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[FOREST ECOLOGY AND MANAGEMENT]

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Chapter one: Humans and Forest dynamics

1.1 Evolutionary dependence of human on forests

A forest is more than trees. It is also the shrubs, wild flowers, and grasses; the animals that depend on and live among these plants; the soil in which the plants grow; the dead trees and plants; the stream that flow through it; the insects, fungi, bacteria, organisms we cannot readily see; and the climate.

Humans have always depended on forests and forest resources.

“Forests are the evolutionary vessel in which were distilled the origins of the most remarkable of all animals: Homo sapiens. Forests were the habitat of our earliest evolutionary ancestors and have remained an important part of the environment of ... the human family tree. The rise and fall of empires, the conquest of nations, and the political, economic, and military power of human societies have been intimately related to the accessibility of forests and/or forest products for most of recent history. Modern humans ... still are – and always will remain – dependent on forests for a wide variety of the necessities and pleasures of life as we know it.” (J.P. Kimmins 2004)

The relation of humans with forests is very ancient. The ancestors of homo, some 7 million years ago, where living on trees, then moved to the ground, and began walking upright, taking advantage of mutations to adapt a new environment. Woody areas become useful for man as a source of heat and light: archeological evidence of controlled use of fire dates from 400,000 to 300,000 years BP.

Humans started to Exploit forest not only for wood and food, but also for space: with the beginning of the Neolithic revolution (6,500 BC) agriculture were born in the fertile crescent (with the domestication of wheat, other grains, legumes), and around 6,000 BC the domestication of animals was achieved with consequent increase in over grazing and tree- grazing due to pastoralist miss management.

It should be apparent...that almost all human evolution, from primeval, primate stock to ground ape and then through agricultural, technical, and cultural revolutions to the present time, has been intimately associated with, and conditioned by, forests." (J.P. Kimmins 1987)

1.2 Sustainability of forest ecosystems

While the concept of sustainability remains somewhat imprecise, there is growing agreements that two basic set of issues underline it.

The first set of issues concerned integrational fairness and the moral responsibility of the current generation to its decedents, both immediate and in the longer term. How much of an obligation do we assume for safeguarding the potential wellbeing of our decedents; what are we willing to give up in terms immediate benefit for ourselves?. The second issues concerns the role of assets provided by nature. Including forest ecosystem, in satisfying both current interest and obligation

Sustainable management means utilizing the forest for human benefit without destroy the capacity of the forest to reproduce itself. Certain ecological characteristics render tropical forests particularly susceptible to disturbance and should be considered if the tropical forest is to be managed sustainably. They are:

High diversity of species

The diversity of species in tropical forests not only helps to ensure the survival of each species, it also helps to ensure he continued existence of

tropical forest ecosystems. While individual populations within a forest peak and crash, the flow of energy and cycling of nutrients within the forest remain relatively stable. At each tropical level, there is a continual dynamic flux, as the population of one species that is rising replaces the population of another that is falling (McCann 2000; Tilman 2000).

High frequency of cross pollination

Research on genetic characteristics of tropical trees has shown that there is considerable genetic variation within populations (Bawa 1992). Genetic heterogeneity can be an advantage for withstanding stress and for adapting to new environmental conditions. Cross pollination increases genetic heterogeneity. Distance between two individuals of the same species is the main factor affecting cross pollination.

Common occurrence of mutualism

Boucher (1985) has classified mutualism into several categories:

Nutrition/ digestion: increasing the availability of nutrients, energy and water to one or both of interacting species. e.g. Mycorrhizae, an association between plants and fungus through which the fungus obtains carbon for energy, and the plants gain an increased ability to take up water and nutrient from the soil.

Protection for one or both interacting species. Insects that live on or in a plant and derive energy from the plant may protect the plant in which they live. When an animal begins to browse a protected plant, the insects attack the intruder.

Pollination of some plants depends upon the action of specialized insects and birds. They benefit from the mutualism by obtaining energy from the plant's nectar.

Seed dispersal: the spread of seeds away from the parent trees by birds, bats and small mammals that eat fruit increase the probability that some seeds will survive and grow.

