receives large amount of sewage or leaf litter.

Therefore, if the succession begins with P>R, it is autotrophic succession and if it starts with P<R, it is heterotrophic succession.

Hydrarch and Xerarch Succession

Depending upon the nature of environment where the process begins, the succession is hydrarch or hydrosere if it starts in substratum where water is in plenty, e.g., in ponds, lakes, streams, swamps, etc. It is xerarch or xerosere, if it begins in dry areas such as deserts, rocks, etc. Xerarch is sometimes classified in further groups - **the lithosere:** initiating in rocks, **psammosere:** on sand, and **halosere**: in saline soil. The succession starting in an area with moderate moisture conditions is called as **mesarch.**

9.4 MECHANISM/MODELS OF ECOLOGICAL SUCCESSION

Clements Hypothesis

Clements, being the most influential ecologists to suggest the mechanism of succession, in *Plant Succession: An Analysis of the Development of Vegetation* (1916), stated the succession a universal process of community development. He believed firmly that climate was the main genomes, and vegetation is like an organism whose characteristics its genome determines. The final driving factor in determining the type of vegetation during succession. As per his philosophy, driving factor in determining the type of vegetation during succession. As per his philosophy, climates are like step in vegetation succession he referred to as a climax. Another major point in Clements hypothesis is that the entire vegetation develops together as a single unit like an organism. This is known as the **super-organism theory.** He considered climax community to be a super-organism and succession the embryonic development of that organism. As an organism, climax arises, grows, matures and dies. The climax is capable of reproducing itself and every time a climax is produced, the essential steps are similar. Thus, succession is orderly, predictable and developmental process. It represents the holistic view.
He recognized the following basic processes in succession (Fig. 9.3):

1. Nudation: It is the formation of a bare area without any life form. It may be a primary bare area if it is a new geological formation or a secondary bare area if formed due to destruction of existing vegetation. It may occur due to topographic factors (soil erosion, landslide, volcanic activity etc.), climatic factors (glacier, drought, frost, fire etc.) or biotic factors (deforestation, cultivation, insect outbreak, agricultural practices, overgrazing, etc.).

2. Invasion: It is invasion and successive establishment of species in the bare area. It has three stages: a) Migration: In primary bare area, the seeds, spores or propagules of plants growing in adjacent areas arrive through dispersal by wind, water or animals. In secondary bare area, the propagules may already be present in the form of buried seeds or rootstocks - called as residuals. They are the pioneer stage of succession. b) Ecesis - It is the process of successful establishment of the species as a result of their adaptation to new area. The seeds and spores germinate, grow into adult forms and then reproduce. c) Aggregation - It is the final maturation of colonizing species; that is the growth of the population of each individual species. As the species reproduce, their number increases and population grow denser.

3. Competition and Co-action: As the species number and size increase, it leads to competition for water, space and food. There can be inter-specific or intra-specific competition. The species which do not succeed in competition will disappear and the species which succeed will establish in that area. The species interact and affect each other’s life in various ways called co-actions.

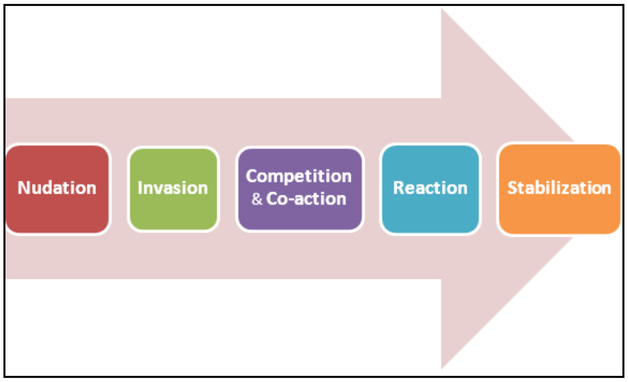

Fig. 19.3: Different processes of Ecological Succession

4. Reaction: It is an important stage of succession and occurs between colonizing species and surrounding environment. The action of colonizing species changes the surrounding abiotic environment like soil, water, temperature and availability of nutrients. These changes make the place unfit for existing species and as a result they are replaced by a fit species.

For example, in a marshy area, reed swamp stage occur which includes amphibious plants with high evapo-transpiration rates. As a result, water availability in the area reduces and it will eventually become dry, thus becomes unsuitable for the existing plants. So, these autogenic changes by the plant species make them disappear and a new species which can grow in dry area will appear. This is termed as reaction of surrounding environment. As a result, various communities form different seral stages. Each stage has its characteristic structure and species composition. A seral stage may last for 1 to 2 years or several decades.

5. Stabilization or Climax: Eventually, a stage is reached when the final plant community becomes more or less stabilized for a longer period of time and maintains equilibrium with the surrounding environment. It is more mature, stable, self-maintaining and self-reproducing through development stages. Further, it is characterized by more or less equilibrium between gross primary production and total respiration, the energy captured from sunlight and energy released by decomposition, the uptake of nutrients and the return of nutrients by decomposition. This final stable community of the sere is the climax community. General process of succession with different developmental stages, viz., pioneer, seral and climax communities under the influence of physical environment, taking the examples of hydrosere and xerosere are shown in Fig. 9.4.

The concept developed due to Clements' work is termed as "Relay Floristics" (Egler, 1954). Species prepare area to make it more suitable for other species. As Clements indicated, if plant communities are super-organisms, they are capable of having a "strategy" as they hand over the site to the next community till a climax community is established. This is similar to a relay race where the runner at start of the race hands over the baton to next runner after covering a certain distance and so on till the final destination is reached.

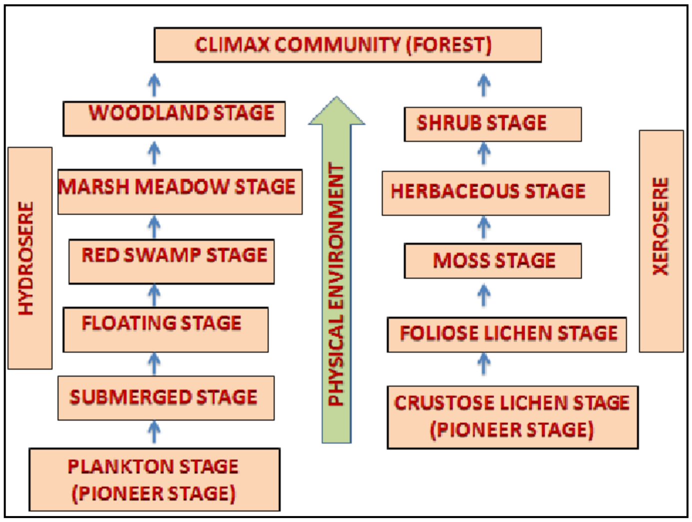

Fig. 9.4: Diagram to show process of succession with pioneer, seral and climax communities under the influence of physical environment, taking the examples of hydrosere and xerosere.

Initial Floristic Model

Egler (1954) proposed 'Initial Floristics' concept by holding the view that most species are present right from the beginning of succession as seedlings or seeds (called as initial floristic pool), and succession merely represents changes in dominance over time. The groups of species grow and die depending upon their variable growth rates. The species dominating at climax stage can be present from the initial stages of succession; they may grow slowly and dominate the site later, replacing the earlier fast growing species.

Further, Drury and Nisbet (1973) stated that many species which characterize later successional stages are present but unremarkable at earlier stages. According to them, to begin with there are short-lived plants with high relative growth rate, then, herbaceous perennials with rapidly growing short-lived trees, followed by slowly growing long-lived trees. They viewed succession as a resource gradient process in which each species requires an optimum set of resources for growth or reproduction, and as the resource availability changes through time, species replacement occurs. This model holds true only for the secondary succession and not for primary succession.

Connell and Slatyer's Models: Three different models of ecological succession were proposed by Connell and Slatyer (1977) (Table 9.1).

Facilitation Model: The facilitation model suggests that the disturbed area is first exploited by certain pioneer species that are most capable of invading and establishing on the site. These initial species
modify the site, making it more suitable for invasion by other species, for example, by adding

nutrients to the soil. Thus the early species 'facilitate' colonization by later species. Once established, the later species eliminate the early species through competition. These ecological dynamics proceed through different stages in which earlier species are eliminated by later species, until the climax stage is reached and there is no longer net change in the community.

Table 9.1: Three different models of ecological succession proposed by Connell and Slatyer (1977) – 1) Facilitation Model 2) Tolerance Model 3) Inhibition Model.

A disturbance develops a relatively large bare area		
Facilitation Model	**Tolerance Model**	**Inhibition Model**
Only certain "Pioneer species" are capable of becoming established in the bare area.	Individuals of any species in the succession could establish and exist as adults under the prevailing conditions.	Individuals of any species in the succession could establish and exist as adults under the prevailing conditions.
Modification of the environment by the early species in terms of availability of water, nutrients, etc. makes it more suitable for the arrival of later species. These early species 'facilitate' colonization by later species.	Modification of environment by the early species has little or no effect on the arrival and growth of later successional species.	Modification of the environment by the early species makes it less suitable for both existing species as well as arrival of later species.
Early species are eliminated through competition for resources with established later species.	Species sequence is solely a function of life history. The later species can invade and grow to maturity regardless of the presence of early species. With passage of time, the early species will be excluded.	As long as early species persist undamaged or continue to regenerate, they exclude or suppress subsequent colonists of all species.
The sequence continues until the current resident species no longer facilitates the invasion and growth of other species. This final stage is climax community.	Juveniles of species dominating at climax can be present from the earliest stages of succession.	If external stresses are present, early colonists may be damaged (or killed) and replaced by species which are more resistant.
This model follows Clement's hypothesis described earlier.	The sequence continues until no species is there that can invade and grow in presence of the residents.	The model assumes that later successional species come to domi- nate the area simply because they live a long time and resist damage by physical and biological factors.

Tolerance Model: The tolerance model suggests that sequence of species in succession is solely a function of life history. The later species can invade and grow to maturity despite the presence of early species. With passage of time, the early species will be excluded. Modification of environment by the early species has little or no effect on the arrival and growth of later successional species.

Inhibition Model: The inhibition model suggests that as long as early species persist undamaged or continue to regenerate, they exclude or suppress subsequent colonists of all species. Modification of the environment by the early species makes it less suitable for both existing species as well as arrival of later species. If external stresses are present, early colonists may be damaged (or killed) and replaced by species which are more resistant. For example, some plants are known to secrete toxic biochemicals into soil (allelochemicals), which inhibit the establishment and growth of other species. Eventually when the inhibitory species die, the later successional species can then establish in the area. These gradual changes eventually culminate in development of climax community. Studies indicate that all of three models may be correct but applicable in different situations.

Individualistic concept: According to Individualistic Concept given by Gleason (1926), the succession is an extraordinary mobile process whose processes are not fixed and do not occur in a definite predictable ways. Moreover, it occurs due to individual response of different species. All communities are unique and ever changing due to internal species variations occurring as a result of disturbances, competition or new arrivals. Therefore, succession is considered as a multidirectional process with different pathways and endpoints.

Three-Plant Strategy model: Grime (1979) recognized three categories of plants: ruderals - these species are fast growing, rapidly complete their life cycles, and produce large amounts of seeds, competitors - these species are able to outcompete other plants by efficiently tapping into available resources, and stress tolerant - these species are tolerant to shortages of resources (stress). According to his theory, ruderals form early sucessional stage and competitive species dominate later stages in succession. A superior competitor is capable of capturing all the resources, e.g. light as well as nutrients, at the same time more efficiently than its neighbours. The rapid growth of strong competitors translates into a rapid development of absorptive surface area which enables them to pre-empt both above and below ground resources. Stress tolerant species are not efficient in resource capture. Grime expanded his theory to describe secondary succession. At the onset, ruderals are established in a disturbed site. Then after, in a favourable environment, with potential for high productivity, competitive species play an important role and result in successive species changes. When conditions are stressful, (nutrient poor soil or climate change), competitive species play less important role and species changes are less. Stress tolerant species replace competitive species as stress increases.

Vital Attribute Model: According to Noble and Slatyer (1980), vital attributes are those attributes of a species which are vital to its role in a vegetation replacement sequence. These are: 1) the method of arrival or persistence of the species at the site during and after a disturbance 2) the ability to establish and grow to maturity in the developing community 3) the time taken for the species to reach critical life stages.

More than one biological mechanism or phenomenon may be responsible for a particular vital attribute displayed by a species, and for a given vital attribute the biological mechanisms may differ from species to species. The vital attribute reflects only the outcome of these mechanisms. These three attributes in turn can be related to (a) duration of their dormancy in the seed bank b) their age at first fruiting and c) their longevity as adults.

Resource Ratio Hypothesis of Competition: This model was proposed by Tilman (1985). According to him, inter-specific competition for resources and patterns of long-term supply of limiting resources are the key factors for plant establishment and growth in an area. Limiting resources give rise to competition among species and a resource ratio level is set, new species adapted to it succeeds. It suggests that if multiple species are competing for a single limiting resource, then species that can survive at the lowest equilibrium resource ratio level outcompete all other species. If two species are competing for two resources, then coexistence is possible only if each species has a lower resource ratio level on one of the resources. For example, two phytoplankton species may be able to coexist if one is more limited by nitrogen, and the other is more limited by phosphorus.

Generally, the major limiting resources for terrestrial habitats are soil nutrient - nitrogen and light. These resources are naturally inversely related, the habitats with poor nitrogen soils have high light availability and the habitats with nitrogen rich soils have low light availability. The life history of a plant should depend on the point along the nitrogen concentration: light gradient at which the plant is a superior competitor. To elaborate, when succession begins on a nitrogen poor soil, the species that has lowest nitrogen requirement may outcompete other species with high nitrogen requirements. As succession proceeds the soil may become rich in nitrogen, but light at the soil surface becomes limiting with increasing plant biomass. Thus, the early successional species which are superior competitors for nitrogen should be inferior competitor for light, while the later successional species would be superior competitor for light and inferior competitor for nitrogen. Because of trade-off, a good competitor for nutrients cannot be a good competitor for light, as they require contrasting traits – more biomass allocation to roots for more nutrient capture, and more allocation to shoots for light capture. This is the directional change in supply of limiting resources that result in directional replacement of one species by the other.
Tilman’s model reflects that succession is tightly linked with interactions between plants. It is a complex process, and therefore cannot be described with one model for all situations and locations.

9.5 STRUCTURAL AND FUNCTIONAL CHANGES DURING SUCCESSION

Odum and Pinkerton (1955) were the first to mention the functional shift of energy during the process of succession in addition to the changes in species structure and composition. Margalef (1968) documented this bioenergetic basis of succession and extended the concept. Odum (1969) has given the list of major structural and functional changes that are expected to occur during succession (Table 19.2). Twenty four different characteristics of ecological systems were analysed by autogenic contrasting the situation in early and later stages. The degree of absolute change, the rate of change, and time required to reach a mature and steady stage vary not only with different climatic and physiographic conditions but also with different attributes of ecosystem in the same physical environment. Further, the effect of external disturbances, as the case of allogenic succession, may change the trend of development.

The functional changes include variations of energy flow and nutrient cycling with time. As depicted from the table 19.2, in the early stages of autotrophic succession, the rate of primary production or gross photosynthesis (P) exceeds the rate of community respiration (R), so that the P/R ratio is greater than 1. Whereas in case of heterotrophic succession, e.g., a sewage pond with organic matter load where the bacteria and other heterotrophs are first to colonize, the P/R ratio is typically less than 1. In both cases, however, the P/R ratio approaches 1 as succession proceeds. The P/R ratio is a functional index of the relative maturity of the system. The energy fixed by the producers tends to be balanced by the energy consumption during maintenance (i.e., total respiration) in the mature or climax ecosystem.

So long as P exceeds R, organic matter and biomass (B) will accumulate in the system. As a result, the P/B ratio will tend to decrease or, the B/P or B/R ratio will increase. In such cases, the amount of standing crop biomass supported by the available energy flow increases to a maximum in the mature or climax stages. As a consequence, the net community production is more in young stages and small or zero in mature stages in an annual cycle.

The structural changes during progression of ecological succession mainly include changes in species composition and species diversity. Odum (1969, 1971) put forth the concept of ecosystem strategy. According to this concept, ecosystems tend to be in a state of homeostasis under the influence of unfavorable external environment. In an autotrophic succession, species diversity tends to increase, with an increase in organic matter content and biomass supported by available energy.

Therefore, in a climax community, the available energy and biomass increases. But in a heterotrophic succession, rates of respiration always exceed production, so there is a gradual decline of energy. In nature, both these types of succession are going hand in hand. The autotrophic ones take nutrients from the soil, water and air, whereas the heterotrophic ones return them back to soil, water or air through decomposition of complex dead organic matter. Thus, succession reaches a stage where the amount of energy and nutrients taken by the producers from surrounding environment is returned in more or less similar amount to the environment by decomposition. This stage may be a climax stage. E.P. Odum has described this stage as a strategy of increased control of the physical environment toward achieving a homeostasis which provides maximum protection from environmental disturbances.

Table 9.2: Different structural and functional changes occurring in an autogenic succession
(Source: Odum and Barrett (2005). Fundamentals of Ecology. Cengage Learning, New Delhi)

Ecosystem Characteristics	**Trend in ecosystem development** **Early Stages → Later Stages** **Youth → Maturity**
Energy Flow	
Gross Production (P)	Increases during early phase of primary succession; little or no increase during secondary succession
Net Community Production (yield)	Decreases
Community Respiration (R)	Increases
P/R ratio	P>R to P =R
P/B ratio	Decreases
B/P and B/R ratios (biomass supported per unit energy)	Increase
Food Chains	From linear food chains to complex food webs
Community structure	
Species Composition	Changes rapidly at first, then more gradually
Size of individuals	Tends to increase
Species diversity	Increases initially, then stabilizes or declines in older stages as size of individuals increases
Total Biomass (B)	Increases
Nonliving organic matter	Increases
Biogeochemical cycles	
Mineral Cycles	Become more closed
Turnover time and storage of essential elements	Increases
Internal cycling	Increases
Nutrient conservation	Increases
Natural Selection and Regulation	
Growth form	From r-selection (rapid growth) to K-selection (feedback control)
Life cycles	Increasing specialization, length and complexity
Symbiosis (Living together)	Increasing mutualism
Entropy	Decreases
Information	Increases
Overall efficiency of energy and nutrient use	Increases
Resilience	Decreases
Resistance	Increases

9.6 SUMMARY

- Ecological Succession is an orderly process of changes in community structure and function n an ecosystem with time mediated through the modifications in physical environment ultimately leading to a stable community over that area.
- It is a directional, continuous process and predictable.
- Succession is a series of complex processes. There are three main causes of succession: initiating causes (climatic and biotic factors), ecesis or continuing causes (dispersal, migration, establishment, aggregation, competition, etc.), and stabilizing causes (climate).
- On the basis of nutrient availability in the soil, succession is of two types: Primary and Secondary succession. Primary Succession starts in a newly formed area not initially occupied by any community. Secondary succession starts in an area previously occupied by a community, but devegetated by some natural or human activities.
- Autogenic succession is self-created succession, while allogenic succession takes place due to external forces.
- Autotrophic succession is characterized by the dominance of green plants and trees. In heterotrophic succession, heterotrophs dominate such as bacteria, actinomycetes, fungi and other consumers. Therefore, if the succession begins with P>R, it is autotrophic succession and if it starts with P<R, it is heterotrphic succession.
- Clements recognized five basic processes in succession – Nudation: formation of a bare area without any life form, Invasion: successful establishment of species in a bare area, Competition: competition among species for water, space and food, results in disappearance of failure species, Reaction: modifications in surrounding abiotic environment by the species, leading to a number of seral communities, and Stabilization; Eventually a stage is reached when the final plant community becomes more or less stabilized for a longer period of time in the equilibrium with the environment of that area.
- Different botanists and ecologists have given different models to describe various factors responsible for the continuity of succession like climate, species characteristics, species interactions, etc.
  Not only species composition and diversity varies with time during succession, functional changes including energy flow also takes place.