High energy flow through primary producers, consumers and decomposers and

A relatively tight nutrient cycle

1.3 Ecophysiology of trees and forests

Ecophysiology, environmental physiology or physiological ecology is a biological discipline that studies the adaptation of an organism's physiology to environmental conditions. It is closely related to comparative physiology and evolutionary physiology.

Plant ecophysiology is concerned largely with two topics: mechanisms (how plants sense and respond to environmental change) and scaling or integration (how the responses to highly variable conditions—for example, gradients from full sunlight to 95% shade within tree canopies—are coordinated with one another, and how their collective effect on plant growth and gas exchange can be understood on this basis).

Basic physiological processes involved in tree growth are photosynthesis, respiration, translocation, transpiration, water and mineral uptake. Extent and rate of these processes depends upon light, temperature, water and nutrient relations which may be influenced or modified by silvicultural treatments.

Photosynthesis

The extent of photosynthetic activity is a major factor in the production of biomass. Rates of photosynthesis are influenced by both plant and environmental factors.

A. Environmental factors

1. Light: - directly affects tree growth by its intensity, quality, and duration. As with most abiotic factors, light intensity can be both suboptimal and excessive.

Suboptimal light (shade) typically occurs at the base of a plant canopy or in an understory environment. Shade tolerant plants have a range of adaptations to help them survive the altered quantity and quality of light typical of shade environments.

Excess light occurs at the top of canopies and on open ground when cloud cover is low. Excess light incident on a leaf can result in photo inhibition and photo destruction. Plants adapted to high light environments have a range of adaptations to avoid or dissipate the excess light energy, as well as mechanisms that reduce the amount of injury caused.

2. Temperature: - In response to extremes of temperature, plants can produce various proteins. These protect them from the damaging effects of ice formation and falling rates of enzyme catalysis at low temperatures, and from enzyme denaturation and increased photorespiration at high temperatures

3. CO₂ concentration:- CO₂ is vital for plant growth, as it is the substrate for photosynthesis. Plants take in CO₂ through stomata pores on their leaves. At the same time as CO₂ enters the stomata, moisture escapes. CO₂ concentration in the atmosphere is low, about 0.03% by volume, or 1/2 gram/m³ of air. Concentrations in the forest are often higher but show vertical gradients which change diurnally and seasonally. The concentration of CO₂ in the atmosphere is rising due to deforestation and the combustion

of fossil fuels. This would be expected to increase the efficiency of photosynthesis and possibly increase the overall rate of plant growth. This possibility has attracted considerable interest in recent years, as an increased rate of plant growth could absorb some of the excess CO₂ and reduce the rate of global warming. Stands whose structure permits continued circulation of air provide more favorable conditions from the standpoint of CO₂ supply than those with a tight canopy or those which are multi-storied. The large quantities of CO₂ which are continuously consumed by photosynthesizing trees can only be supplied by the CO₂ contained in layers of air which are many times thicker than the height of the stands.

4. Water availability: - Too much or too little water can damage plants. If there is too little water then tissues will dehydrate and the plant may die. If the soil becomes waterlogged then the soil will become anoxic (low in oxygen), which can kill the roots of the plant.

5. Wind- The main impact of wind on plants is through its influence on the canopy, which in turn influences the way leaves regulate moisture, heat, and carbon dioxide. When no wind is present, a layer of still air builds up around each leaf. This is known as the boundary layer and in effect insulates the leaf from the environment, providing an atmosphere rich in moisture and less prone to convective heating or cooling. As wind speed increases, the leaf environment becomes more closely linked to the surrounding environment. It may become difficult for the plant to retain moisture as it is exposed to dry air. On the other hand, a moderately high wind allows the plant to cool its leaves more easily when exposed to full sunlight. Plants are not entirely passive in their interaction with wind. Plants can make their leaves less vulnerable to changes in wind speed, by coating their leaves in fine hairs (trichomes) to break up the air flow and increase the boundary layer. In fact, leaf and canopy dimensions are often finely controlled to manipulate the boundary layer depending on the prevailing environmental conditions.

In areas where very strong winds are common, plants respond by reducing their above ground growth (known as dwarfing) and by strengthening their stems. Trees have a particularly well-developed capacity to reinforce their trunks when exposed to wind. In the most extreme cases, plants can be mortally damaged or uprooted by wind.