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UNIT-10 MAJOR FOREST TYPES OF INDIA

Content

10.1 OBJECTIVES

After reading this unit students will be able -

- To understand classification of Forest of India
- To know about Forest of Himalaya particularly Sal forests, Pine forests and Oak forests

10.2 INTRODUCTION

Forest refers to plant life that grows naturally and without human intervention. The word "forest" is derived from the Latin word "foris," which means "outside" and must have included all uncultivated and uninhabited land. It is a large tract of land covered with trees. A forest is a complex ecosystem composed primarily of trees, shrubs, and, in general, a closed canopy. They serve as a repository for a wide range of flora and fauna. They are also the home to a large number of microorganisms and fungi, both of which are essential for the decomposition cycle that enriches the soil. Forests cover nearly 30% of the total land surface of the Earth. The percentage corresponds to approximately 4 billion hectares of forest cover. The forest is a major natural resource that plays an important role in maintaining environmental balance. At present, a forest is any land managed for forestry purposes, whether it is covered with trees, shrubs, climbers, or other plants. In simple terms, a forest is a plant community dominated by trees and other vegetation, usually with a closed canopy.

India has a diverse range of edaphic, climatic, and physiographic conditions, which has resulted in a large diversity of flora and fauna. The country's forests range from tropical evergreen forests in the Andaman and Nicobar Islands to dry alpine scrub high in the Himalayas. The country has semi-evergreen forests, moist deciduous forests, thorn forests, subtropical pine forests in the lower mountain zone, and temperate montane forests in between the two extremes.

The Indian Forest Act, 1927 does not define the forests, and the legal extent of forests depends upon the process of notifications. The definition of a forest given in Indian Forest Record (new series), Vol. 2(1) published in 1936 reads as "an area set aside for the production of timber and other forest produces or maintained under woody vegetation for certain indirect benefits which it provides, e.g. climatic or protective." Hon. Supreme Court of India has taken a view regarding extending preview of the Forest Conservation Act, 1980 to all the areas falling in the "dictionary meaning" of forests irrespective of ownership and control.

Forests are classified based on their nature and composition, the type of climate in which they thrive, and their relationship to their surroundings. The India's forests which are currently governed by The National Forest Policy, 1988, has a focus on environmental balance and basic needs.

According to the India State of Forest Report, 2021, the total forest and tree cover of India is 8,09,537 sq km, which is 24.62 percent of the country's geographical area. The term 'forest area' refers to the legal status of the land as recorded by the government, whereas the term 'forest cover' refers to the presence of trees on any land. In comparison to the 2019 assessment, the total forest and tree cover of the country has increased by 2261 square kilometres. The increase in forest cover is 1540 sq km, and the increase in tree cover is 721 sq km.

Madhya Pradesh has the largest forest area of any Indian state, followed by Arunachal Pradesh, Chhattisgarh, and Odisha.

Forest Cover of India		**(in sq km)**
Class	**Area**	**Percentage of Geographical Area**
Very Dense Forest	99,779	3.04
Moderately Dense Forest	3,06,890	9.33
Open Forest	3,07,120	9.34
Total Forest Cover	7,13,789	21.71
Scrub	46,539	1.42
Non-Forest	25,27,141	76.87
Total Geographical Area	32,87,469	100.00

(Source: ISFR-2021)

The forest cover is divided into four categories: very dense forest, moderately dense forest, open forest, and mangrove. The cover is classified into dense and open forests using internationally accepted classification standards. Due to the enormous amount of work required for ground validation and the limitations of the methodology, it has not been possible to further divide the dense forest into more classes. Mangroves have been classified separately due to their distinct tone and texture, as well as their distinct ecological functions. Scrub and non-forest are two other classes. The definitions for these classes are given below.

Classification Scheme

Very dense Forest	All Lands with tree cover (Including mangrove cover) of canopy density of 70% and above
Moderately Dense forest	All lands with tree cover (Including mangrove cover) of canopy density between 40% and 70% above
Open forest	All lands with tree cover (Including mangrove cover) of canopy density between 10% and 40%
Scrub	All forest lands with poor tree growth mainly of small or stunted trees having canopy density less than 10 percent
Non-Forest	Any area not included in the above classes

India is one of the top ten countries with dense forests. Furthermore, these forests provide habitat for a diverse range of flora and fauna, including endangered species such as tigers and elephants, as well as ecosystem services such as soil conservation, water regulation, and carbon sequestration. Forests are vital in terms of supplying us with resources such as fuelwood, fodder, fruits, and medicines. In India, after agriculture, forests occupy the second-largest land area. According to the National Forest Policy, there should be a tree cover or forest on one-third of the land. The country has a high level of endemism due to its status as a mega-biodiversity country. These forests have a close relationship with the surrounding environment. India's forest ecosystem is very diverse i.e. from the rain forest of Kerala in the south to the alpine pastures of Ladakh, and from the desert of Rajasthan in the west to the evergreen forest of the north east.

10.3 FOREST CLASSIFICATION OF INDIA

There are various types of forests around the world. Forests cover 30% of the earth's surface and are estimated to contain 3 trillion trees. They play an important role in maintaining the global climate by sequestering 70% of carbon, which amounts to approximately 296 gigatonnes of carbon. There are three types of forests in the world: tropical forests, temperate forests, and boreal forests:

1. **Tropical Forest-** A tropical forest is a diverse forest that grows around the equator. It is found in Africa, Southeast Asia, and South America along the equator. In comparison to the total forest area worldwide, it has the highest species diversity.
2. **Temperate Forests-**The temperate forest is found in the next latitude ring after the tropical rainforest. It is native to North America, Northeast Asia, and Europe. It has four distinct seasons, with a prominent winter, giving it 4-6 frost-free months and 140-200 days for growing**.**
3. **Boreal Forests-** The boreal forest, also known as taiga forest, is found between 50 and 60 degrees north latitude. It can be found throughout Eurasia and North America, particularly in Siberia, Scandinavia, Alaska, and Canada.

The total area of India that is covered by forest is approximately 19.26%. There are different types of forests in India which include the Taiga type forests (made up of pine, spruce, and other conifers), mixed temperate forests with both coniferous and deciduous trees, temperate forests, subtropical forests, tropical forests, and equatorial rainforests. However, in India, forests are classified mainly into six types: moist tropical, dry tropical, montane subtropical, montane temperate, subalpine, and alpine.

In 1936, Sir HG Champion classified India's forest types for the first time in his massive work 'Preliminary Survey of Forest Types of India and Burma'. Champion and Seth published 'A Revised Survey of the Forest Kinds of India' in 1968. In India, forest types are classified based on climate, physiognomy, species composition, phenology, terrain, soil variables, altitude, aspect, and biotic factors. The forests have been divided into six "major groupings" ranging from tropical to alpine. These major groups were further subdivided into 16 sub-groups based on temperature and moisture regimes.

I-Moist Tropical forests

1. Tropical wet evergreen forests
2. Tropical moist Semi-evergreen forests
3. Tropical Moist Deciduous Forests
4. Littoral and Swamp forests

II- Dry Tropical Forests

5. Tropical dry deciduous forest
6. Tropical thorn forests
7. Tropical dry evergreen forests

III-Montane Subtropical Forests

8. Subtropical broad-leaved hill forests
9. Subtropical pine forest
10. Subtropical dry evergreen forests

IV-Montane Temperate Forests

11. Montane wet temperate forests
12. Himalayan moist temperate forests
13. Himalayan dry temperate forests

V- Sub alpine forests

14. Sub alpine forests

VI- Alpine Forests

15. Moist-Alpine Scrub
16. Dry-Alpine Scrub

1. **Moist Tropical forests:** Evergreen forests degenerate into semi-evergreen forests in regions with annual rainfall between 200 and 250 cm, mean annual temperatures between 24 and 27, and humidity levels of 80 percent or higher; these regions include the western coast, Upper Assam, the eastern Himalaya's lower slopes, the coast of Orissa, and nearby hills. Bamboos, epiphytes, aini, semul, gutel, mundane, hopea, benteak, kadam irul, rosewood, haldu, kanju, bijasal, kusum, bomsum, Indian chestnut, litsea, holloch, champa, and mesua are a few examples of major plant species.

Fig. 10.1 Moist Tropical Forest

Image Courtesy: 3.bp.blogspot.com/-OUoO7Lmzaig/UMXEVNdfjfI/SANY0003.JPG

1-Tropical wet evergreen forests: The forests are mostly found in the Western Ghats, north-eastern India, and the Andaman and Nicobar Islands. The diversity of tree species is high in these forests. These are climatic climax forests with very dense growth of tall trees which are more than 45 meters high. Tropical wet evergreen forests are typically found in areas with more than 200 cm of rainfall and temperatures ranging from 15 to 30 degrees Celsius. They cover about 7% of the planet's land area and are home to more than half of the planet's autotrophs and heterotrophs in terrestrial ecosystems. They are dominated by evergreen trees with a dense canopy. The climax vegetation consists of evergreen trees. These forests produce fine-grained, hard, and long-lasting wood. Locally dominant trees include legumes, myrtales, figs, and Dipterocarpus, with Shorea being a common species in northern India and Hopea in southern India.

2- Tropical moist Semi-evergreen forests: The tropical semi-evergreen forests of India are found on the country's western coast, in Assam, on the Eastern Himalayas' lower slopes, in Odisha, on Andaman Island, and in the Western Ghats. These forests are found near tropical wet evergreen forests and serve as a transition zone between evergreen and moist deciduous forests.
The deciduous species grow intermixed with the evergreen species, and therefore, the forests are called semi-evergreen. The lower canopy is evergreen, whereas the upper canopy is deciduous for short periods during the dry seasons. The trees are 25-35 m tall. The tropical semi-evergreen forest type comprises for 13.79% of the Indian forest types. The annual rainfall average is 200-250 cm. The majority of tropical semi-evergreen forests have red soil, laterites, black soil, and humid soil. In comparison to evergreen forests, the canopies are not continuous, and the species richness is lower. There are many epiphytes, including ferns and orchids. These edaphic sub-climax formations, which are found on shallow, poor soils, are not climate climax formations.

Some of the indigenous and exotic tree and plant species found in this forest include teak, jamun, cashew, hog plum, coral tree, jasmine, and crossandra. The Indian Leopard, Indian-giant Squirrel, Lemur, Deer, One-Horned Rhinos, Birds, Great Horn Bill, Bats, Sloth, Scorpions, and Snails are common in this area.

3- Tropical Moist Deciduous Forests: These are one of India's most common types of forest. These forests are found in southern and northern states such as Tamil Nadu, Arunachal Pradesh, Assam, Meghalaya, Mizoram, Bihar, West Bengal, Odisha, and Uttarakhand. Deciduous trees also predominate in these forests. Lower-story trees are almost always evergreen. The trees shed their leaves in the winter and blooms in March and April. These forests account for 19.73% of India's forest types (FSI 2011). The trees range in height from 30 to 40 m. These forests can be found in areas where the annual rainfall ranges from 100 to 200 cm. These forests may have poor soil because topsoil is frequently washed away by heavy rains. The most common species are Adina, Anogeissus, Calycopteris, Cedrela, Pongami, and Termilia.

4- Littoral and Swamp forests: These forests can be found along the coasts of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, and Gujarat. The species are mostly evergreen and are found in mangrove and freshwater swamp forests. These forests are mostly in the early stages of development and are seral in nature. In the deltas of the Ganga and Brahmaputra rivers, tidal and swamp forests (mangrove scrub) are dominated by several evergreen and semi-evergreen species. Mangroves can be found on India's east and west coasts, as well as in the Andaman and Nicobar Islands, the Gulf of Kachchh, and Khambat (Gujarat). Sundarban (40% in West Bengal) is the world's largest mangrove forest. Trees from the genera Rhizophora, Avicennia, Sonneratia, Bruguiera, and Ceriops dominate mangrove forests. Tropical fresh water swamps like Myristica swamp forest can be found in Travancore (Kerala), and contain species like *Myristica* spp. and *Lagerstroemia speciosa*. The mangrove ecosystem is extremely productive, serving as a shelter and nursery for a variety of fish species as well as other animals in the area. *Baringtonia spp*. and *Syzygium cumini* are found in swamp forests in UP and West Bengal.

II- Dry Tropical Forests

This type of forest is mostly found in northern India's hilly regions and in a few southern Indian states. Basically, these forests grow in areas where the average annual rainfall ranges from 51 cm to 151 cm. The trees in these forests shed their leaves in the winter (when the weather is the driest), and new leaves grow after the winter. During the rainy season, these types of forests are completely covered in lush green leaves. Sal, acacia, mangoes, and bamboo are all dominant trees in the dry tropical forest.

Fig.10.2: Dry Tropical Forest

(Source: https://sierrraaamann.wordpress.com/2013/11/04/5-tropical-dry-forest-fun-facts/)

5- Tropical dry deciduous forest: They are also known as tropical monsoon forests and are found in Vindhyan and South India, specifically Maharashtra, Uttar Pradesh, Bihar, and Madhya Pradesh. These are India's largest forest types, covering approximately 38.2% of the country's forest area. In these forests, trees are less than 25 metres tall, with a light-demanding canopy of deciduous trees. Temperature and rainfall are major factors of the distribution of these forests. These forests can be found from Kanyakumari to the Himalayan foothills in low rainfall areas ranging from 800 to 1200mm; large areas of these forests are suitable habitat for wildlife. The soil of tropical dry deciduous forests is generally deficient in nutrients. The main canopy trees found here are teak (*Tectona grandis*), coromandel ebony (*Diospyros melanoxylon*), dhaora (*Anogeissus latifolia*), *Lagerstroemia parviflora*, *Terminalia tomentosa*, *Lannea coromandelica*, *Hardwickia binata*, and *Boswellia serrata*. The tropical dry deciduous forests of Madhya Pradesh are home to the Bengal tiger (*Panthera tigris tigris*), gaur (*Bos gaurus*), packs of dhole or Asiatic wild dogs (*Cuon alpinus*), sloth bear (*Melursus ursinus*), chousingha (*Tetracerus quadricornis*), and blackbuck (*Antilope cervicapra*), none of which are endemic.

6- Tropical thorn forests: Tropical thorn forests are mostly found in northern India, as well as some drier areas of the Deccan Plateau. These forests are commonly found in Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, Uttar Pradesh, Rajasthan, Gujarat, and Punjab. Due to very low rainfall, these forests are also known as xeric forests. The annual rainfall is less than 70 cm. The dry season lasts a long time. The tree's height ranges from six to nine metres. These forests are open, with short trees that are mostly thorny. *Acacia senegal*, *Prosopis spicigera*, *Prosopis cineraria*, *Acacia leucophloea*, *Acacia nilotica*, *Ziziphus* spp., and *Salvadora* spp. are examples of desert thorns. In this region, *Acacia tortilis* and *Prosopis chilensis* have been widely planted. This ecoregion is home to a variety of wild cats including the common leopard, caracal, Indian desert cat, jungle cat, and rusty-spotted cat as well as canids like the grey wolf, golden jackal, desert fox, Indian fox, and striped hyena. Along with these diverse carnivore species, there are various herbivorous animals.

7- Tropical dry evergreen forests: The Tropical Dry Evergreen Forests are a type of forest found only in Tamil Nadu and Andhra Pradesh. These are low-growing forests, with trees ranging in height from 9 to 12 meters and forming a complete canopy. Rainfall in these forests ranges between 870 and 1200mm. The soil of tropical dry evergreen woods contained a higher percentage of fine pores. This forest's soils clearly had higher clay content. *Manilkara hexandra*, *Memecylon edule*, Diaspyros, Eugenia, Chloroxylon, and *Albizzia amara* are the most prominent trees. These forests have a wide range of trees, shrubs, and herbs. The ecoregion's consumers include the dhole (*Cuon alpinus*), sloth bear (*Melursus ursinus*), and Indian spotted chevrotain (*Moschiola Indica*).

III-Montane Subtropical Forests

These kinds of forests are primarily found in the states of Assam, Nagaland, Mizoram, Meghalaya, Manipur, Arunachal Pradesh, etc. They can also be found in the Western Ghats mountain ranges. Poonspar, Cinnamon, Rhododendron, Sal, Sandan, Laburnum, Pomegranate, Olive, Ooleander, and other significant trees of Montane subtropical forest.

Fig.10.3: Montane Subtropical Forests

(Source: https://encrypted tbn0.gstatic.com/images?q=tbn:ANd9GcRmuNDycu7LAbhN2g3s72mwfuNQTrUq3kD1g&usqp=CAU)

8- Subtropical broad-leaved hill forests: The subtropical broadleaf forests ecoregion extends from the middle hills of central Nepal through Darjeeling and Bhutan, as well as into India's Uttar Pradesh and Bihar. It consists of an east-west oriented strip of subtropical broadleaf forest in the Outer Himalayan Range at heights ranging from 500 to 1,000 m. (1,600 to 3,300 ft). Although the annual rainfall can reach 2,000 mm, it varies from east to west. In these forests, trees are tall, that can grow to a height of 30 to 50 metres. Sal, or *Shorea robusta*, as well as Terminalia, Bauhinia, Schima, and Castanopsis species, are common in these forests. Climbers and epiphytes can be found in abundance. The ecoregion's threatened mammals include the Bengal tiger, Indian elephant, smooth-coated otter, clouded leopard, gaur, Sumatran serow, Irrawaddy squirrel, and particolored flying squirrel. The endemic golden langur has a limited range and can only be found in the broadleaf forest north of the Brahmaputra River.

9- Subtropical pine forest: All the hilly states of northeast India includes Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, and Uttrakhand etc are covered in extensive subtropical pine forests that range in height from 800 to 2000 metres. The majority of the rainfall in the subtropical pine forests is caused by the southwestern monsoon, which arrives from the Bay of Bengal and lasts from May to September. The rocks are covered with a thin layer of leached, nutrient-depleted soil that serves as the plant's rooting medium. The main characteristics of these forests are *Pinus roxburghii* with broad-leaved species. Pinus and Quercus species are the most common in the forests. Climbers and bamboos are not present. The most common trees found in Himalayan subtropical pine forests are Shisham, Teak, Sal, Pine, Fir, Juniper, and Rhododendron. Due to a lack of vegetation and browse, the ecoregion does not support many grazing or browsing herbivores, with the exception of a few goral (a goat-like mammal) and small barking deer. Because wild prey is scarce, the ecoregion cannot support stable populations of large carnivores. The bird fauna is more diverse however it is shared with neighbouring ecoregions.

10- Subtropical dry evergreen forests: These forests are distributed in Bhabar tract, Shiwalik hills, and the foothills of western Himalaya, Jammu and Punjab region. Olea cuspidata grows on alluvial ground in larger valleys in Punjab, Uttrakhand, and Himachal Pradesh. The dominant species of these scrub forests in Jammu and Kashmir are *Olea cuspidate*, *Acacia modesta*, and *Dodonaea viscose*. These forests grow 1000 metres above sea level. The annual rainfall average is only 800 millimetres. The majority of the precipitation falls between October and December, during the short northeast monsoon. The ecoregion's flora and fauna have adapted to the hot, dry climate. Some of the most common trees are *Manilkara hexandra*, *Diospyros ebernum* (Ceylon ebony), *Strychnos nuxvomica* (strychnine tree), *Drypetes sepiaria*, and *Flacourtia indica* (Indian plum). The diversity of birds is greater in these forests, which are home to the lesser florican, a species that is threatened on a global scale, as well as numerous large, rare birds like the woolly-necked stork, white-bellied sea eagle, and Indian grey hornbill. *Acacia*, *Olea*, *Dodenea*, and numerous hardwood species predominate in these low xerophytic scrubs and open forests.

IV-Montane Temperate Forests

These types of forests are primarily found in the Northern Middle Himalayas (1801–3800 m) and the Southern Nilgiri higher mountain ranges. The climatic conditions include a yearly rainfall total of more than 150 cm, an average annual temperature of 18°C with a freezing point from

December to February, and heavy fog. These dense forests (tree height 15-18 m) with much undergrowth and many epiphytes, mosses, and ferns are known as sholas in south India. Rhododendrons, Ferns, Oak, Maple, Juniper, Deodar, Chilgoza, and other trees are important in the Montane temperate forest. Outside plants such as cinchona, wattle, and eucalyptus have been introduced. In north India, common tree species include oak, chestnut, and laurel.

Fig.10.4: Montane Temperate Forests
(Source:https://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue47/posters.htm)

11- Montane wet temperate forests: Montane Wet Temperate Forests occur on moderate-height Mountains. These forests can be found in higher hilly areas of Kerala and Tamil Nadu, as well as the Eastern Himalayas region to the east of 88°E longitude, which includes the hills of Assam, West Bengal, Sikkim, Arunachal Pradesh, and Nagaland. The majority of these forests are located between 1000 and 2000 metres above sea level. Rainfall varies from 150 to 300 cm per year on average. Montane wet temperate forests have high humidity and moderate elevations. The vegetation is evergreen in montane wet temperate forests. This ecosystem is dominated by oaks and chestnut trees. The montane wet temperate forests are also known for their red young leaves, which change colour as they mature. Common epiphytes that grow on trees include lichens, ferns, and bryophytes. The trees form a canopy at 15 to 20 metres, and the forests are multistoried and rich in epiphytes, particularly orchids. Important species include Indian chestnut, Deodar, Machilus, Cinnamomum, Litsea, Plum, Blue pine, Birch, Oak, Hemlock, and others. Nilgiri langur (*Semnopithecus johnii*), Malabar large-spotted civet (*Viverra civettina*), brown palm civet (*Paradoxurus jerdoni*), Salim Ali's fruit bat (*Latidens salimalii*), Nilgiri striped squirrel (*Funambulus sublineatus*), and Layard's palm squirrel (*Funambulus sublineatus*) are also found in these forests.

12- Himalayan moist temperate forests: These forests cover the entire length of the Himalayan region, between subtropical pine forests and subalpine forests. It is distributed in Sikkim, Assam, Kashmir, Himachal Pradesh, Punjab, Uttrakhand, and the Darjeeling district of west Bengal. The altitude varies from 1500m to 3300m. Except in areas where rainfall falls below 1000 mm, these are concentrated in the central and western Himalaya. The average annual temperature is 12-13°C, the annual rainfall is 100-300 cm, and the annual humidity is 56-65 percent. Temperate forests are dominated by oak species such as *Quercus leucotrichophora*, *Q. floribunda*, *Q. incana*, *Q. semecarpifolia*, *Q. dilatata*, and *Q. larginosa*. All Himalayan oak species are evergreen, with leaf fall in the summer but are never leafless. The tree canopy is dense, the herbaceous layer is not well developed, grasses are generally lacking, and epiphytes are abundant. The upper form of *Abies pindrow*, *Picea smithiana*, and *Q. semecarpifolia* becomes dominant as altitude increases. The most important trees are pines, cedars, silver firs, spruces, and others. They form a high, open forest with shrubby undergrowth, which includes oaks, rhododendrons, laurels, and some bamboos.

13- Himalayan dry temperate forests: Dry temperate forests found in Kashmir, Ladakh, Baltistan, Chamba, Lahaul, inner Garhwal and Sikkim. These are distributed between 1700 and 3000 metres in elevation, with rainfall usually less than 1000mm, most of which falls as snow during the winter months. These are primarily coniferous forests with xerophytic shrubs, with the main trees being Deodar, Chilgoza, Oak, Ash, Maple, Olive, Celtis, Parrotia, and others. These forests can be found in the inner, dry Himalayan ranges, where the south-west monsoon is very weak and the precipitation is below 100 cm, primarily snow. Coniferous forests have an evergreen canopy and are tall (30–35m). These forests are made up of both coniferous and broad-leaved trees. The characteristic species in the western Himalaya are *Pinus gerardiana*, *Cedrus deodara*, and Juniperus. Abies and Picea are the most common species in the eastern Himalaya. *Juniperus wallichiana* is common in higher hills. Other species found locally between 2500 and 4000 m elevation include *Larix griffithiana*, *Populus eupheretica*, Salix spp., Hippophoe spp. and Myricaria spp.

V- Sub alpine forests

Fig.10.5: Sub alpine forests
(Source: https://www.sciencephoto.com/media/770158/view/sub-alpine-forest-australia)

14- Sub alpine forests: Subalpine forests can be found throughout the Himalaya above 3000 m elevation, with rainfall ranging from 83 to 600 mm. The forests are mostly evergreen, with Rhododendron as a common plant. Tall trees are conifers, and the largest deciduous tree is Betula utilis, which grows alongside *Quercus semecarpifolia*, Sorbus, and Rhododendron sp. Sub-alpine forests in the Western Himalaya have been reported from Jammu and Kashmir, Himachal Pradesh, and Uttrakhand. There are two types of forests in the western Himalaya: (i) *Abies spectabilis* and *Betula utilis* forests, and (ii) west Himalayan sub-alpine birch/fir forests. These forests can be found above 3000 metres in the eastern Himalaya. These forests can be found in the states of Arunachal Pradesh, Sikkim, and West Bengal. *Abies densa*, *Betula utilis*, and Rhododendron spp. predominate. These are climax formations that self-generate with remarkable resilience.

VI- Alpine Forests

Fig.10.6: Alpine Forests
(Source: https://depositphotos.com/71648283/stock-photo-alpine-forests.html)

These grasslands begin at elevations above 3000 m and grow to a region just below the snowline. They are common in both the main Himalayan regions and the Trans Himalaya's barren cold deserts. Low alpine grasslands are common, with vegetation that does not grow higher than 1.5m. The climate varies from subarctic to arctic, with snow covering the ground for more than 5 months of the year. The plants' growing season is thus shortened. During the summer, migratory cattle graze on pastures. The vegetation is dominated by black juniper and drooping juniper, with honeysuckle and willow as common trees.

15- Moist-Alpine Scrub: Moist Alpine Scrub is found throughout the Himalaya, above the timber line to 5,500m altitude, and is made up entirely of Rhododendron species, with some birch (Betula) and other deciduous trees. These forests have been identified in Arunachal Pradesh, Sikkim and West Bengal as well. The ground is covered in moss and ferns, and the tree trunks are short and highly branched. Heavy snowfall covers the Moist Alpine Scrub. Usually, more than five months of the year have snow covering the ground. Summer temperatures range between 20 and 22 degrees Celsius on average. Temperatures in the winter are typically well below freezing. Birch woods meet fir forests at elevations above 3000 metres. Low-lying vegetation that doesn't rise higher than 1.5 metres is common in lower alpine grasslands. Growing between shrubs and meadows, trees are weak and irregular. The soil is generally moist and covered in a thick layer of humus. Throughout the spring and summer, the alpine moist scrub meadows are covered in brightly coloured flowers. On the top slopes, low grasses and cushion plants grow among the gravel and stones. Snow leopards (*Uncia uncia*), Himalayan blue sheep (*Pseudois nayaur*), Himalayan tahr (*Hemitragus jemlahicus*), takin (*Budorcas taxicolor*), Himalayan musk deer (*Moschus chrysogaster*), Himalayan goral (*Naemorhedus baileyi*), and Himalayan serow are among the larger mammals found in these forests. The smaller animals include Himalayan marmots (*Marmota himalayana*), weasels, and pikas.

16- Dry-Alpine Scrub: With an elevation of more than 3500 metres above sea level, the Dry Alpine Scrub is a type of alpine forest. These forests can be found in the main Himalayan mountain ranges as well as in the trans-Himalayan barren freezing deserts of Jammu and Kashmir, Himachal Pradesh, Uttrakhand, and Arunachal Pradesh. It is a xerophytic formation dominated by dwarf shrubs. These forests are characterised by freezing temperatures and snow-covered landform. Dry arctic conditions prevail, with annual snowfall lasting 5 to 6 months. The average annual rainfall is less than 370 millimetres. The soil is deficient in nutrients. Summer temperatures range between 20 and 22 degrees Celsius on average. Winter temperatures are usually well below freezing. There are no trees in the area. Shrubs coexist with pasture areas. *Juniperus wallichiana*, Lonicera spp., and Potentilla spp. are common plants in dry alpine scrub forests. The vegetation along the streams consists of Salix, Myricaria, and *Hippophae rhamnoides*. Dwarf junipers can also be found rarely. In the eastern Himalaya, *Juniperus recurva* and *Juniperus wallichiana* can be found growing at elevations between 3000 and 4600 metres. The landscapes are home to giant, endangered species such as snow leopards and Tibetan wolves. These species prey on large mountain goats and sheep such as goral, serow, Himalayan tahr, argali, and blue sheep. The bird fauna is more diverse, with over a hundred species, including several that are adapted to high-altitude habitats. Large bird predators such as lammergeier, golden eagle, Himalayan griffon, blood pheasant, western tragopan, *Satyr tragopan*, and Himalayan monal can be used as focal species in conservation management planning. During the summer, migratory cattle graze on the shrubs.

India's Forest Types: A New Classification

The compositions of India's forest types are very diverse, with a long evolutionary and geological history that occurs under a wide range of climatic and edaphic conditions. They have noticed significant changes in forest composition since Champion and Seth (1968) revised the forest types. The revised forest classification is based on a field survey of more than 200 forest types and subtypes representing very diverse climatic and edaphic conditions across the country.

Data on forest types, basal area, importance value index, stem density, and diversity indexes, including similarity indexes, were collected from field surveys.

Table-1: The major forest types of India (based on Champion and Seth, 1968)

Major Forest Groups	Forest Sub Groups
I- **Moist Tropical forests**	1-Tropical wet evergreen forests
	2-Tropical moist Semi-evergreen forests
	3-Tropical Moist Deciduous Forests
	4-Littoral and Swamp forests
II- Dry Tropical Forests	5-Tropical dry deciduous forest
	6-Tropical thorn forests
	7-Tropical dry evergreen forests
III- Montane Subtropical Forests	8-Subtropical broad-leaved hill forests
	9-Subtropical pine forest
	10-Subtropical dry evergreen forests
IV- Montane Temperate Forests	11-Montane wet temperate forests
	12-Himalayan moist temperate forests
	13-Himalayan dry temperate forests
V- Sub alpine forests	14- Sub alpine forests
VI- Alpine Forests	15-Moist-Alpine Scrub
	16-Dry-Alpine Scrub

The effects of climate change on vegetation have been thoroughly examined. The new forest type classification reflects current ecological, climatic, bio-geographic, and edaphic influences on vegetation composition and stand formation. In the proposed new classification, 10 major groups and 48 sub-groups have been identified (ICFRE 2013; Bahuguna et al. 2016). The study reported various changes at the species and forest subtype levels. Different types of forests have undergone some positive and negative changes. The following are some trends in the new forest type classification:

1. In terms of distribution and species density, changes at the species level were most noticeable in *Shorea robusta* (Sal), *Tectona grandis* (Teak), and Bamboo forests. According to the findings, teak is absent from very moist and moist teak sub-types, and many moist deciduous and semi-evergreen species are present.

2. The decline of *Shorea robusta* (Sal) and the occurrence of dry deciduous species in central India, as well as fragmentation and changes in species composition as a result of anthropogenic and climate change.
3. Climate change is affecting the vegetation composition, particularly the alpine flora
4. The species composition of Shola forests and evergreen forests has changed.
5. Positive changes in forest composition and density have been observed in Andhra Pradesh, Karnataka, and Gujarat Forests.
6. Based on national-level data, an analysis of temperature and rainfall patterns revealed that many forests, particularly temperate forests, are shifting to drier conditions. The distribution patterns of oaks and conifers are changing.
7. The blue pine (*Pinus wallichiana*), which was previously found in higher elevations up to 1700 m, is now found in even higher elevations up to 2700 m, indicating a shift in tree lines towards higher elevations.

10.4 FOREST OF HIMALAYA

The word "Himalaya" comes from Sanskrit, an ancient Indian language, which means "abode of snow" (Hima-snow and alya-abode). Geologists consider the Himalaya to be the world's youngest mountain chain, and it is thought to be still evolving, making it geologically and geomorphologically unstable. They cross through the nations of India, Pakistan, Nepal, Bhutan, and China. There are 12 states in India that are considered to be Himalayan states: Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, Assam, and West Bengal. Himalaya broadly divided into Eastern Himalaya, Central Himalaya and Western Himalaya. The Himalayan mountain ranges are named as: the Greater Himalayas, also known as the Himadri, the Trans Himalayan range, the Lesser Himalayas, also known as Himachal, and the Outer Himalayas, also known as the Shivaliks.

The Himalayas cover approximately 2500 kilometres from west to east. Its average width along its entire longitudinal extension ranges between 100 and 400 kilometres. The vast area covered by the mountain range, combined with some fantastic altitude gradients, results in the Himalayan region's tremendous biodiversity. The vegetation of the Himalayas varies according to altitude and climatic conditions. They range in altitude from tropical deciduous forests in the foothills to temperate forests in the middle. Coniferous, subalpine, and alpine forests emerge higher up. These are eventually replaced by alpine grasslands and high altitude meadows. They are followed by scrublands that lead up to the permanent snowline. The vegetation also varies from the unnoticed tropical rainforests of the Eastern Himalayas to the dense subtropical and alpine forests of the Central and Western Himalayas to the limited desert vegetation of the cold desert parts of the Transhimalaya. Thousands of flora and fauna species live in the region, each adjusting to its particular weather circumstances, predators, and other challenges. However, as in other regions, man's entry and exploitation into the region has resulted in the extinction of many species or the threat of extinction in others.

The Himalayas, which contain the entire Indian Himalayan Region (IHR), are one of four biodiversity hotspots in the country (the other three are the Western Ghats, the Indo-Burma region, and Sunderland). The IHR occupies around 5,30,000 square kilometres, or almost 16% of the country's overall geographical area. Himalayan vegetation is essentially categorized into four types: tropical, subtropical, temperate, and alpine, each of which dominates in a zone defined primarily by height and precipitation. With decreasing precipitation and increasing elevation westward, the rainforests give way to tropical deciduous forest, where the important timber tree Sal (*Shorea robusta*) is the dominating species. Further west, steppe forest (an expand of grassland planted with trees), steppe, subtropical thorn steppe, and subtropical semi desert vegetation all coexist. Temperate mixed forests range in elevation from 4,500 to 11,000 feet (1,400 to 3,400 metres) and comprise conifers and broad-leaved temperate species. The alpine zone begins above the tree line, between heights of 10,500 and 11,700 feet (3,200 and 3,600 metres), and extends up to roughly 13,700 feet (4,200 metres) in the western Himalayas and 14,600 feet (4,500 metres) in the eastern Himalayas. These zones contain all of the wet and moist alpine vegetation. The species found in each zone vary significantly due to changes in relief and climate, as well as exposure to sunlight and wind. Tropical evergreen rainforest is limited to the humid slopes of the eastern and central Himalayas. The evergreen dipterocarps are a common group of timber- and resin-producing trees; their various species grow on different types of soil and hill slopes of varying steepness.

Indian Himalayan States

State Code	State/region	% share of geographical area in the Indian Himalayan Region (IHR)
1	Jammu & Kashmir	41.65
2	Himachal Pradesh	10.43
3	Uttarakhand	10.02
4	Sikkim	1.33
5	West Bengal hills	0.59
6	Meghalaya	4.20
7	Assam hills	2.87
8	Tripura	1.97
9	Mizoram	3.95
10	Manipur	4.18
11	Nagaland	3.11
12	Arunachal Pradesh	15.69

(Source: http://gbpihedenvis.nic.in/him_states.htm)

10.4.1 Sal forests: The scientific name of Sal tree is *Shorea robusta* Gaertn. It is a tree species in the Dipterocarpaceae family, also known as sla, shala, sakhua, or sara. Sal forest is a type of forests dominated by a single plant species referred to as the Sal tree. It is classified as a 'Tropical moist deciduous forest'. The distribution of Sal forests is determined by geography, geology, and soil conditions. A total of 208 plant species from 165 genera and 72 families were identified. About 200 species of *Shorea* Roxb.ex. Gaertner f., has been reported in Southeast Asia, including Indonesia, the Philippines, and 4 in India.

The natural Sal forest is distributed in south-east Asia, and mostly prevalent in the Himalayan foothills of India, Bhutan, Bangladesh, Nepal, and Tibet. Sal trees are native to Nepal and India, and they cover nearly one-eighth of India's entire forest area. The Sal tree grows up to 1700 metres in elevation in North East and Central India. The species is found throughout India, from Himachal Pradesh to Assam, west Bengal, Bihar, Orissa, Tripura, and eastern parts of Madhya Pradesh, with further distribution into the Eastern Ghats of Andhra Pradesh. It is abundantly grown in the Himalayan foothills.

Characteristic Features of Sal

Sal grows well in moist deciduous forests. They occasionally shed their leaves during the dry season and stay without leaves for a relatively short period, but they are generally evergreen since the areas where they grow receive enough water throughout the year. In the Tarai region of the Himalayas, trees can grow up to 45 m in height.

Fig.10.7 Sal tree

Fig.10.8 Flower branch of Sal tree

Sal trees are moderate to slow growing. A Sal tree is rarely leafless. It has leathery leaves and yellowish blooms. They have a rough texture. The crown is round and spreads out. The leaves are simple, glossy, and glabrous, with delicate green leaves that are roughly oval at the base. Sapwood is whitish in colour, thick, and less durable. When exposed, the heartwood turns dark brown to black in colour. The pores in the wood are filled with resin. The Sal tree needs well-drained, wet, sandy loam soil. From February to March, it sheds its leaves under dry conditions. In the months of April and May, new leaves grow. In the summer, the flowers mature into fruit, and in June and July, the seeds ripen.

Uses of Sal tree

1. Sal wood is strong, long-lasting, and fireproof. It is used to construct houses, telephone and power poles, sleepers, boats, furniture, and other carpentry proposes.
2. The leaves of the Sal tree are used by tribal people to make rice cakes and for smoking. The leaves are used to form platters, bowls, tiny baskets, and other items.
3. Distilled leaves yield oil that is used in fragrance. It is also used to flavour chewing gums and tobacco.
4. Its dried and fallen leaves are utilised as fertiliser. It is used to caulk ships and boats.
5. The oil extracted from its seed is edible and known as Sal butter. It is frequently used in cooking and for lighting oil lamps. Sal seeds have lots of applications. They can be turned into flour and used for making bread. The kernels contain 14-20% oil (Sal butter), which is used in cooking, as a cocoa butter substitute in lighting, and in industrial uses.
6. The seeds of the Sal tree are used to extract fat. Its oil is also used for adulterating ghee. Tribal people sent marriage invitations in the form of folded Sal leaves with a small amount of turmeric and rice inside.