B. Plant factors

Within-tree variation in net photosynthesis is attributable to:

Leaf age - Difference between age classes is mainly a consequence of varying rates of respiration, and by insect or disease damage.

Position within crown. The most productive leaves are in the upper crown. The lowest whorls contribute little to net photosynthesis.

Crown classes and species- Differences in photosynthetic efficiency between dominant, co-dominant, and suppressed trees are relatively minor when one compares similarly exposed foliage and expresses efficiency per unit of leaf surface. The major factor causing differences in photosynthetic capacity of trees of different crown classes and of different species is the enormous difference found in leaf area.

Sun and shade adaptations- Not all tree species possess the same photosynthetic efficiency just as photosynthetic efficiency varies between shade and sun leaves on the same tree.

Shade leaves and shade-tolerant species have higher photosynthetic efficiency per unit of leaf area under low light conditions than sun leaves and intolerant species. Under high light conditions the reverse is true. For practical purposes this means that intolerant trees in the suppressed and intermediate crown classes released from a relatively shaded position to full exposure may show decrease in growth or even die. This is because shade leaves of intolerant species lose photosynthetic efficiency when they are

suddenly exposed to high light intensities. Shade leaves of tolerant species are usually better able to adapt to this kind of change.

Chapter 2: Ecosystem Ecology

2.1 The science of ecology and its historical background

The term “ecology” was coined by combining two Greek words, oikos (house or dwelling place), and Logos (the study of), to denote the relationship between organisms and their environment. Ecology is a multidisciplinary enterprise, which cannot be made to fit into one channel of scientific inquiry: it ranges from reductionism in the study of individual species populations, through less reductionist approaches in the study of communities, to the holistic in the studies of the totality of communities on earth.

The science of ecology is “the study of the relationships between organisms to each other and to their environments.”

The basic concepts of ecology include the following:

All living organisms and the environment they live in are mutually reactive, affecting each other in various ways.

Environment plays a major role in the critical stages of the life cycle of the species.

The species reacts to the environmental changes and adjusts itself structurally and physiologically.

The environment also changes according to certain species- specific activities like growth, dispersal, reproduction, death, decay, etc.

All plants and animals are related to each other by their coactions and reaction on the environment.

Under similar climatic conditions, there may simultaneously develop more than one community, some reaching the climax stage, and others under different stages of succession.

Ecosystem

The bio-sphere is made up of the living system consisting of plant and animal kingdom, and the non-living components including minerals, water etc., the entire system is sustained by the source of energy, the Sun. Organisms belonging to different species either of plant kingdom or animal kingdom interact among themselves as well with the physical environments they occupy. This system is called ecological system or ecosystem.

A more precise definition is “the study of the interactions that determine the abundance and distribution of organisms.”

The term “ecosystem ecology” is philosophically and historically rooted in terrestrial ecology and deals with the flow of energy and matter through the biotic and abiotic components of ecosystems. The ecosystem concept has evolved rapidly during the last 100 years. The important idea that physiological processes are fundamental to ecosystem structure and function remains central to ecology. In a nutshell, ecosystem ecology provides the basic science needed to avoid degradation and to restore ecosystem processes that provide for basic human needs.

Ecosystem ecology is an inherently interdisciplinary field of study with ecosystem being its principle unit of study. It mainly focuses on functional processes, ecological mechanisms that maintain the structure and services produced by ecosystems. These include **primary productivity (production of biomass), decomposition, nutrient cycling** and **flow of energy through trophic interactions**.

Biomass productivity is one of the most apparent and economically important ecosystem functions. Biomass accumulation begins at the cellular level via photosynthesis. Photosynthesis requires water and consequently global patterns of annual biomass production are correlated with annual precipitation. Amounts of productivity are also dependent on the overall capacity of plants to capture sunlight which is directly correlated with plant leaf area and nitrogen content.

Decomposition and nutrient cycling are fundamental to ecosystem biomass production. Most natural ecosystems are nitrogen limited and biomass production is closely correlated with nitrogen turnover. Typically external input of nutrients is very low and efficient recycling of nutrients maintains productivity. Decomposition of plant litter accounts for the majority of nutrients recycled through ecosystems.

Energy and Nutrients- Trophic dynamics refers to process of energy and nutrient transfer between organisms. It is an important part of the structure and function of ecosystems. In a food chain, energy gained by primary producers (plants) is consumed by herbivores, which are consumed by carnivores, which are themselves consumed by “top- carnivores”.