Medicinal Uses

1. The resin is used as an astringent in indigenous medicine and is used for diarrhoea and dysentery. Due of its soothing and astringent characteristics, Sal tree resin can help to reduce swelling and control bleeding when taken orally.
2. It is also used as a component in ointments to treat skin ailments and ear problems. It is also used in foot cream.
3. The fruits of Sal trees are used to treat chlorosis, epilepsy, and excessive salivation.
4. Powered seeds have insecticides properties. Powders of seeds are used to treat dental problems. It cleanses the skin of oily secretions and is used to wash hair.

10.4.2 Pine forests

Pinus roxburghii Sarg., known as chir pine and named after William Roxburgh, is a Himalayan pine tree. Pinus is the most common genus in the Pinaceae family, which is the largest family in the coniferous. It is a large genus with over 110 species around the world. Himalayan subtropical pine forests are restricted to Nepal, Bhutan, and Pakistan to the west, the northern Indian states of Sikkim, Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh and Uttarakhand. They are the most common in the Indopacific region. The Himalayan subtropical pine forests of India cover the low slopes of the Great Himalayan range as well as other northern Indian states. The subtropical pine forests are divided into two types: Lower Siwalik Chir Pine Forest and Upper (Himalayan) Chir Pine Forest. Subtropical pine forests cover a vast area between 800 and 2000 metres in height in all of northeast India's mountainous states.

A pine, often referred to as chir locally, that covers around 16 percent of the forest area in Uttarakhand. There are five native pine species in India: *P. roxburghii* (Chir pine), *P.*

wallichiana (Blue pine), *P. kesiya* (Khasi pine), *P. gerardiana* (Chilgoza pine), and *P. merkussi* (Teriasserian pine). In Himalayas *P. roxburghii species P. wallichiana* and *P. gerardiana* are found, while *P. kesiya* and *P. merkussi* are native to Assam (India) and Burma.

Characteristic Features of Pine

Pinus roxburghii is a giant tree that can grow up to 30-50 metres (98-164 feet) tall with a trunk diameter of up to 2 m, and in some cases 3 m (10 ft). Immature tree bark generally appears dark-grey and extensively fissured, whereas older tree bark usually appears red, turning light grey on the surface with exposure. Flowering season is normally from February to April, and the flowers are yellowish green before maturity, turning light reddish brown once the pollens are shed. The cones are ovoid conic, 12-24 cm long and 5-8 cm broad at the base when closed, green at first, turning glossy chestnut-brown after 24 months. They open slowly during the next year or so, or after burned by a forest fire, for releasing the seeds, opening to 9-18 cm in width. The seeds are long and distributed by the wind. It prevents vegetation from growing around it by making the soil more acidic with its falling needles.

The formation of a carpet of needles on the forest floor under these trees usually makes conditions adverse for the growth of many common plants and trees. It is drought tolerant. The Himalayan subtropical pine forests are at risk of fire. Grass species such as *Imperata cylindrica*, *Arundinella setosa*, *Themeda anathera*, and *Cymbopogon distans* are growing rapidly on the burnt slopes of this Himalayan subtropical pine forest habitat. Berberis, Rubus, and other thorny bushes comprise a diverse range of vegetation.

Uses of Pine tree

1. The pine tree is utilised mainly for resin tapping. After distillation, the resin, locally known as lisa, is used to make turpentine oil.
2. People use the wood for fuel and locally sourced timber for their homes and other wooden furniture purposes.
3. The ability of pine trees to support local ecosystems is a major benefit. Pine trees play an important role in keeping the ecosystem balanced and in control by providing shelter and food for local species.
4. The thick forest protects local wildlife populations from the sun, severe weather, and predators. Furthermore, the seeds produced by pine trees are high in nutrients and serve as a significant source of food for many species, particularly birds and squirrels.
5. A pine forest is also one of nature's most effective natural air filters. The needles filter and absorb micropollutants in the air, leaving the environment feeling fresh and clean.
6. Pine trees are excellent soil stabilizers because their roots work to keep the soil in place. Pine trees are a popular choice for erosion prevention because they are extremely resistant and can live and grow in almost any soil condition.

7. Rosin is the material that remains after turpentine has been removed. This is used by violinists on their bows as well as in the making of sealing wax, varnish, etc.


Fig.10.9 Pine tree


Fig.10.10 Needles of pine tree


Fig.10.11 Male cone


Fig.10.12 Female cone

Medicinal Uses

1. Chir pine oil is used as an antibacterial, a lotion to improve vascular circulation, and a repellent for parasites in the body.
2. Turpentine derived from the resin of pine trees is antibacterial, diuretic, rubefacient, and vermifuge.
3. The powder from the stem is used for relieving fever and intestinal worms.
4. Bark powder is applied as a paste to treat skin problems such as ringworm and eczema. Burns and cracks are also treated with bark paste.
5. The oil derived from the tree is used to clean the wound and to apply to the area affected by inflammation.
6. The leaves (needles) are used to stimulate the flow of urine (diuretic).

7. A decoction of the leaves is administered locally to relieve sprains.
8. Resin is used to treat boils, pimples and blisters, pus production, heel cracks, and swelling above the eye.
9. The Roasted seeds are consumed as a galactagogue and source of oil.

Effects of pine trees in the Himalayas

1. **Forest Fires**: Pine needles are extremely ignited and are the major cause of forest fires in the region. Because pine trees are fire-resistant, they do not burn in this fire and shed their leaves again the following year, continuing the cycle.
2. **Lack of Water Retention**: The water holding capacity of the soil reduces due to a lack of microbes. In contrast to locations with a lot of oak trees, the region with the pine trees is generally drought-prone.
3. **No Bacterial Growth, thus Degraded Lands**: Because of the presence of the pine, bacteria in the soil die and are replaced by a parasitic fungal relationship that only helps the pine live and develop while taking away nutrients that could be used by other plants.
4. **Biodiversity Loss:** Every year, forest fires burn many animals and useful plant species that are not fire-resistant, resulting in a loss of fauna and flora in the region.
5. **No Use for Livestock:** Pine needles are not used as cow feed or bedding material for people's livestock, therefore they are effectively useless to the locals in terms of animal welfare.

10.4.3 Oak forests

Oak belongs to the genus "*Quercus*" of the family Fagaceae which include around 600 various species of trees. The majority of oak tree species are deciduous, with only a few being evergreen. Oak trees are mostly found in the temperate zones of Himalaya. In the Central Himalaya, oak (*Quercus* spp.) forests are the climax evergreen vegetation between 1000 and 3600 m.

The dense banj oak (*Quercus leucotrichophora*) forests of the Indian Himalaya at mid-altitude ranging from 1500 to 2200 metres. The oak tree can reach heights of up to 100 feet and a width of up to 150 feet. There are over 450 Quercus species found primarily in North America, tropical America, Eurasia, and North Africa; and around 20-25 are found in India.

Oak trees are susceptible to fungal diseases that cause rotting of the plant from inside. In addition to fungi, insects frequently damage oaks and cause the leaves to fall. Due to habitat loss, overuse, disease, and the introduction of alien species, 78 species of oaks are identified as endangered. Many plants that are often referred to as "oak" are not Quercus species, such as African oak, Australian oak, bull oak, Jerusalem oak, poison oak, river oak, she-oak, silky oak, tanbark oak, Tasmanian oak, and tulip oak.

Characteristic Features of Oak Trees

In many species, oak leaves are spirally arranged, with lobate margins; others have serrated leaves or whole leaves with smooth margins. Many deciduous species are marcescent and do not shed their dead leaves until the spring. A single oak tree produces both male and female flowers in the spring. The male flowers appear as hanging yellow catkins before or after the leaves. Female flowers appear alone or in two- to many-flowered spikes on the same tree; each flower has an overlapping scale husk that expands to hold the fruit, or acorn, which matures in one to two seasons. The fruit is an acorn, which is borne in a cup-like structure called a cupule; each acorn contains one seed and matures in 6-18 months, depending on the species. Oaks are easily grown from acorns and flourish in moderately damp rich soil or dry sandy soil. Many re-grow from stump shoots. There are two types of oak acorns:

1. **Oak with sweet acorns:** Those that yield acorns low tannin content. These are edible and mature in a year.
2. **Oak with bitter acorns:** Those with a higher tannin content in the acorns. These grow in a couple of years, are not edible, and can cause poisoning if consumed in large amounts, even the fact that their bad flavour discourages ingestion.

Oak trees are strong and long-lived, although they are not shade-tolerant and can be damaged by leaf-eating organisms or the oak wilt fungus. Many oak tree species are facing extinction in the wild, mainly due to land use changes, livestock grazing, and unsustainable harvesting. These forests are still under threat from exploitation for timber, fuel wood, and charcoal. Due to increasing temperatures, oak forests in India's Himalayan region are being replaced by pine forests.

Types of Oak Trees

The oak family is one of the largest in the world. Oak trees are classified into main three types: white oak, red oak, and black oak.

1. **White Oak tree:** The white oak tree, commonly known as Quercus alba, is native to North America. White oak trees can also be found in Europe, Asia, and North Africa. The white oak is an evergreen or deciduous tree. The white oak tree's bark is scaly and light grey in colour. These trees' branches spread widely. White oaks range in height from 60 to 100 feet. The trunk of a white oak tree can grow to be 4 feet in width. The leaves of the white oak tree have 5 - 9 rounded lobes and are 4 - 9 inches long. During fall, the leaves of white oak trees become red or brown. Male flowers are greenish yellow and placed in a form of catkins. The female flowers are tiny reddish spikes.
2. **Red Oak Trees:** The red oak tree is also known as Quercus rubra and champion oak tree. Red oaks are big trees that can grow to be 50 to 80 feet tall. The bark of the red oak tree has a shining stripe in the centre that extends the length of the main trunk. The oak tree's leaves are simple and alternately arranged on the twig. The acorns of red oak trees mature during two growing seasons. During the autumn season, the leaves change colour from

red to orange-red to a deep reddish brown. Red oak wood is thick and strong, but it is less durable than white oak wood.

3. **Black Oak Trees:** Black oak is also referred to as *Quercus velutina*. The black oak tree is named from its dark-colored trunk. It also has very twisted branches and a root system. Even without leaves, the black oak's contoured shape makes it easy to recognise. They can reach a height of 80 feet. The black oak tree has lobed leaves. In the autumn, the leaves of the black oak turn a bright red colour. The black oak blooms in the spring, beginning in mid-May. The black oak acorn takes around two years to mature and begin growing.

Fig.10.13 Oak Tree

Uses of Oak Tree

1. The main use of the timber is for fuel, and the leaves make good fodder. Many animals feed on oak twigs, shoots, buds, and leaves.
2. The locals utilise oak wood to make agricultural implements.
3. Oak bark is also very high in tannin and is used by tanners to tan leather.
4. The oak tree is one of the most valuable trees for wildlife. A variety of animals use oak trees for food, shelter, cover, and nesting grounds.
5. Acorns, which are produced by oak trees, are an essential source of winter food for bears, foxes, deer, squirrels, turkeys, wood ducks, and many other species.
6. Oak wood is well-known for its strength and durability. For thousands of years, it has been used to construct furniture, houses, ships, and barrels. Wood is still used to construct things like floors and wooden beams.
7. Branches of Oak tree, crannies, nooks, and hollow regions provide shelter from the elements, a place for rest and protection from predators, and nesting areas for raising young.

Medicinal uses of Oak tree

1. Tea made from oak bark is used to treat fever, cough, arthritis, colds, diarrhoea, and bronchitis, as well as to stimulate appetite and improve digestion.
2. The bark can be consumed to heal mouth ulcers.
3. Galls that grow on the tree are highly astringent and can be used to treat haemorrhages, chronic diarrhoea, dysentery, and other ailments.
4. A decoction of white oak bark is used to treat pain and bruising.
5. It is a hepatoprotective substance, which aids in the prevention of liver damage in the body.

Toxicity in Oak Tree

Large quantities of the oak tree's leaves and acorns, which contain the toxin tannic acid, are toxic to cattle, horses, sheep, and goats and can result in gastroenteritis and kidney damage. Loss of appetite, depression, constipation, diarrhoea, blood in the urine, and colic are all signs of poisoning.

10.5 SUMMARY

A forest is a plant community dominated by trees and other vegetation, usually with a closed canopy. Forests cover nearly 30% of the total land surface of the Earth. India has a diverse range of forests; from the rainforests of Kerala in the south to the alpine pastures of Ladakh in the north, from the deserts of Rajasthan in the west to the evergreen forests of the north-east. 'Forest cover' refers to the presence of trees on any land. The forest cover is divided into four categories: very dense forest, moderately dense forest, open forest, and mangrove. There are three types of forests in the world: tropical forests, temperate forests, and boreal forests. In India, forests are classified mainly into six types: moist tropical, dry tropical, montane subtropical, montane temperate, subalpine, and alpine. Champion and Seth (1968) gave the detailed classification of forest types in India based on climate, physiognomy, species composition, phenology, topography, soil factors, altitude, aspect, and biotic factors. The forests have been classified into six major forest types and 16 major groups on the basis of temperature and moisture regimes. The new classification of forest types has been proposed reflecting the present ecological, climatic, bio-geographic and edaphic influences on the vegetation composition and stand formation. The Himalayan range one of the youngest mountain ranges on earth. They cross through the nations of India, Pakistan, Nepal, Bhutan, and China. There are 12 states in India that are considered to be Himalayan states: Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, Assam, and West Bengal. Himalaya broadly divided into Eastern Himalaya, Central Himalaya and Western Himalaya. Some of the important trees of Himalayas are- Sal, Pine and Oak etc.

10.6 GLOSSARY

Canopy: Cover of branches and foliage formed by the crowns of tree.
Forest area: The area classified as a forest in government records.
Scrub: Degraded forest lands with a canopy density of less than 10%.
Sap wood: It is the outermost layer of the tree, immediately beneath the bark.
Heartwood: It is the dead wood at the tree's centre.
Mangrove: Salt-tolerant evergreen forest areas found primarily along tropical and subtropical coasts and in intertidal zones.
Non forest land: The Land without forest cover.
Resin: Resin is a substance derived from the secretions of plants and trees.
Serration: It is a saw-like appearance or a row of sharp or tooth like projections.
Spike: A type of inflorescence (flower arrangement) with taller-than-average flowers, most often on an unbranched axis.
Acorn: A small oak tree nut that develops in a base with a cup-like form.
Tannin: A brownish or yellowish bitter-tasting chemical compound found in some barks, galls, and other plant tissues that is made up of gallic acid derivatives.
Lobes: A section of a leaf into which it is divided.
Catkins: A unisexual, generally male spike or extended axis that falls as a unit after flowering or fruiting.
Galls: It is generated from the tree's inner bark and round growths known as galls.

10.7 SELF ASSESSMENT QUESTION

10.7.1 Multiple Choice Questions:

1- Botanical name of Sal is –
(a) *Corchorus capsularis* (b) *Cocos nucifera*
(c) *Shorea robusta* (d) *Gossypium herbacium*
2-Pine is a ___ tree.
(a) Tropical (b) Coniferous
(c) Evergreen (d) Deciduous
3-Sal forest is –
(a) Temperate deciduous forest (b) Tropical rain forest
(c) Taiga (d) Tropical evergreen forest
4-Deciduous forests have:
(a) Variety of grasses (b) Broad-leaved trees
(c) Narrow-leaved trees (d) Variety of crocodiles
5- Which Indian state has the largest area under forest cover?
(a) Arunachal Pradesh (b) Chhattisgarh

(c) Kerala (d) Madhya Pradesh

6- *Quercus rubra* also known as-

(a) Red oak tree (b) Black oak tree

(c) White oak tree (d) None of the above

7- Which one of the following is the World's largest Mangrove Forest?

(a) Godavari-Krishna Mangroves (b) Gulf of Panama Mangroves

(c) Sundarbans Mangrove (d) Pichavaram Mangrove

8-Which one of the following are biodiversity hotspots in the country?

(a) The Western Ghats (b) Indian Himalayan Region (IHR)

(c) The Indo-Burma region (d) All of the above

9- Oak belongs to the family-

(a) Dipterocarpaceae (b) Fagaceae

(c) Pinaceae (d) Moraceae

10-In how many types' mainly Indian forests are classified?

(a) Two (b) Four

(c) Six (d) Eight

10.7.1 Answer key: 1-(c), 2-(b), 3-(a), 4-(b), 5- (d), 6-(a), 7-(c), 8-(d), 9-(b), 10-(c)

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10.10 TERMINAL QUESTIONS

10.10.1 Short answer type questions

1. What are the characteristics of pine trees?
2. Write a short note on types of oak tree?
3. Discuss about Sal tree in brief.

10.10.2 Long answer type questions

1. Classify major forest types of India based on Champion and Seth classification?
2. Describe in detail about Moist Tropical forests.
3. Explain in about the Dry Tropical Forests in detail.
4. Give a detailed note on characteristics and uses of Chir pine.

UNIT-11 GLOBAL CLIMATE CHANGES AND FOREST

Content

10.1 OBJECTIVES

After reading this unit students will be able:

- To learn about the global climate change
- To know the causes if climate change
- To understand about the impacts of climate change

10.2 INTRODUCTION

The long-term condition of the weather is referred to as the climate. The climate of an area shows the general state of the climate system at that location. A region's climate is defined as its usual weather patterns. The atmospheric conditions that are present in a region at any given time are known as the weather, and they can change from hour to hour, day to day, month to month, or even year to year. A region's climate is determined by its weather patterns, which are generally monitored for at least 30 years.

According to the World Meteorological Organization (WMO), climate is the "synthesis of weather conditions in a given area as defined by long term statistics of the variables of the state of the atmosphere."

The term "climate change" refers to shifts and variations in weather patterns over space and time of various scales and magnitude resulting into change of climatic type. For example from warm and moist climate to warm and dry climate, from warm and moist climate to cool and moist climate (as happened during carboniferous period in India) etc. According to the Inter-governmental Panel on climate change (IPCC), Climate change refers to “any change in climate over time, whether due to natural variability or as a result of human activity” (IPCC, 2001a).

The popular definition of "Change" has evolved over the last few decades. In the 1960s, the term "climate change" was mostly used to refer to "climatic variability," or climatic inconsistencies or anomalies. Climate change happens over time, typically over decades or longer. Climate variability, on the other hand, includes changes that occur over shorter time periods, such as a month, season, or year. Climate variability explains the system's natural variability. For example one unusually dry or warm air followed by an unusually cold or wet air, would not be considered a sign of climate change. In the 1970s, climate change was generally associated with very long-term changes, possibly on the order of thousands of years. The meaning of climatic change shifted once more in the 1980s, this time to refer to differences in 30-year average periods. Thus, climatic change is defined as differences in atmospheric variables over a 30-year period, such as

1951-1980 versus 1961-1990, even though this comparison of "normal's" may indicate short-term variability trends rather than long-term climatic change.

Climate change is any long-term significant change in the expected patterns of average weather in a specific region over an adequate long period of time. It refers to abnormal variations in the expected climate within the earth's atmosphere, as well as the subsequent effects on other parts of the earth, such as the ice caps, over periods ranging from decades to millions of years. For example, a large area of United States was covered in glaciers 20,000 years ago. It describes a change in the region's average weather conditions over a long period of time. The climate is warmer and there are fewer glaciers in the United States today. Although the climate on Earth has been stable enough to support life for millions of years, but it is dynamic and subject to change.