An ecosystem can be any size, from an area as small as a pinhead to the whole biosphere. The term was first used in the 1930s to describe the interdependence of organisms among themselves and with the living (biotic) and non-living (abiotic) environment. At ecosystem level, the units of study are comparatively very large and there are no practical units, if the nature is conceived as a single, giant ecosystem.

The overall view of this type of approach is that living organisms and their non-living environment are inseparably interrelated and interact with each other. Keeping this view in mind, A.G. Tansley in 1935 proposed the term “ecosystem”. Eco implies the environment, and ‘system’ ‘implies an interacting, interdependent complex.

Ecology is a young discipline, with many different branches that originated from disparate sciences such as botany, zoology, forestry, mathematics, engineering, and geography.

Ecosystem Ecology emphasizes the movements of energy and nutrients (chemical elements) among the biotic and abiotic components of ecosystems.

2.2 .Components of Ecosystem

An ecosystem has two major components:

1. Abiotic (non-living) component:

It includes inorganic substances, inorganic chemicals and climate of the given region. These comprise of inorganic and organic compounds present in the environment. The inorganic components of an ecosystem are oxygen, carbon dioxide, water, minerals etc., whereas carbohydrates, proteins, lipids, amino acids etc., are examples for organic material. The climate, light and heat can be either studied under abiotic component, or as separate entities. The predominant source of energy in the earth's biosphere is sun. The abiotic substances are circulated in the ecosystem through material cycles and energy cycles.

2. Biotic (living) component:

Living organisms in the ecosystem -various species of plants and animals including microbes are termed as biotic components. They can be classified as:

(i) Autotrophic component

(ii) Heterotrophic component:

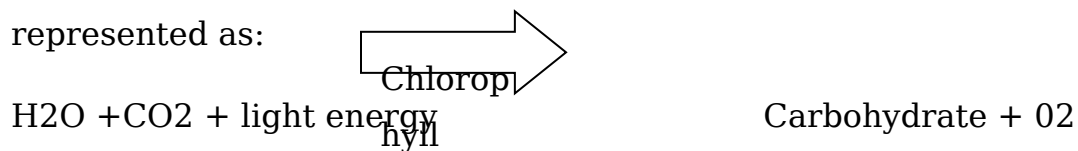
(a) Macro consumers: herbivores, carnivores, omnivores

(b) Micro consumers: bacteria, actinomycetes and fungi

(i) Producers (Autotrophs)

Autotrophs produce their own food from inorganic substances, using light or chemical energy. Green plants including the unicellular algae which contain the pigment chlorophyll are producers. They take up simple substances such as water, carbon dioxide, and oxygen, as well as inorganic nutrients and produce biological molecules needed for life from the inorganic substances. This production activity is vital for the existence of the ecosystem as the products of photosynthesis support the life on earth.

The overall effect of photosynthesis is to unite the hydrogen atoms of water with the atoms of carbon di-oxide to form carbohydrate. In the process oxygen gets released. A generalized photosynthesis reaction can be represented as:



Energy obtained from solar radiation plays the key role in this process. Hence the photosynthetic activity is essentially brought about during day time, although some insignificant amount of photosynthesis takes place during night time utilizing the faint light emitted from the heavenly bodies.

(ii) Consumers (heterotrophy)

The heterotrophy do not have the ability to produce their own food. All these species are consumers. Bacteria, although belong to plant kingdom are not capable of production and are classified as consumers. The animals which feed on plants are called herbivores. They are primary consumers. Those feeding on animals are called as carnivores which are secondary consumers. Another category of consumers which feed on both plants and animals are called as omnivores.