10.3 GLOBAL CLIMATE CHANGE

Climate change on a global scale refers to average long-term changes across the Earth. These include shifting precipitation patterns, rising sea levels, and melting ice in Greenland, Antarctica, and the Arctic. They also include warming temperatures and other consequences of global warming, such as changing flower and plant blooming seasons. Plants, animals, air, land, ocean, and solar energy all interact with one another. The sum of these effects results in our global climate change. In other words, the Earth's climate operates as a single, interconnected system. Small changes in one location can contribute to larger changes in the global climate of the Earth. Even before humans existed, the climate of the Earth was constantly changing. Scientists have recently noticed unusual changes. For example, over the past 150 years, Earth's average temperature has been rising much more quickly than they would have expected.

The global temperature change will not be uniform everywhere and will fluctuate in different regions. Higher latitudes will be warmed up more than tropics during late autumn and winter. The poles may experience 2 to 3 times the global average warming, while the tropics may experience only 50 to 100% of the average warming. The increased warming at the poles will reduce the thermal gradient between the equator and high latitude regions, reducing the energy available to the heat engine that drives the global weather machine. This will disturb the global pattern of winds and ocean currents, as well as the timing and distribution of rainfall. Rainfall disruption will cause some areas to become wetter and others to become drier.

Generally, global climate change happens over thousands or millions of years and is very slow. The average temperature of the Earth is maintained at about 600 F by heat from the Sun, which is in a range that supports biological life and maintains the planet's liquid reservoirs. On the surface of the Earth, incoming solar radiation is distributed unevenly due to astronomical variations and atmospheric shielding. Climate zones are formed as a result of heat and moisture being redistributed by ocean currents and winds. Climate zones have distinctive annual patterns of temperature, precipitation, wind, and ocean currents that together determine the local, short-term weather and affect the development of ecologically adapted plant and animal species. Global climate change can result from changes in the astronomical, oceanographic, atmospheric, and geological factors that affect the world's climate.

Although both human and natural factors have an impact on the climate of the Earth, only human activity can account for the long-term trend that has been observed over the past century. Research has found that the climate today is changing more rapidly than what can be seen in the geological records.

10.4 CAUSE OF CLIMATE CHANGE

The climate of the earth is dynamic and constantly undergoing a natural cycle. Climate change may be caused by natural internal processes (exchanges of energy between the atmosphere, hydrosphere, lithosphere and cryosphere or by both at local, regional and global level) or external factors (such as variations in orbital characteristics of the earth, solar variability, tectonic processes, vulcanicity etc) or by long-term anthropogenic changes in atmospheric composition or land use. There are many factors that contribute to climate change. Some of these causes are natural such as- Ocean currents, continental drift, Earth's tilt, etc., but the changes that are taking place today have been accelerated by man's activities. Since the 1800s, human activity has been the primary cause of climate change, mainly as a result of burning fossil fuels like oil, coal, and gas. Scientists agree that human activity has caused the earth to warm over the last 50 to 100 years. The carbon dioxide level has increased by more than 20% over the last century. Although other factors also affect the global climate, changes in the tropospheric concentrations of carbon dioxide, a major greenhouse gas, are closely correlated with changes in the mean surface temperature of the earth and, accordingly, its climate. Climate change causes can be divided into two categories: those caused by natural causes and those caused by man.

Natural causes: Climate change is caused by a number of natural factors such as-astronomical, geological, solar, and oceanographic mechanisms are known to contribute to climate change and variability, on time scales ranging from millions of years to a few months. The significant causes and related theories of climatic change may be stated as follows-

1-Astronomical factors: Astronomical factors include variations in solar activity, variations in the eccentricity of the Earth's orbit around the sun, variations in the tilt of the Earth's axis (obliquity), precession of the Earth's axis, and collisions with asteroids or comets. Astronomical theories take into account five main effects:

(i) Changes in the eccentricity of the earth’s orbit-period 96,000 years, resulting variations in the mean distance from earth to Sun could affect temperatures on earth.

(ii) Changes in the angle formed by the earth with respect to the plane of the ecliptic. The tilt angle slowly varies between 22.10 and 24.50 over a 41, 000-year cycle, possibly affecting temperature distribution, seasons, and general circulation.
(iii) The precession of the equinoxes is the regular change in the time when the earth is at a given distance from the Sun.
(iv) Shifting of the earth on its polar axis.
(v) Changes in the rate at which the earth rotates on its axis, influencing the diurnal heat budget and, ultimately, global climates. The earth receives a certain amount of insolation (short waves) and gives back heat into space by terrestrial radiation (long wave radiation). Through this inflow and outflow of heat, the earth maintains a constant temperature and this phenomenon is referred to as the heat budget of the earth.

Climate has previously been greatly impacted by changes to the earth's orbit and rotational axis. For example, the amount of summer sunshine in the Northern Hemisphere, which is influenced by variations in the planets' orbits, appears to be the main factor in past cycles of ice ages, during which the earth has experienced both long periods of extremely cold temperatures (the ice ages) and shorter interglacial periods (periods between the ice ages), during which temperatures were relatively warmer. The Earth's orbit, axial tilt, and wobble change over persistent periods of time, and this phenomenon is known as a Milankovitch cycle. Over extended periods of time, these variations influence climate change. They start off ice ages and naturally occurring periods of global warming. A century ago, Serbian scientist Milutin Milankovitch hypothesized the long-term climate, and is responsible for triggering the beginning and end of glaciations period (ice age). Seasonal variations are explained by changes in the earth's orbit around the sun according to the Milankovitch or astronomical theory of climate change. It is known that, in the geological past, the Milankovitch cycle induced ice ages.

2-Geological factors: The earth's climate has undergone a number of significant changes, according to geological records. These have been caused by different types of natural phenomena, such as volcanic emissions, continental drift, rock weathering, changes in the topography of the ocean floor, and mountain building. Volcanic ash has increased atmospheric albedo (fraction of light that a surface reflects), reducing insolation at the earth's surface. Ash layers in Antarctic ice disclose a period of intense volcanic activity between 30, 000 and 17, 000 years ago, when temperatures dropped by about 30 degrees Celsius. Continental drift during previous geological eras would account for significant climatic changes as land masses shifted in relation to one another and assumed different latitudinal positions. Geophysicists have improved the theory of plate tectonics since the middle of the 20th century, supporting explanations of climatic change based on crustal movements.

3-Oceanic factors: The structural warping of ocean basins changes sea level and oceanic circulation, affecting heat and moisture transport. Water temperatures and circulation may change in response to climate change which in turn affects climate. For example- the El Nino effect changes in ocean circulation, ice formation, sea level changes, dimethysulphide production, and phytoplankton blooms. El Nino is best understood as a natural occurrence in which the temperature of the ocean rises, particularly in parts of the Pacific Ocean. La Nina is a similar natural occurrence to El Nino. Since it causes the ocean water to "cool" in some areas of the Pacific Ocean, it is referred to as the opposite of the El Nina phenomenon. The term El Nino basically means ‘the child’. This is due to the fact that this current starts to flow around Christmas and hence the name referring to baby Christ. Another natural phenomenon, similar to El Nino is La Nina, which is also in news these days. The term La Nina literally means ‘little girl’. It is termed as opposite to the phenomenon of El Nino as it results in the ‘cooling’ of the ocean water in parts of the Pacific Ocean.

Along with oceanic changes, both of them also cause changes in atmospheric conditions.

4-Land Surface Factors: A change in the use or management of land is referred to as a "land-use change." A number of human activities, including changes in agriculture and irrigation, reforestation, deforestation, and afforestation, as well as urbanisation and traffic, may cause such change. The physical and biological characteristics of the land surface are altered as a result of land use change, and the climate system is also affected. Changes in land use may affect the local, regional, or even global climate. They also have a significant impact on the carbon cycle. Physical processes and feedbacks caused by land-use change, that may have an impact on the climate, include variations in albedo and surface roughness, and the exchange of water vapour and greenhouse gases between the atmosphere and the land. Land-use change may also affect the climate system through biological processes and feedbacks involving the terrestrial vegetation, land-use change may also have an impact on the climate system. These changes may affect the sources and sinks of carbon in all of its forms. It includes the impact of vegetation on surface albedo (the percentage of solar energy that is reflected back to space), evapo-transpiration, the effects of open water, such as irrigation, and dust.

Changes in land use (human management and activities on land, such as mining or recreation) and land cover (the physical features that cover the land, such as trees or pavement) can both affect and be affected by the climate. Farmers may shift from traditional crops to crops with higher economic returns under changing climatic conditions. For example, legumes, millets, and grasses, which were once common components of cropping systems in Indian agriculture, have largely been dropped out in high-yielding areas due to low economic returns, and have been replaced by high-yielding sugarcane, wheat, rice, and other crops. During the past 40 to 50 years, consumption of NPK fertilisers as well as the use of pesticides like HCH and DDT both increased significantly. Thus, pesticide levels in soil increased, particularly in Punjab, Karnataka, and Uttar Pradesh. The increased use of N-fertilizers has resulted in an increase in NH_3 and nitrogen oxides in the atmosphere, causing global warming and other environmental issues.

The International Geosphere Biosphere Programme (IGBP) in 1995, reported that changes in soil and land use patterns have an impact on the environmental conditions of any area. Changes in the earth's terrestrial or landcovers cause significant changes in several biophysical processes, which affect the global environment.

5- Sunspot Theory: Changes in solar irradiance have been linked to variations in sunspot activity. In the photosphere (the Sun's outermost layer), sun spots are denser and colder regions. The sun goes through a natural solar cycle approximately every 11 years. The cycle is marked by the increase and decrease of sunspots which are caused by the Sun’s magnetic fields. In any given solar cycle, the term "solar maximum" and "solar minimum" are used to describe the highest and lowest numbers of sunspots, respectively. The temperature of Earth may rise if there are more sunspots, while the temperature of the atmosphere may fall if there are fewer sunspots. Earth's orbit could be changed by the magnetic pull of sunspots. The prolonged period of minimum sunspot activity, called as Maunder minimum, is connected to the little Ice age, a time of markedly lower temperature, in particular in the Northern hemisphere. The most recent grand solar minimum took place during the Maunder minimum (1645–1710), which resulted in a 0.22% decrease in solar irradiance from the present and a 1.0–1.5^{0}C decrease in the average terrestrial temperature. It should be noted that no perfect correlation has been established between sunspot activity and atmospheric temperature. It is possible that periodic fluctuations in sunspot cycles will cause weather changes on a shorter time scale.

6- Atmospheric Dust Hypothesis: Dust, pollen, salt, smoke, soot, ash, and volcanic dusts are a few examples of the solid particulates in the air. Solid particles caused by vegetation burning, wind erosion, and pollution from industries and cities all contribute to atmospheric dust. The atmosphere maintains a suspension of the majority of solid particles. High concentrations of these solid particulate matters in the atmosphere reduce solar radiation by absorbing or scattering sunlight before it reaches the surface of the earth. Approximately 23 percent of incoming solar radiation is scattered by dust particles and haze, with 6 percent of the energy returned to space and 17 percent reaching the earth's surface as diffuse day light much later. As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by clouds, air molecules, dust, volcanoes, pollutants, forest fires, and so on. This is referred to as diffuse solar radiation. Direct beam solar radiation is the solar radiation that reaches the earth's surface without being diffused. The total of diffuse and direct solar radiation is referred to as global solar radiation. Direct beam radiation can be reduced by 10% on clear, dry days and by 100% on thick, cloudy days due to atmospheric conditions.

It is well known that powerful volcanic eruptions cause sudden increases in dust particles, which significantly lower the earth's surface temperature at its lower atmosphere and cause changes in weather and climatic conditions, at least on a shorter time scale. For example, the violent eruption of a volcano on the island of Krakatoa on August 27, 1883, produced 9TNT equivalent of approximately 100 million tonnes and nearly 20 cubic kilometres of fragmentary materials, dust, and ashes that were thrown (in the air up to 32 kilometres) in the atmosphere, which caused a global reduction in solar radiation received at the earth's surface of between 10 and 20 percent.

7-Radioactive forcing: Solar radioactive forcing is thought to be a major contributor to climate change. The term "planet's radioactive forcing" refers to the difference between incoming and outgoing radiation (RF). According to the basic principles of thermodynamics, the earth must eventually release an equal amount of energy into space for every amount of energy it absorbs from the Sun. When the amount of energy entering the Earth's atmosphere differs from the amount of energy leaving it, radioactive forcing results. The Sun's solar radiation, which enters the atmosphere, and infrared radiation, which is heat, are both forms of radiation that carry energy. If the amount of radiation entering the earth is greater than the amount of radiation leaving the earth, the atmosphere will warm. This phenomenon is referred to as "radioactive forcing" because the energy imbalance can cause climate change on Earth. The planet will warm when forcing results in incoming energy being greater than outgoing energy (positive RF). On the other hand, if outgoing energy exceeds incoming energy, the planet will cool. A complex network of physical processes, many of which are connected, results in changes in precipitation, temperature, and other climate variables when the radioactive balance (or forcing) changes.

Human-induced climate variations

The effect of human activities on the climatic conditions of the planet is known as anthropogenic climate change. The United Nations frame work Convention on Climate Change (UNFCC) in Article 1 defined it as: “Climate change refers to a change in climate that is attributed directly or indirectly to human activity that changes the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period” (IPCC, 2001a).

The majority of the current climate changes are being caused by humans through the burning of fossil fuels, deforestation, etc. The biological and physical factors of the earth's surface are affected by land-use change as a result of urbanisation, human forestry, and agricultural practices. Since the industrial revolution, gases like carbon dioxide, chlorofluorocarbons, nitrous oxide, water vapour, trace amounts of ozone, methane, and other gases have been massively released by human activity into the atmosphere, changing the climate of the earth. These gases function somewhat similarly to the glass walls of a greenhouse, collectively known as greenhouse gases. They trap infrared waves that radiate from the earth's surface are responsible for the green house effect.

Greenhouse effect: The greenhouse effect is the process by which solar radiations are absorbed by greenhouse gases (like carbon dioxide) and not reflected back into space. It is the natural process that warms the Earth’s surface and keeps the earth's temperature constant. Without greenhouse gases, the earth would be too cold for life to exist. These gases keep the earth warm in the same way that glass in a greenhouse keeps plants warm. Human activities, such as the use of fossil fuels to power factories, automobiles, and buses, are altering the natural greenhouse effect. Because of these changes, the atmosphere traps more heat than it used to, resulting in a warmer Earth. The green house effect is a phenomenon that is primary cause of climate change.

The main cause of the greenhouse effect is carbon dioxide that is produced by human activity. Additional gases that contribute to global warming include methane, CFCs, and nitrous oxide. These gases are more effective at enhancing the greenhouse gases because they are better at absorbing long wave radiation. The main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), water vapour (H_2O), nitrous oxide (N_2O), and ozone (O_3). Since the pre-industrial era, concentrations of carbon dioxide, methane, and nitrous oxide have increased by 30%, 145%, and 15%, respectively. This increase is primarily due to the use of fossil fuels, changes in land use, and agriculture. The main gases responsible for the greenhouse effect are as follows:

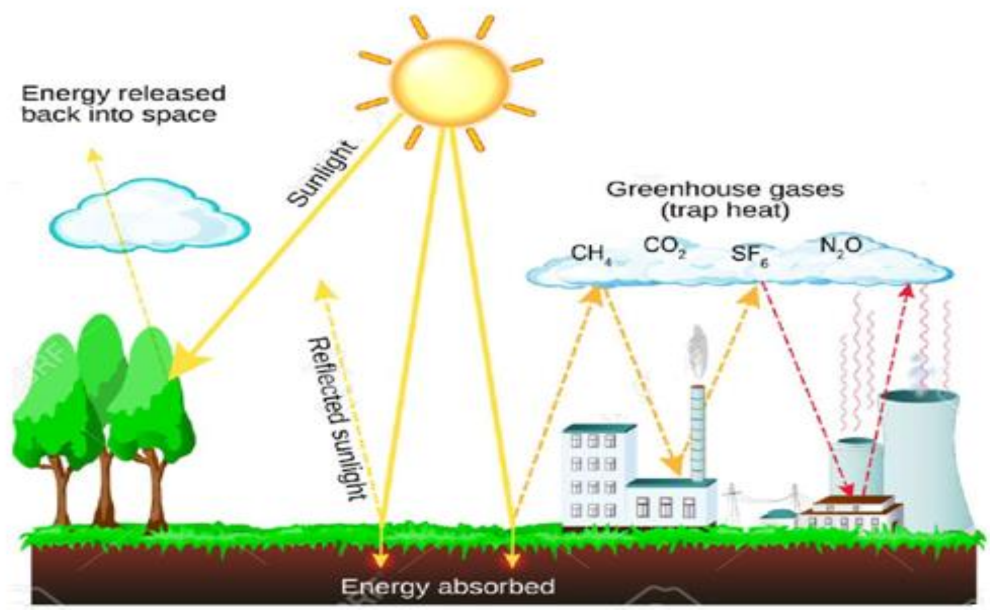

Fig.10.1: Diagram showing Greenhouse effect
(Source: https://www.123rf.com/photo_66662245_greenhouse-effect-diagram-showing-how-the-greenhouse-effect-works-global-warming.html)

1. **Carbondioxide:** The second-most abundant greenhouse gas is carbon dioxide (CO_2), which accounts for only about 0.038 percent of the atmosphere. Carbondioxide is naturally present in the atmosphere as part of the earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants and animals). Human activities are changing the carbon cycle by increasing the amount of CO_2 in the atmosphere and by affecting the capacity of natural sinks, such as soils and forests, to absorb and store CO_2. Although there are many different natural sources of CO_2 emissions, since the industrial revolution, the amount of CO_2 in the atmosphere has increased due to human-related emissions. Carbon dioxide concentration in the

atmosphere will nearly double to 550 ppm (by volume) by the end of the twenty-first century, even if emissions are maintained at 1994 levels.

2. **Methane (CH_4):** Methane is released during the production and transport of oil, coal and natural gas. Land use, livestock and other agricultural practices, as well as the decomposition of organic waste in municipal solid waste landfills, all contribute to methane emissions. It is produced anaerobically by bacterial activity in bogs, rice paddies, ruminative animals' digestive tracts, and insects like termites. On a global scale, wetlands, such as swamps, bogs, and tundra, contribute approximately 27% of atmospheric CH_4. Methane-producing bacteria thrive in the rich organic matter and low oxygen content. The bacteria present in the anaerobic digestive process of animals (particularly ruminants) such as cattle and certain species of termites are the second leading source, accounting for approximately 22 percent of the total. Termites alone emit 4% of the atmospheric CH_4. Although other animals emit CH_4, the total is thought to be negligible. The flooding of rice fields, where certain types of bacteria flourish, is a third major source of CH_4 (11 percent). The remaining of the atmospheric CH_4 is thought to be accounted for by fossil fuel combustion, biomass combustion, landfills, and biological oceanic processes.
3. **Nitrous oxide (N_2O):** Nitrous oxide is released during land use, industrial, and agricultural processes, as well as when solid waste and fossil fuels are burned and when waste water is being treated. Bacterial activity in the soil naturally produces this gas. Nitrous oxide is produced as a result of denitrification of nitrates. In compare to other nitrogen oxides, N_2O has a longer life span (140–190 years), and its concentration in the atmosphere is 380 ppb and is increasing at a rate of about 0.3% per year due to the increased use of fossil fuels and chemical fertilizers. One N_2O molecule traps heat 250 times more effectively than one CO_2 molecule. It contributes 4% to overall global warming.
4. **Other green house gases or Tropospheric Ozone (O_3):** Tropospheric ozone is reactive gas that occurs in two layers of the atmosphere: the stratosphere (upper layer) and the troposphere (at ground level and upto 15 km). Tropospheric ozone is not directly emitted, as it is a secondary gas formed when sunlight interacts with hydrocarbons, including methane and nitrogen oxides, which are released by vehicles, factories, refineries, fossil fuel, power plants, and other man-made sources. It is a climate pollutant with a short lived atmospheric lifetime of a few hours to a few weeks. Good ozone naturally occurs in the upper atmosphere where it forms a shield that protects us from the Sun's harmful ultraviolet rays. At lower levels, however, it is a significant air pollutant and greenhouse gas that traps heat and contribute to climate change. Ozone is a dangerous air pollutant at ground level, because of its negative effects on both people and the environment, and it is the main component of "smog". The ozone layer blocks UV-B from reaching the earth's surface, and as it thins, more UV-B light penetrates the atmosphere. A rise in UV-B can have a negative impact on people's health, plants, and the degradation of materials.