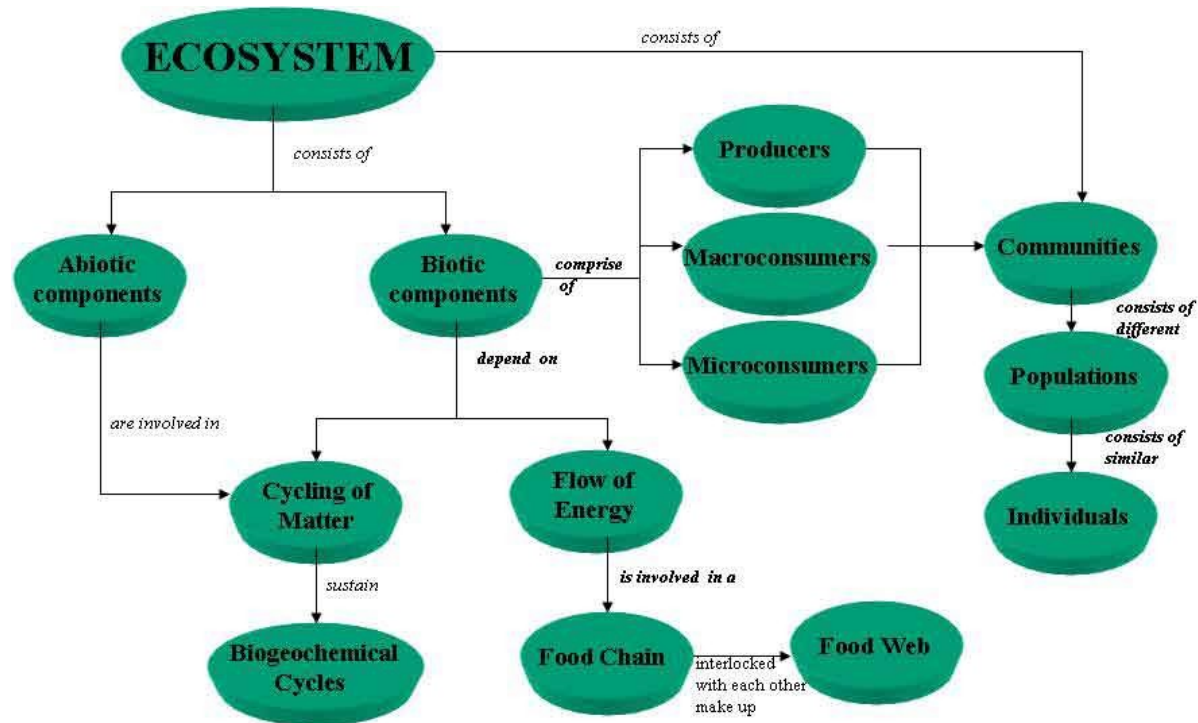


Fig. 1: components of ecosystem

An ecosystem is a vast and complex natural system. It consists of large pools of material resources and living organisms supported by sources of energy. There is a constant exchange of materials and energy in the ecosystem. The dynamics of such systems in which we live has to be properly understood so that we live happily, at the same time keeping the health of the whole system in good condition. Study of the ecosystem in all aspects is called 'ecology'.

An ecosystem consists of the biological community that occurs in some locale, and the physical and chemical factors that make up its non-living or abiotic environment.

2.3 Classification of Ecosystems / Ecology

Ecosystems are broadly classified as:

Terrestrial Ecosystems - which encompass the activities that take place on land, and

Aquatic ecosystems - the system that exists in water bodies

These ecosystems can be further subdivided as:

Terrestrial ecosystem - Forest ecosystem, Mountain ecosystem, Desert ecosystem, Grassland ecosystem, Urban ecosystem...

Aquatic ecosystem - Marine ecosystem, Fresh water ecosystem, Estuarine ecosystem

2.3.1 Subdivisions of Ecology

For ease of understanding, ecology is studied as following sub divisions:

Aut ecology - deals with the study of the individual organism or an individual species. For example study of a tree in a forest.

Synecology - deals with the study of groups of organisms which are associated together as a unit. Studying the whole forest as an ecosystem falls under this category

Terrestrial Ecology - Studies related to the ecosystem on land, that is terrestrial ecosystem are dealt under 'Terrestrial ecology'

2.3.2 Levels of biological organization

Genes → populations → species → communities → ecosystems (landscapes regions).

Biosphere= all ecosystems. It is made up of all that is living on earth, from the smallest bacterium to the largest whale. Biosphere is a life supporting global ecosystem, where each living thing depends on each other and the

environment. It includes all living organisms and abiotic or non living environment on which they depend for their energy and the nutrients they need to live.