According to a photograph taken by the NIMBUS-7 satellite on October 5, 1987, the protective ozone layer showed a hole covering more than 50% of the area of the Antarctic continent. This hole is about 7 million square kilometres in size. According to some studies, sunlight and the presence of ice crystals speed up the breakdown of ozone. Although man-made CFCs are the main cause of ozone depletion, natural events such as volcanic eruptions can also contribute to ozone depletion. Rumen Bujkov of the UN International Ozone Commission reported in 1994 that ozone levels had decreased by 10% globally over the last twenty-five years. More concerning for Americans is that the ozone shield over the United States was thinned by 15% during the winters of 1992 and 1993. On some days, the depletion was as high as 45%, with similarly high levels over Europe and Siberia. An international conference was held in Montreal, Canada, because of the importance of the situation. At this conference, 24 countries agreed to reduce ozone-depleting chemical production and use by 50% by the year 1999. Chile, the only populous country located under the Antarctic ozone hole, has seen a fourfold increase in malignant melanoma since 1980. If the model and measurements of ozone depletion and its possible effects are accurate, the production of any ozone depleting chemicals must stop immediately. Even if we stop producing ozone depleting chemicals, models show that it will take 50-100 years for the ozone layer to return to 1985 levels, and another 100-200 years for fall recovery.

5. **Fluorinated gases:** Fluorine-containing gases are referred to as fluorinated greenhouse gases (F-gases). They act as powerful greenhouse gases, storing heat in the atmosphere and causing global warming. They are stronger than the greenhouse gases that occur naturally, and their use is controlled. F-gases are commonly used in aerosol sprays, foaming agents, fire extinguishers, solvents, coolants, etc. Hydrochlorofluorocarbons (HCFCC), Chlorofluorocarbons (CFCs), Hydrofluorocarbons (HFCS), Sulfur Hexafluoride (SF_6), and perfluorocarbons (PFCS) are all part of this group. F-gases are important greenhouse gases that have an even greater potential for warming than carbon dioxide (CO_2). Thus, by trapping heat, they significantly contribute to climate change. According to the Montreal Protocol, CFCs were gradually phased out of production in developed countries by 1996 and in developing countries by 2010 and are now being replaced by other products like hydrofluorocarbons (HFCs). Compared to CFCs, HDFCs have a much lesser impact on the loss of stratospheric ozone.

Acid Rain: Acid rain is any form of precipitation like rain, fog, snow, dew with acidic components, such as nitric or sulfuric acid that fall to the ground from the atmosphere in dry or wet forms. In the presence of oxygen and high combustion temperatures, sulfur compounds are oxidized to become sulfur oxides (SOx). Sulfur dioxide is itself a poison, but it can also react with ozone, water vapour and hydrogen peroxide in the atmosphere to form sulfuric acid (H_2SO_4) combustion at high temperatures in power plants and smelters also create oxides of nitrogen, mostly as atmospheric nitrogen combines with oxygen. Although nitric oxide (NO) is not very harmful as it does not readily dissolve, nitric oxide can combine with oxygen to form nitrogen dioxide:

$$2NO + O_2 = 2NO_2$$

Nitrogen dioxide is similar to sulfur dioxide; through various reactions with substances in the atmosphere, nitrogen dioxide is converted into nitric acid (HNO_3).

Millions of metric tons sulphuric acid and nitric acid fall in on earth each year, principally on the Canada, Europe and United States. The detrimental effect of acid rain on forests was evident in Northern Europe in the 1980s.

Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NOx) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NOx react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. Acid rain inflicted devastating losses to alpine vegetation, water quality fisheries, and soil health. Acid rain can be formed by natural causes, such as volcanic eruptions, lightning, or organic decay. More commonly, however, acid rain is due to human activities such as burning fossil fuels, oil refineries, manufacturing, vehicles and electricity generation all release sulfur and nitrogen oxides into the atmosphere. Rapid industrialization is the main cause of increase in the incidence of acid rain and precipitation with low pH value is common in industrialized nations. Acid rain also removes minerals and nutrients from the soil that trees need to grow. Acid rain causing pollution also causes climate change. For example, coal –fired power plants that produce acid rain also emit high levels of carbon dioxide that accelerate climate change. In the Czech Republic, many trees lost all their leaves as a result of acid rain. In 1984 it was reported that almost half of the trees in the famous black forest in Germany had been damaged by acid rain. The past, present, and future likely trends of various green house gases are given in table 1.

Table-1: Past, Present, and Future details of important Greenhouse Gases

Parameter Concentration	**CO_2**	**CH_4**	**N_2O**	**CFCS**
1850	280ppm	1150 ppb	285 ppb	0 ppb
1985	345 ppm	1790 ppb	305 ppb	0.4 ppb
Expected 2075	526 ppm	4402 ppb	478 ppb	3.8 ppb
Annual concentration increases %	0.4	1	0.2	5
Relative greenhouse efficiency CO_2^{-1}	51	25	230	1500
Current greenhouse contribution %	57	12	6	25
Anticipated rate between 1985 & 2075 %	0.57	1.0	0.5	2.5
Equilibrium temperature change 1850-2075 ^{O}C	3.12	0.62	0.28	0.93=total 4.95 ^{0}C
% total temperature change	63	12	06	19=100%
Life time year	100	10	150	100

Global Warming: Global warming refers to the gradual, long-term rise in the average temperature of the Earth's atmosphere caused by the greenhouse effect. The global mean surface air temperature (the earth's surface temperature) has increased between 0.3 ^{O}C and 0.6 ^{O}C,

particularly in the latter half of the twentieth century. According to IPCC projections, global mean surface temperature will be about 2 ^{O}C above pre-industrial levels by 2030 and about 4^{0}C above pre-industrial levels by 2090. Global warming is the term used to describe a rise in global temperature. It is a phenomenon that occurs when the amount of greenhouse gases in the atmosphere rises. In addition to the natural causes, human activities like extensive industrialization and the accumulation of polluting gases in the atmosphere also play a significant role in the phenomenon of global warming. The effects of this global warming include extreme heat, protected drought, increased flooding, more intense storms, and rising sea levels. These changes have also dramatically altered natural cycles and weather patterns. Climate change is the collective term for these unpleasant and occasionally fatal effects.
An international committee of scientists commissioned by various world governments also provides a definitive verdict on what has happened to the weather around the world in the last decade." According to the report, the world has been warming since the 1980s. The world has already warmed up by about 0.50 degrees Celsius. By 2030, temperatures are expected to rise by 4^{O}C.

10.5 IMPACTS OF CLIMATE CHANGE

Climate change is the term used to describe changes in the Earth's climate that produce new weather patterns that last for a few decades or millions of years. The earth's environment is changing suddenly due to climate change. For humans, this change poses a serious threat. The winter season is getting shorter and shorter every year, while the summer season has increased in temperature. The ecosystem and ecology are being affected by these climate changes in a number of different ways. Major problems like severe storms, heat waves, floods, melting glaciers, etc. are as a result of these changes.

1. **Impacts of climate change on ocean:** The most of the excess heat from greenhouse gas emissions is absorbed by the ocean, which raises ocean temperatures. Marine species and ecosystems are affected by rising ocean temperatures. Because of the ocean's capacity to absorb excess heat, people have been protected from even more rapid climatic changes. Ocean warming causes deoxygenation (reduction of the oxygen content of the ocean), as well as sea-level rise caused by the thermal expansion (general increase in the volume of a material as its temperature is increased) of sea water and the melting of continental ice. These changes, along with ocean acidification (a decrease in the ocean's pH as a result of absorbing CO_2) affect marine species and ecosystems. Due to the significant increase in carbon dioxide emissions into the atmosphere the acidity of the ocean's surface water has gradually increased. The average pH of the ocean is now around 8.1, which is basic (or alkaline), but as the ocean absorbs more CO_2, the pH drops and the ocean becomes more acidic. Ocean acidification is causing a sea change that is endangering the ocean's fundamental chemical balance. The ocean's acidity is raised when this CO_2 reacts with seawater to produce carbonic acid. Scientific research

indicates that the oceans' surface pH has decreased by about 0.1 pH units, which is equal to a 30% increase in acidity. Higher acidity disturbs the mineral balance in the water, making it more difficult for certain marine animals to build their protective skeletons or shells. For example- the Great Barrier Reef.
Increases in temperature also have an impact on vegetation and species that form reefs, like corals and mangroves, protecting coastlines from erosion and sea level rise. Particularly low-lying island nations in the Pacific Ocean will be impacted by erosion and rising sea levels, which will destroy housing and infrastructure and force people to relocate.

As ocean temperature rise, the density of the ocean water will likely decrease, leading to a slight volume expansion of the oceans. According to estimate, this factor alone may account for up to 25% of the potential sea level rise. In the following century, it is expected that sea level will significantly rise as a result of both the effect of melt water addition and other factors. Sea level projected to rise between 9 cm and 29 cm by 2030 and 96 cm by 2090.

An increase in tropical cyclone activity is another possible indirect effect. Because hurricanes and other tropical cyclones require warm water to form, rising temperatures are likely to expand the surface area of the Earth where tropical cyclones can form and track, as well as lengthen the season. The extra energy released by global warming would then be available to drive evaporation and subsequent latent heat release, thereby energising tropical cyclones. Although tropical cyclones may be more intense than in the past as a result of global warming, some scientists believe the effect is excessive and that other natural cycles in tropical cyclone activity exceed any trends caused by global warming.

2. **Snow and ice:** The loss of snow and ice cover is affecting our climate system and changing ecosystems. Ice protects the Earth and its oceans. Snow cover affects the temperature of the Earth's surface. The amount of sunlight that the Earth absorbs or rejects is determined by its surface and atmosphere. On average, the earth absorbs 70% of the sunlight that it receives. The soil, forests, and ocean are examples of dark objects and surfaces that tend to absorb more sunlight. Snow and clouds are examples of light-colored objects and surfaces that often reflect sunlight. These brilliant white spots, which reflect excess heat back into space, keep the planet cool. Snow and ice reflect more sunlight than open water or bare ground due to their light colour, so as less snow and ice is present, the Earth's surface warms. The poles are experiencing the fastest rise in global temperatures. As a result, ice sheets and glaciers melt and shrink. Melting glaciers contribute to rising sea levels, which promotes coastal erosion and tidal waves as

warming air and ocean temperatures affect and increase coastal storms such as typhoons and hurricanes.

3. **Ecological impact:** The term "ecological impacts" refers to changes in the number, distribution, and functions of organisms, including their interactions with one another and the effects on the abiotic environment. Examples of impacts include a rise in the extinction of many species, increases or decreases in freshwater fish populations depending on geographic location, and diverse effects on migratory birds, with some arctic-nesting herbivores benefiting and continental nesters and shorebirds suffering.
4. **Impact on Ecosystem:** Ecosystems are significantly impacted by the climate in many different ways. Rising temperatures change ecosystems, affecting the timing of the seasons as well as the geographic range of particular habitat types. Various changes in ecosystems are being caused by the combined effects of climate change. The diverse components of the ecosystems, such as the animals, plants, temperature, wind, etc., are adversely affected by changes in the climatic conditions. The water cycle, animal migration and nesting habits, the timing of natural processes like flower blooms, and habitats are all affected by climate change. For example, species may be forced to migrate to higher latitudes or elevations where temperatures are more favourable for their survival. As sea levels rise, saltwater intrusion into freshwater systems may cause some important species to move or go extinct, removing predators or prey that are essential to the current food chain. Many species experience key stages of their annual life cycle, such as migration, reproduction, and blooming, as a result of the climate where they live or spend a portion of the year. If increases in global average temperature exceed 1.5–2.50°C, it is likely that 20–30% of plant and animal species assessed thus far will face an increased risk of extinction. Lowered oxygen levels, a decline in phytoplankton (the tiny plants that serve as the base of the marine food chain), and coral reef destruction are all effects of climate change that have an impact on ocean habitats.

   In order to adjust to changes in temperature or other environmental conditions, some birds change their wintering grounds or their migratory patterns. Increases in global average temperature exceeding 1.5-2.50 degrees Celsius and persistent atmospheric carbon dioxide concentrations are expected to cause significant changes in ecosystem structure and function, species ecological interactions, and species' geographic ranges. These changes will primarily harm biodiversity and ecosystem goods and services, such as food supply and water, and will alter how ecosystems function and interact with one another.
5. **On human health:** The World Health Organization has described climate change as the greatest threat to health in the twenty-first century, affecting health and well-being in a variety of ways: directly, through increased intensity and frequency of extreme weather events such as floods, heat waves, and bushfires; and indirectly, by worsening air quality, changes in the spread of infectious diseases, effects on mental health, and threats to food and water. The most at risk groups for climate-related health effects are the elderly,

children, the poor, and those with existing medical conditions. Extreme heat and poor air quality make it more difficult for people to recover from respiratory and heat-related conditions like renal failure, asthma, and preterm birth. It is likely that disease-carrying ticks and mosquitoes will multiply and spread to new areas. Mosquito-borne diseases such as dengue and malaria fever are now being reported at higher elevations than earlier. Climate change may have a significant impact on fresh water supplies. Reducing the availability of clean water causes the death of both humans and animals.

6. **Impact on Agriculture:** Global climate change affects agricultural productivity in both direct and indirect ways. Changes in the length of the growing season, altered rainfall patterns, and the frequency of heat waves have direct effects, while changes in top soil management practices have indirect effects. In many areas, higher temperatures that shorten a crop's growing season could result in lower dryland yields of corn, soybeans, and wheat. Conversely, as temperatures rise, corn and soybean yields on dry land could increase by 5 to 20%. Irrigation would almost certainly increase in many areas because irrigated yields are more stable than dry-land yields under conditions of increased heat stress and decreased precipitation. Water availability has a significant impact on agriculture in general. Changes in climate will affect rainfall, runoff, evaporation, and soil moisture storage. Changes in total seasonal precipitation or its distribution pattern are both significant. Moisture stress during flowering, pollination, and grain filling is harmful to most crops, especially soyabeans, wheat, and corn. Moisture stress will be caused by increased evaporation from the soil and accelerated transpiration in the plant itself; as a result, crop varieties with greater drought tolerance will be required. Climate and atmospheric variables influencing plant productivity include temperature, water, solar radiation, and CO2 concentrations in the atmosphere. Increased CO2 levels in the atmosphere result in increased crop productivity. In experiments, wheat, rice and soyabeans belongs to a physiological class (called C_3 plants) that exhibit an increase in productivity of about 20-30% at doubled CO_2 concentrations. C_4 plants, such as sugarcane, maize, corn, sorghum and millet, show a much less pronounced response than the C_3 crops, increasing productivity on average by 5-10 %. In general, higher CO_2 concentrations also lead to improved water-use efficiency of both C_3 and C_4 plants. Response, however, depends on crop species as well as soil fertility conditions and other possible limiting factors.

10.6 FOREST

Climate change is one of the world's most serious issues, and it has an impact on the forest ecosystem. A forest is a complex ecological system. The dominant life form in a forest is a tree. According to the United Nations' food and agriculture organization, Forest is defined as "Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10%, or tree able to reach these thresholds in this situation". There are forests all over the world, which make up the majority of the terrestrial ecosystem. They can grow in different conditions within these climatic boundaries, and the types of soil, plants, and animals that can be found depend on the extremes of environmental conditions. Every living thing depends on forests to survive. They are essential to our survival because they provide oxygen, shelter, food, fuel, and a means of livelihood for the tribal people who live in and around the forest. About 80% of the world's terrestrial biodiversity can be found in forests, which are also the source of all the essential resources for nearby human settlements. Forests help to keep the climate stable. They protect biodiversity and regulate ecosystems, play an important role in the carbon cycle, support livelihoods, and provide goods and services that can drive long-term growth.

The health of forests is greatly impacted by climate, which also affects the structure and functioning of forest ecosystems. There are many threats to forests, such as pest outbreaks, fires, human development, and drought, may become worse as a result of climate change. Temperature, rainfall, weather, and other factors are just a few of the ways that climate change affects the growth and productivity of forests. These modifications have a wide range of effects on complex forest.

10.7 EFFECTS OF CLIMATE CHANGE ON FOREST

Forest ecosystems are experiencing unprecedented environmental changes as a result of the effects of climate change. The physiology and growth of individual trees to the cycling of nutrients are all impacted by changes in the global nitrogen and carbon biogeochemical cycles and the resulting climate change.

Climate change is likely to influence the frequency and severity of forest disturbances, such as wildfires, storms, insect outbreaks, and the appearance of invasive species. Changes in temperature, precipitation, and the amount of carbon dioxide in the atmosphere could all have an impact on forest productivity and distribution. Climate change, mainly increased temperatures and carbon dioxide levels in the atmosphere, as well as changes in precipitation and the frequency and severity of extreme climatic events, is having a major effect on the world's forests and the forest sector. The following are the effects of climate change on forest:

1. **Tree Migration:** The duration of the growing season usually gets longer as temperatures rise. It also causes some tree specie’s geographic ranges to shift. Some tree species will shift their ranges and migrate into landscapes where they do not normally grow in response to climate change. For example- As temperatures rise, some tree species may migrate uphill and toward the north, whereas others may migrate westward and downward as drier conditions are brought on by shifting precipitation patterns. Other species will face local or regional extinction if conditions in their current geographic ranges are no longer suitable. Plant distribution has shifted poleward in 30 alpine peaks. The species that relocated the quickest were those with shorter life spans and faster

reproduction cycles, such as ferns, mosses, and herbs; larger long-lived trees and shrubs did not show a significant shift and are thus more vulnerable to the effects of climate change because they cannot adapt to local conditions quickly enough and must relocate.

2. **Wild fires (Forest fires) and Climate change:** Climate change has played a significant role in increasing the risk and extent of wildfires. Wildfires are a natural occurrence, but they are becoming more dangerous and affecting larger areas. The risk of a wildfire is determined by a variety of factors, including temperature and the presence of trees, shrubs, and other potential fuel. All of these factors have strong direct or indirect links to climate variability and change. Climate change is causing higher temperatures, drier vegetation, and longer droughts. Severe heat and drought fuel wildfires, which scientists associate to climate change. Previously, wildfires rarely spread to humid tropical forests. However, due to deforestation and forest fragmentation, these forests are becoming increasingly at risk. The risk and severity of forest fires are greatly increased by rising temperatures. The effects of fire on the forest ecosystem include the death of individual trees, change of the habitat for wildlife, and accelerated nutrient cycling. The quantity and frequency of precipitation as well as the structure and composition of the forest all affect the frequency, intensity, size, seasonality, and type of fires. Fire plays an important role in controlling the carbon balance of forests and weakens their capacity as carbon sinks. Forest wildfires reduce most soil nutrients, affecting available macronutrient concentrations. The ability of prescribed fire to reduce nitrogen saturation caused by atmospheric deposition and disturbances that can result in comparable nutrient loss in such a short period of time.

3. **Invasive species:** Climate change may make conditions more favourable for invasive species. It is likely that alien species will completely replace one dominant species in native habitats because it is no longer adapted to the environmental conditions of its environment. This will have a significant impact on successional patterns, ecosystem function, and resource distribution. Climate change and rising levels of greenhouse gases can both have a significant impact on the success of invasive species. Higher carbondioxide concentrations increase photosynthetic rates and water use efficiency in plants and ecosystems, and the resulting increased soil moisture has the ability to provide habitat for late-season annuals that may be invasive. Major changes in the species composition and dynamics of terrestrial ecosystems are to be expected, because not all plant species are affected in the same way by increased CO_2 levels. Changes in nitrate deposition from the atmosphere caused by the combustion of fossil fuels have resulted in significant changes in vegetation that may favour the growth of some invasive species. Changes in a species' or community's distribution, particularly at their altitudinal or latitudinal extremes, are typically linked to the consistent responses of the species or community to climate change, or the "fingerprints" of the species or community.

4. **Drought:** Excessive radiation causes severe desiccation of plants and soil. This results in drought. Droughts have varying effects on plant species depending on species, age, soil cover, destruction, locality condition, crop density, weather, and season. Drought has a greater impact on plains than on hills. Drought hardy plants such as zizphus, acacia, prosopis, and others can withstand drought conditions, whereas evergreen and drought tolerant species suffer greatly during drought conditions. Climate change will almost certainly increase the risk of drought in some areas while decreasing the risk of extreme precipitation and flooding in others. The timing of snowmelt is altered by rising temperatures, which has an impact on the seasonal water supply. According to research, trees respond to drought stress by closing their stomata, the pores that allow carbon dioxide to enter the tree. Because of this, trees are forced to rely on stored sugars and starches, and if they discharge those reserves before the drought is over, they risk "carbon starvation," which causes them to die. Additionally, during a drought, trees that lose too much water too quickly may develop air bubbles that restrict the movement of water from the roots to the leaves, a process that can lead to death. Although many trees can withstand some drought, rising temperatures may cause future droughts to be more destructive than those that have already occurred.

   With increasing temperature, precipitation, and nutrient availability, forest productivity and species diversity typically increase, though species may vary in their tolerance. Changes in precipitation and temperature will have a significant impact on moisture availability in forests. Warmer temperatures cause increased water losses from evapotranspiration and evaporation, as well as decreased plant water use efficiency. Warmer, longer growing seasons can worsen these effects, causing severe moisture stress and drought.

5. **Impacts on forest Pests:** Climate change can have an impact on forest pests and the damage they cause by directly affecting their reproduction, development, survival, spread, and distribution, altering host physiology and defences, and affecting the relationships between pests, their environment, and other species. Changes in disturbance patterns caused by forest pests (pathogens, insects, and other pests) are expected as the climate changes. Insects and pathogens have been observed to respond to warming in all expected ways, including changes in phenology and distribution, as well as influence on community dynamics and composition. While some climate change effects may be helpful for maintaining the health of forests for example- increased winter mortality of some insect pests because of inadequate snow cover, slowdown larval development, and increased mortality during droughts, many effects will be quite detrimental For example- accelerated insect development rate; ranges expansions of pests.

   When trees are exposed to wildfires or drought, they can become less resistant to pathogens and pests, and as climate change causes drier, warmer conditions in some parts of the country, outbreaks could become more common. When trees are stressed by drought or other adverse conditions, they have less energy to defend themselves. They become more sensitive to insects, bacteria, viruses, and fungi, among other things. Pests and pathogens are generally found in low population or infection levels in forests, but they can cause trouble on trees on occasion. The range and presence of forest pathogens and pests will expand as a result of climate change. Drought-related warmer temperatures and drier conditions, in particular, may increase the reproductive rate of certain insect species.

6. **Effect on Forest Nutrient Cycling:** Forest nutrient cycling is defined as the processes of nutrient uptake, incorporation of mineral nutrients into biological tissues of plants and trees, litter fall, and the decomposition of organic matter with the simultaneous release of nutrients to soil by microorganisms. There are important connections between trees and soil nutrient availability. One of the most important aspects of forest ecosystem functioning is nutrient cycling between soil and plant. Climate change can have a direct impact on nutrient cycling by affecting temperature and precipitation. The productivity and integrity of forest ecosystems are linked to nutrient supply, and climate change can influence nutrient dynamics by changing the rate of litter decomposition. Climate change and nitrogen deposition have additional effects on litter fall dynamics, as well as subsequent decomposition and nutrient mineralization processes.

7. **Effects on forest processes and productivity:** Climate change has an impact on the productivity of the forest. There are various direct and indirect ways. Changes in phenology, such as when trees leaf out in the spring or flower buds open, are examples of direct effects. Damage caused by an insect whose range expands due to warmer winters could be an indirect effect. Many forest processes are influenced by photoperiod rather than climate change. Temperature and other weather variables have an impact on other processes. One common example is the timing of leaf expansion. Dr. Andy Burton (Michigan Technological University) noticed that the length of the sugar maple growing season has increased by 11.5 days in Michigan over the last 20 years across a variety of sites. Climate change is affecting forest productivity. Longer periods of warmer weather enable plants to have longer growing seasons and more time for photosynthesis. Photosynthesis requires heat, light, carbon dioxide, and water nutrients for trees to grow. Temperature and carbon dioxide concentrations in the atmosphere are changing photosynthesis rates and growth. Plants have their own mechanism for tolerating a certain level of temperature increase. Rising temperatures have an effect on leaf phenology (leaf maturation, bud break, and leaf senescence), making trees more vulnerable to late spring frosts and soil freezing, stressing them and reducing their productivity. Warmer temperatures combined with drier conditions during the growing season can also cause tree stress and reduce overall forest productivity. As the temperature rises, organic matter in the soil will decompose more quickly, which will increase the availability of nutrients

for plant uptake. Properties of soil, mineral, nutrient availability, and water determine how the effects of rising carbon dioxide concentration and temperature interact and vary. A tree's ability to grow will depend on the resources available in the forest, which will also change the ratio of growth to mortality, altering the forest's productivity. Increases in temperature, carbon dioxide, and precipitation change the carbon cycle over a longer period of time and have an impact on the length of the growing season, the composition of the forest, and the water cycle.

Impacts of Forest on Climate change

Forests have a large impact on climate change by influencing the amount of carbon dioxide in the atmosphere. Carbon is removed from the atmosphere and absorbed in wood, soil, and leaves when forests grow. Forests (and oceans) are referred to as "carbon sinks" because they can absorb and store carbon over a long period of time. This carbon is stored in the forest ecosystem, but when forests are burned, it is released into the atmosphere. Understanding the global carbon cycle and consequently climate change requires measuring the significant contributions that forests make to the absorption, storage, and release of carbon.

Carbon Sink: Forests contribute to climate change protection by absorbing carbon dioxide emitted into the atmosphere by human activities, primarily the combustion of fossil fuels for energy and other purposes, into the terrestrial carbon sink. The "carbon sink function" of forests helps to slow climate change by slowing the rate at which CO_2 accumulates in the atmosphere.

A carbon sink is anything that absorbs more carbon from the atmosphere than it emits, such as soil, ocean, and plants. A carbon source, on the other hand, is anything that emits more carbon into the atmosphere than it absorbs, such as volcanic eruptions or the combustion of fossil fuels. Forests are typically carbon sinks, absorbing more carbon than they emit. Through the process of photosynthesis, they continuously remove carbon from the atmosphere. Forests, which are the second-largest carbon sink after the oceans, have the capacity to store a significant amount of additional carbon in their biomass, wood products, and soil, accounting for about 30% of the current levels of carbon emissions from industry and fossil fuels. Carbon is necessary for all life on Earth. It's in our DNA, the air we breathe, and the food we eat. It moves between the atmosphere and the organisms on Earth as it is absorbed and released. This is known as the carbon cycle. Human activity is interrupting the balance. Humans are releasing more carbon into the atmosphere than the earth's natural carbon sinks can absorb. In order to deal with climate change and maintain the stability of climate, carbon sinks must be protected. Every year, the world's forests absorb 2.6 billion tonnes of carbon dioxide. Forests play an important role in the global carbon cycle. Forest carbon uptake slows the rate at which carbon accumulates in the atmosphere, slowing the rate of climate change. The future rate of carbon increase in the atmosphere will be influenced by how well forests continue to remove the proportion of carbon now emitted by human activities. By stabilising local weather conditions, including rainfall and water flow, forests can also help communities adapt to the effects of climate change.

Forest as a climate solution: Forests are among the most effective "Natural climate solutions" on the earth. Climate change and forests are closely related to one another. Air, temperature, solar radiation, rainfall, and carbon dioxide concentrations in the atmosphere all play important roles in forest productivity and dynamics. Forests, in turn, influence climate by absorbing and releasing large amounts of atmospheric carbon, as well as absorbing or reflecting solar radiation (albedo), cooling through evapotranspiration, and producing cloud-forming aerosols. Climate change affects forest growth and productivity directly or indirectly through changes in temperature, rainfall, weather, and other factors. Furthermore, higher carbon dioxide levels have an effect on plant growth. Forests contribute significantly to the Earth's ability to maintain its climate through the global impact of photosynthesis. They are a natural defense against climate change, removing carbon dioxide from the atmosphere and producing oxygen. Available data suggest that one hectare of a healthy forest can produce about 10 tonnes of oxygen and absorb 30 tonnes of carbondioxide in a year.

This contributes to the purification of the atmosphere and the control of rising temperatures. These advantages are reduced by deforestation. We could achieve up to one-third of the emission reductions required by 2030 to keep global temperatures from rising more than 2^0C if we can slow or stop deforestation and manage natural land practices. According to the Intergovernmental Panel on Climate Change (IPCC), carbon emissions must be reduced so that global warming is restricted to an additional 1.5^0C in order to prevent the worst effects of climate change. In order to avoid the worst effects of global warming; must achieve net-zero carbon emissions by 2050. Reducing the use of fossil fuels that emit carbon, increasing the use of renewable energy sources like wind and solar, utilising the ability of nature to absorb carbon, and introducing technologies that do so.

The climate convention must promote the use of renewable energy sources. This is the only alternative for dealing with climate change. A shift to renewable energy sources such as solar, hydrogen, wind, and biomass will result in a zero-carbon economy. Maintaining existing forest cover, new plantations, and better long-term management of biomass all help to reduce global warming. Forests cover approximately 30% of the world's land surface. As forests grow, trees absorb carbon from the atmosphere and store it in wood, plant matter, and soil. Without forests, much of this carbon wood would remain in the atmosphere as carbondioxide, the most important greenhouse gas driving climate change.

International and National efforts to tackle climate change: Some of the international and national initiatives to mitigate the climate change are as follows:

1. In November 1988, the United Nations Environmental Programme (UNEP) and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC). The IPCC is a group of over 2000 scientists and policy analysts from over 100 countries that produced three major reports on various aspects of climate change in 1990, 1995, and 2001. The IPCC provides technological guidance to the international community in dealing with climate change issues.
2. In March 1994, the United Nations Framework Convention on Climate Change (UNFCCC) came into effect with the goal of stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.
3. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) entered into force in February 2005, with the 37 most industrialised countries of the 146 nations ratifying the Kyoto Protocol agreeing to reduce their GHG emissions below 1990 levels over an initial commitment period of 2008 to 2012.
4. The first global ozone depletion conference was held in Vienna, Austria in 1985. The Montreal Protocol is a series of international agreements aimed at reducing and eliminating CFCs and other ozone-depleting substances that followed the Vienna Convention on the Protection of the Ozone Layer, which was adopted in 1985.
5. India has signed and ratified the (UNFCCC). The Ministry of Environment and Forest is India's nodal agency for climate change issues, with working groups on the UN Framework Convention on Climate Change and the Kyoto Protocol.

10.8 SUMMARY

Climate refers to the long-term weather conditions. The term "climate change" refers to shifts and variations in weather patterns over time and space that occur on a various scales. Weather patterns determine a region's climate, which is generally monitored for at least 30 years. Small changes in one location can contribute to larger changes in the earth's global climate. Climate change on a global scale refers to average long-term changes across the globe. The earth's climate is affected by both human and natural factors- include astronomical factors, geological factors, oceanic factors, land use and land cover, sunspot theory, atmospheric dust, and radioactive forcing. Since the industrial revolution, Human activity has massively released gases such as carbon dioxide, chlorofluorocarbons, nitrous oxide, water vapour, trace amounts of ozone, methane, and other gases into the atmosphere, changing the earth's climate. Climate change is having a negative impact on ecosystems and ecology. As a result of the effects of climate change, forest ecosystems are undergoing unprecedented environmental changes. The effects of climate change on tree migration, wildfires, invasive species, drought, forest pests, human health, and so on. Forests and climate change have a close relationship. Air, temperature, solar radiation, rainfall, and atmospheric CO_2 concentrations all play important roles in forest productivity and dynamics. Forests influence climate by absorbing and releasing large amounts

of atmospheric carbon, as well as absorbing or reflecting solar radiation (albedo), cooling through evapotranspiration, and producing cloud-forming aerosols. Climate change actions have been initiated on a global and national scale.

10.9 GLOSSARY

Insolation: The energy emitted by the sun which reaches the earth's surface.
Irradiance: the output of light energy from the entire disk of the sun, measured at the earth.
Particulate matter: It refers to anything suspended in the air.
Albedo: It is the portion of solar energy reflected from the surface of the earth back into space.
Acid rain: The fallout of acids with rains is called acid rain. In other words, the precipitation of more acidic water having average pH 5.0 or less caused by sulphur dioxide pollutants, is called acid rain.
Phytoplankton: Floating or freely suspended plants.
Phytoplankton blooms: Phytoplankton blooms occur when sunlight and additional nutrients are readily and abundantly available to the plants in the environment. These plants grow and reproduce to the point where their presence is so dense that it changes the colour of the water in which they live.
Radioactive forcing: The radioactive forcing refers to 'the effects which greenhouse gases have in altering the energy balance of the earth-atmosphere system' (IPCC).
Scrub: Vegetation dominated by shrubs, with few tall trees.
Snow line: The altitude above which snow lies throughout the year.
Swamp: An area saturated with water for most time in which soil surface is not deeply submerged.
Sunspots: are dark and cool areas within the photosphere of the sun and are surrounded by chromosphere.
Heat Budget: Heat budget is a balance between incoming heat (insolation) absorbed by the earth and outgoing heat (terrestrial radiation) escaping it in the form of radiation.
Cryosphere: It is the frozen water part of the earth system.
Thermal expansion: It is the process by which warmer water takes up more space, is causing the ocean to increase in volume, which leads to rising sea levels.
Ocean Acidification: Ocean acidification is the gradual decrease in the pH of the ocean caused primarily by the uptake of carbon dioxide (CO2) from the atmosphere.
Latent heat: Latent heat is the heat or energy that is absorbed or released when a substance undergoes a phase change.
Deoxygenation: Deoxygenation is a chemical reaction in which oxygen atoms are removed from a molecule.

10.10 SELF ASSESSMENT QUESTION

10.10.1 Multiple Choice Questions

1- In the absence of greenhouse gases, the earth would be......
(a) Too cold to sustain life.
(b) Too hot to sustain life
(c) Cooler but still able to sustain life
(d) If depends on the species of aerosol in the GHG-free atmosphere.

2- Since the beginning of the industrial revolution, the acidity of ocean surface water has
(a) Decreased by 25% (b) increased by 10%
(c) Increased by 30% (d) remained constant

3- Global warming is also referred to as-
(a) Climate change (b) Ecological change
(c) Atmosphere change (d) none of the above

4- A phenomenon known as E1- Nino occurs in-
(a) Indian Ocean (b) Atlantic Ocean
(c) Pacific Ocean (d) Arctic Ocean

5- Which among the following is not a Green house gas?
(a) Ozone (b) Nitrous oxide
(c) Methane (d) Hydrogen

6- Burning fossil fuels causes-
(a) Increased oxygen level (b) Increased greenhouse gases
(c) Decrease greenhouse gases (d) Increased ethane level

7- The ozone layer prevents-
(a) x-rays and gamma rays (b) visible light
(c) Ultraviolet radiation (d) infrared radiation

8- Which of the following gases is most frequently released from rice fields?
(a) Sulphur dioxide (b) Methane
(c) Carbon dioxide (d) Carbon monoxide

9- Which of the following is related to the formation of ozone?
(a) Photochemical process (b) Chemosynthesis process
(c) Hydrolysis process (d) Photosynthesis process

10- Global warming is caused by the emission of -
(a) Hydrocarbon (b) Nitrogen
(c) Carbon dioxide (d) Carbon monoxide

11- Which of the following statements about ozone is correct?
(a) Ozone is present only in troposphere
(b) Ozone in troposphere is not good for breathing
(c) Ozone in troposphere is good for breathing
(d) All of the above

12- What is climate?
(a) Current weather outlook of a place

(b) Atmospheric conditions of a place at a particular point in time
(c) A long period of time
(d) Average atmospheric conditions of a place over a long period of time, usually 30 years.
13- Full form of IPCC is-
(a) International Panel on Climate Conservation
(b) Intergovernmental Panel on Climate Change
(c) International Panel on Climate Change
(d) None of the above

10.10.1 Answer Key: 1-(a), 2-(c), 3-(a), 4-(c), 5-(d), 6-(b), 7-(c), 8-(b), 9-(a), 10-(c), 11-(b), 12-(d), 13-(b)

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10.12 SUGGESTED READINGS

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- General climatology by Howard J. Critchfield published by PHI learning private limited, New Delhi
- Introduction to Environmental Science by Y Anjaneyulu, published by BS publications, Hyderabad

10.13 TERMINAL QUESTIONS

10.13.1 Short answer type Questions:

1. What is climate change?
2. What is greenhouse effect?
3. How does climate change affect the ocean?
4. Write short notes on-
   (a) Astronomical factors
   (b) Geological factors
   (c) Sunspot theory
5. Discuss about the gases responsible for the greenhouse effect.
6. Write a brief note on global warming.
7. What is the difference between weather and climate?

10.13.2 Long answer type Questions:

1. Define climate change. Explain the causes of climate change.
2. Describe in detail Global Climate change.
3. Describe the Impacts of climate change in detail.
4. Define forest. What are the effects of climate change on Forest?

UNIT-12- MAN AND FOREST

Contents:

12.1 OBJECTIVES

After reading this unit the learners will be able to

- This module will enable to clear the concept of Shifting Cultivation
- This module will equip the students with certain theoretical aspects of Shifting cultivation
- This module highlights about the shifting cultivation practices in China and India with reference to North Eastern India
- This module explains the changing nature of Shifting Cultivation

12.2 INTRODUCTION

It is widely accepted that shifting cultivation is an agricultural system characterized by a rotation of fields rather than of crops. Shifting cultivation is a way of discontinuous cropping in which periods of fallowing are typically longer than periods of cropping. Shifting cultivation typically has a way of clearing the fields, generally termed as ‘swiddens’ through the use of slash-and-burn techniques. Shifting cultivation is known by a variety of terms (including field-forest rotation, slash and burn, and swiddening).

It is reported that shifting cultivation is widespread throughout the humid tropics, but was also practiced in temperate Europe until the nineteenth century (and sometimes later) (Conklin, 1962). It is estimated that there are over 250 million shifting cultivators world-wide, with 100 million in South- East Asia alone. Shifting cultivation is enormously heterogeneous and subtypes can be distinguished according to crops raised, crop associations and successions, fallow lengths, climatic and soil conditions, field technologies, soil treatment and the community’s mobility of settlement. It is understood that in all shifting cultivation systems, the burning of cleared vegetation is critical to the release of nutrients, which ensures field productivity.

Shifting cultivation is the practice of bringing into agriculture previously uncultivated land for several seasons followed by abandonment as part of a human nomadic culture. It is increasingly recognized that the traditional shifting cultivation practiced by traditional and indigenous communities, particularly in the tropics, represents a sustainable form of agriculture that is well adapted to natural and semi natural ecosystems, most notably in the rain forests. Far from proving an inefficient or wasteful form of agriculture, as was once thought, shifting cultivation is now regarded by many scientists and grass root environmentalists as the least harmful to the environment and to the diversity of wildlife.

Operationally, shifting cultivation can be defined as a system of agriculture under which plots of land were cultivated for a limited period without the application of manure until crop yields declined. The land was then abandoned and left to revert to forest with new plots being cleared. This is believed to have been one of the main forms of agriculture in Neolithic Europe and was characteristic of marginal forest areas into times. It survived in North Scandinavia into the early 20th Centuary and is still used in tropics, though on a much smaller scale than formely. Shifting agriculture is known as Ladang in Malaysia and Indonesia, Milpa in central America, Chitenmene in parts of Africa, Jhum/ Kumri in India and Chena in Sri Lanka.

Rath (2015) defines Shifting cultivation as "any continuing agriculture system in which impermanent clearings are cropped for shorter periods in years than they are allowed to remain fallow, it is also defined as an agricultural system which is characterized by 'slash and burn' and by short period of cropping alternating with long fallow periods".
It is an agricultural system which is characterized by a rotation of field rather than a crop, by a short period of cropping alternating with long fallow periods of cropping and clearing by means of slash and burn. It is also a labour intensive and land extensive process of cultivation. Its origin is traced to as far back as the Neolithic period between the years 1300 to 3000 B.C. It occupies a distinct place in the tribal economy and constitutes a vital part of the lifestyle and socio-economic set-up of hill and tribal regions. This form of cultivation is regarded as a distinct stage in the evolution of agriculture (Ninan, 1992).

It is understood that Shifting cultivation is the most primitive among all types of agriculture. The variety of soil, climate and vegetation is responsible for many types of agriculture in the world. The development of agriculture has passed through two distinct lines: plains cultivation and hills cultivation. Shifting cultivation falls in the later category, this system of cultivation has been considered to be the most ancient, dating back to the Neolithic period between the years 13,000 to 3,000 B.C. It is a distinctive type of agriculture practiced at a primitive level of operation under certain environmental constraints.

According to Verrier Elwin, shifting cultivation is a stage in the evolution of human culture and almost all the races have resorted this practice in some stage or the other. Shifting cultivation occupies a distinct place in the tribal economy; it constitutes a vital part of the socio-economic network of the tribal life particularly the hill tribal economy, which is regarded as the principal source of livelihood. Shifting cultivation is an ancient system of agriculture, in which a patch of hill is cleared through fire and is cropped through rotation. Therefore the shifting cultivation is also known as "field forest rotation" or "slash and burn" agriculture as it always involves the impermanent agriculture use of plots produced by cutting hacks and burning of vegetation cover. Shifting cultivation is a process which consists of cutting of trees on tops and slopes of hills, burning the fallen trees and bushes and dibbling or broadcasting seeds in the ash covered soil. Goods crops are harvested for the first two or three years at a diminishing rate and then the land is abandoned leaving only 'bald hills' devoid of any economic or ecological importance. Then a new clearing is opened for fresh cultivation. The cultivation is thus shifted from one patch of land to another abandoning one after another bringing large scale devastation of soil fertility and vegetation (Rath, 2015).

Fig 12.1 Slash and burn cultivation / Jhum cultivation (Source: ttps://commons.wikkimedia.org)

Process of shifting cultivation: The meaning of the shifting cultivation is discussed in the above paragraphs. In the hill slopes the practice of shifting cultivation using slash and burn method is typical of aboriginals. They periodically cut down the forest trees and burn them in order to clear an area for planting. The ash thus collected is spread on the entire patch of land which works as manure, afterwards the seeds are dibbled in the soil. On this land crops are raised for one to three years and after the fertlity of the soil diminishes and when the soil is unable to support any crops further, the field is abandoned to get recouped naturally. Naturally cultivation is shifted to another land and the cultivator returns to the original plot after the soil regains its fertility (Rath, 2015).

Geographical location: Shifting cultivation takes on its most characteristic forms in regions which have one or more seasons of copious rain, alternating with shorter periods when little or no rainfalls. In such places relative humidity remains high throughout the dry season. In such climate the natural vegetation is rain forest. The shifting cultivation extends beyond the limits of the rain forest across a marginal zone covered with similar vegetation (Whittlesey, 1937).

Shifting cultivation is practiced with variations throughout the tropical and sub- tropical regions of the world. It is also practiced by the pre-historic man. The primitive communities of 63 countries in Africa, Asia, South America and Central America follow this practice of agriculture. Shifting cultivation is practiced by a number of tribes in the world. The Yuruba of Congo Basin, the Bemba of Northern Rhodesia, the Yao of Southern Nyasaland, the Malaysians of Solomon Islands, the Boro of Western Amazon Forest, the Bakairi Indians of Upper Xingu Region in South America, Hill tribes of North Borneo and Veddah of Ceylon are few examples of tribes who are still practicing this primitive form of cultivation (Rath, 2015).

12.3 SHIFTING CULTIVATION AND ITS CHANGES IN CHINA

In the 1980s shifting cultivation in China became a hot issue, it became the subject of debate among national and international scholars, along with the questions such as what shifting cultivation really was, and whether or not it destroyed forests. During 1970s and 1980s there was serious rainforest destruction in Asia, Africa and South America for the greed of timber shown by enterprises based in developed countries. While forest destruction became a global environmental issue, the indigenous people who lived in this forest and their shifting cultivation has become a subject of close attention by scholars around the world.

Shifting cultivation has a very long history in China; with the loss of forest area the practice of shifting cultivation diminished. With the end of the Cultural Revolution in the mid 1970s, international ideas became popular and the people began to pay more and more attention to environmental problems. However the ethnic minorities living in the Southwest of Yunnan Province continued the practice of shifting cultivation and they are blamed for destroying forest.

12.3.1Theoretical background

Marxist ethnic theory

This theory was followed and practiced well in China: with the motive of social development which can be found in relationship between productive forces and society’s need for production. The history of social development reflects five kind of social evolution: among them is that affecting shifting cultivators. According to this theory, shifting cultivation refers to the productive forces of primitive society, so there is compulsion for change, which the superior societies must have transformed or replaced.
This gives rise to a number of questions: why do the productive forces of a primitive society

continue to exist without change? Why do ethnic minorities living in mountain areas still choose shifting cultivation for their livelihood? Is it appropriate, for most of the natural scientists and anthropologist to prove that shifting cultivation is backward and primitive, but neglect the points of view of indigenous people?

Agricultural evolution theory

There are three distinct periods in the evolution of agriculture, beginning with primitive shifting cultivation, moving to hoe farming and to cultivating the soil with ploughs. Therefore, in the mountain areas of Southwestern Yunnan province, we can find 'living fossils' where indigenous people still practice shifting cultivation.

In primitive societies people would have used knives and axes and other tools made of stones for shifting cultivation. Today, indigenous people not only use iron and steel knives for shifting cultivation, but they also use hoes and ploughs made from iron and steel for farming.

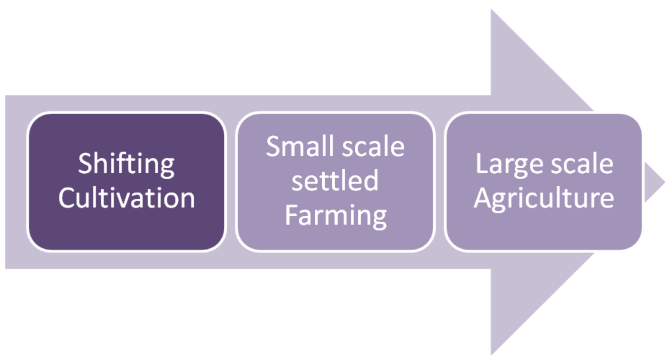

Fig 12.2: The Evolution of agriculture

Economic- cultural theory

This theory refers to the synthesis created by people who live in the same physical conditions and at a similar level of social development. It is difficult to fix the boundaries between different economic- cultural typologies referred to the synthesis created by people who live in the same physical conditions and at a similar level of social development.The question then arises: is the type of shifting cultivation determined by environment or physical conditions?

Cultural ecology (1940s) and ecological anthropology (1970s)

In traditional societies, the focus was mainly upon the livelihood of the people and their adaptation to their living environment. The ability of human beings to adopt is an effective means of defining the relationship between people living in a small-scale society and their natural environment.

The disadvantage of this 'ecological adaptation' rule is that it cannot measure the characteristics of a society that is, or has been, strongly impacted by the decisions of the country's government, or by the demands or fluctuations of the market (Yin, 2015).

12.3.2 The main causes of change of shifting cultivation

1. ***The ideology of the state:*** Shifting cultivation is regarded as the productive force of a primitive society. In China, people use advanced productive force to replace primitive ones, which is the only one direction beyond the primitive society towards a socialist society.
2. ***Government policies:*** To change and replace shifting cultivation, the central government has implemented a number of policies, law and regulations to forbid shifting cultivation.
3. ***Social reform:*** The implementation of a socialist transformation by using its administrative system to replace traditional social organization and cultural systems, resulted in traditional production and living systems to lost their balance.
4. ***Population growth:*** The population of ethnic minorities living in mountainous areas of Yunnan Province has tripled, over the past 60 years. With the increase in the number of individuals the relationship between the population and use of the land has become uneasy, so it is difficult for minority groups to continue shifting cultivation.
5. ***Market economy:*** Along with other reforms and policies the central government of China is paying close attention to developing the market economy. In order to pursue economic interests, most ethnic minority groups started planting rubber and other cash trees such as tea and various fruits. As a result, shifting cultivation is disappearing quickly.

12.4 SHIFTING CULTIVATION IN INDIA

Shifting cultivation is commonly known as Jhum cultivation in India. The practice is similar to the form of shifting cultivation like other countries from the different corners of the world. It occupies a distinct place in the tribal economy of India. Many studies on shifting cultivation in India have been conducted by different institutions and researchers. In India shifting cultivation is largely found in the states of Andhra Pradesh, the hill districts of Assam, Arunachal Pradesh, Madhya Pradesh, Meghalaya, Mizoram, Manipur, Nagaland, Odisha and Tripura.

12.4.1 Basic features of shifting cultivation

(Rath, 2015) has classified the basic features of shifting cultivation as (Fig 12.3):

1. This system of cultivation is practiced mainly by simpler cultures and small population but occasionally used by almost anyone for whom the cropping system appears expedient.

2. Human labour is the chief input, and a few simple hand tools are used in the cultivation.
3. Labour pattern frequently cooperative, but involving many variations in working group structure.
4. Clearing of fields primarily by felling, cutting, slashing and burning, and using fire to dispose of vegetative debris after drying.
5. Frequent shifting of cropped fields, normally in some kind of sequence in land control, resting in special social groupings under customary law, but sometimes occurring under other legal institutions of land control.
6. Many different systems in crop planting in given fields but both multiple cropping and specialized cropping present.
7. Use of crops primarily for subsistence but exchange pattern may reach total sale of whole product.
8. Field per acre and per hour of man normally compared with those of permanent field agriculture within regions in which comparison is properly made but yields are often below those of mechanically powered permanent field agriculture.
9. Use of vegetable cover as soil conditioner and source of plant nutrient for cropping cycle.
10. When the system is efficiently operated soil erosion is not greater than soil erosion under other systems that are being efficiently operated.
11. Details of the practice vary depending upon the physical environment and cultural milieu.
12. Destruction of natural resources only when operated inefficiently and not more inherently destructive than other systems of agriculture when these are operated inefficiently.
13. A residual system of agriculture largely replaced by other systems except when retention of practice is expedient.
14. Transiency of residence common but not universal, with many patterns of residence according to the evolutionary level or detailed system employed and preference of culture group.
15. Operaed chiefly in the regions where more technologically advanced systems of agriculture have not become economically or culturally possible or in regions where the land has not yet been appropriated by people with greater political or cultural power.

12.4.2 Causes of shifting cultivation

In India the practice of shifting cultivation is not an abnormal one, as it is the main means for the survival of the indegenous tribes. As Rath, (2015) mentioned that the “primitive method” is the only negative factor and it is further differentiated as absolute, induced and accused.

1. Absolute: under this category the tribals carry on the practice as an age old tradition, the tribes like Bonda, Didayi, Sora and Kandha are practising shifting cultivation as an age old tradition.
2. Induced: the outside unscrupulous money lenders volunteer to lend money to the tribals

and induce them to carry on with an understanding, take a lion's share of the produce as "interest". The outstanding capital remains as heavy burden on the tribals and also ultimately engages the tribals as "bonded labourers".

3. Accused: under this category some of the antisocial elements exercise their unauthorized influence to lure the *Adivasis* with a false hope to record the land in the name of the cultivator. But ultimately the cultivator is being accused as an offender.

Fig 12.3: Characteristics of Shifting Cultivation

12.4.3 Effects of shifting cultivation

Economic and social impacts of shifting cultivation are viewed differently by different groups. As shifting cultivation damages forest, this practice is ruinous and wasteful, dries up the spring in the hills which causes soil erosion: destroy valuable forests, affects rainfall and deprives the people the benefit of forest and forest produce. Shifting cultivation upsets the accumulated natural resources by removing more from it than that it can produce. The evil effects of shifting cultivation have been summed up by Mr Harries, Agency Commissions of Madras in 1918 (Rath, 2015).

1. It causes springs below the hills to dry up.
2. Causes the soil below the land to be washed away.
3. Ruins valuable timber for the sake of much less valuable crops of gain.
4. Causes the hot weather supplies in these rivers to diminish and this reduces the water available for second crop cultivation.
5. Causes very heavy floods in the rivers and endangers life and property.
6. It brings down heavy silt in to tanks and makes them useless to fields and destroys crops.

Thus the main effects of shifting cultivation are deforestation, soil erosion, diminished rainfall, silting up of the river channel, stream bed and reservoirs and deterioration of the climate of a region. It creates a bad impact on the forest ecosystem, as the forest ecosystem consists of major components like atmosphere, climate, soil and its living organisms. As the living organism (plants and animals) maintain a balance between carbon dioxide and oxygen in the atmosphere. This balance is disturbed as the tribes set fire to the forest for clearing the ground for the purpose of cultivation which result in increase of the quantity of carbon dioxide in the atmosphere and it also generate poisonous gas in the region by large scale destruction of plants and trees.

The seminar conducted on Socio- Economic Problems of Shifting Cultivation held at Shillong on June 18, 1976 provided a session on the general problem of shifting cultivation, where some participants stated that “shifting cultivation” as “necessary evil” and concentrated on speculations as to how the evil could be removed or at least tempered with the civilizing influence of green revolution. If it is not taken into consideration then problems like soil erosion, deforestation and consequent ecological imbalances might occur. It was further stated that low productivity, absence of agricultural surplus, primitive technique of production and hence non-industrialization were the inevitable results of shifting cultivation (Majumdar, 1976).

12.5 SHIFTING CULTIVATION (JHUM) IN NAGALAND, NORTHEAST INDIA

The traditional agricultural system which is practiced by the people of Nagaland is shifting cultivation. It is believed that due to this practice the forest area are destructed which creates the problem of erosion of topsoil.

Many research studies are conducted in Nagaland in order to adapt to better agricultural practices to prevent climate change. One of the misconceptions about *jhum* is that it converts primary forest to agricultural land, it cumulatively reduces the forest cover and its environmental threats extend as far as loss of biodiversity. In reality, *jhum* farmers use and reuse the same areas of land when a cropping periods ends, the particular plot is abandoned and farmers move to another plot that has been used before. But it has to be fallowed for long enough to have rejuvenated the soil nutrients under secondary forest.

Studies were conducted in the years from 2002 to 2007, set out to determine how *jhumming* was affecting Nagaland’s forest cover. The results of the studies in the villages where the research was conducted, was that in some villages the primary forests which are converted for agricultural uses occurred around 100 years ago or even longer. Since then, their primary forests have remained intact. In some villages, the most recent conversion of primary forest for *jhum* cropping occurred between 41 and 50 years ago. Whereas in some villages the primary forest for *jhum* cropping occurred as recently as 11 to 20 years ago. However, in the villages where the research has been conducted, it recorded the conversion of primary forest which occurred only as an extension of land already within the existing *jhum* rotational cycle.

The survey conducted in many villages, showed that the area under *jhum* had been decreasing. The survey conducted by the Nagaland Empowerment of People through Economic Development (NEPED) project, which covered 119 villages in 10 of Nagaland's 11 districts (excluding Dimapur). In 75 out of 119 villages (67%), the total *jhum* area was decreasing in 12 villages (12%) it showed an increase, and in 32 villages (27%) it remained static (Toy, 2015).

The decrease of *jhum* results in the people to adopt available alternative sources of livelihood, such as off- farm activities (e.g pig rearing, masonry, wage labour, and (so on), salaried jobs (private and public), and private enterprises (shop keeping, trading, contract work) and rural urban migration. The northern districts of Mon, Longleng, Tuensang and Kiphire where increase in the area of *jhum* was observed, could be linked to a lower literary rate. The large scale pratice of jhum cultivation in these areas could also be due to the rules enforced by the village authorities under customary law.

Therefore, it may be safely assumed that any decrease in the forest area in Nagaland is being compensated by an increase in under fallow re-growth, which eventually leads to permanent secondary forest. Perhaps the area of land reverting from agricultural use back to forest is greater than that being converted from primary forest to agriculture (Toy, 2015).

12.6 SUMMARY

For centuries, indigenous and traditional communities throughout the tropics have used shifting cultivation for generations as part of a life-giving, sustainable forest agriculture system. It is proved that shifting cultivation is often the only way in which the nutrient-poor rainforest soils can support crops. It is one of the traditional agricultural system, in which plots of land are cultivated temporarily, then abandoned and allowed to revert to their natural vegetation while the cultivators move in to another plot. It is practiced throughout the tropical and subtropical region of the world. In china, this practice has become a hot issue and a subject of debate for many scholars from within and outside the country. There is counter argument stating that Shifting cultivation is mainly effecting the environment and also disturbs the ecology. In India, the practice is still followed mostly by the tribal communities, as some suggest that it has some negative effects. Many scholars have showed their interest to study the problems related to such matters. Notwithstanding the positive effects of shifting cultivation, at the level of Government and International Financial Institutions, however, management of forests in a sustainable way through shifting cultivation has yet to be recognized as an environmentally beneficial form of economic activity.

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