Ecosystem= consists of all organisms living in a particular area, as well as the nonliving, physical components of the environment. It is an ecological community comprised of biological, chemical and physical components considered as a unit.

Community= consists of various populations of organisms living together in a given area. It is a group of population living together in the same area.

Population= a group of organisms of the same species in any given area.

Species =a group of organisms whose member are so similar or closely related as to be able to breed.

Organism= within a population there are organisms, just one of those organisms is called an organism. For example, within a population lions, there is a lion.

Life is dynamic and involves multi-scale ecological patterns and processes. Although each scale is important, the interdependence of scales needs to be understood and assessed in order to conserve biodiversity.

The cross-scale nature of ecosystems includes ecological processes that operate from centimeters and days to hundreds of kilometers and millennia and collectively affect biodiversity. In a forest, for example, this ranges in increasing scale from physiological processes that affect the life history of leaves, competition between plant species in a clump or gap that affect populations, disturbance and predation processes that influence the composition and structure of a community, to climatic processes that influence landscapes and regions. Each of these scales interacts with their

finer/faster and coarser/slower neighboring scales resulting in hierarchies and adaptive cycles that have been referred to as a *panarchy*

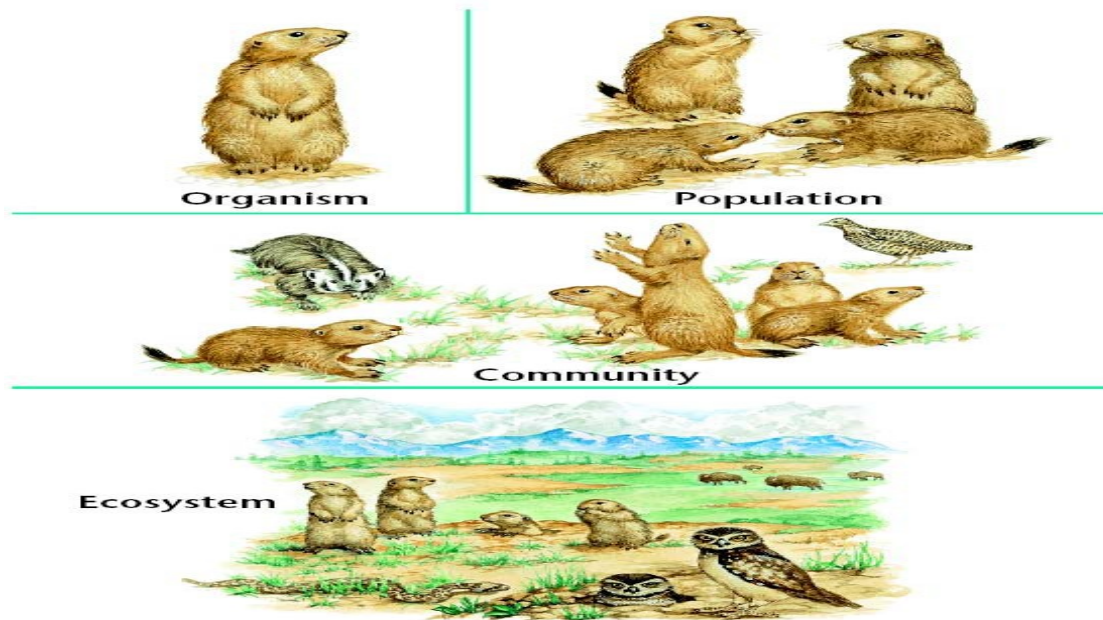


Fig 2 level of organization with in ecosystem

2.4 Forest ecology

Forest ecology is the study of forest ecology. Forests are ecosystems in which the major ecological characteristics reflect the dominance of ecosystem conditions and process by trees. Ecosystems are ecological systems that have the attributes of structure, function, interaction of the component parts, complexity (that reflects the structure, function and interactions) and change over time. An ecosystem can be of almost any physical size as long as it exhibits these key characteristics from a single plant growing in soil, to entire world ecosystem.

Forests are local or regional segments of landscapes in which biological and ecological conditions and process are dominated by the presence of trees-large, generally long lived perennial plants characterized by a large woody

stem and a large woody root system. The size and longevity of trees confer on them the ability to dominate other plant types by expropriating light and soil resources. This enables trees to control the major ecological process to determine the habitats for animals, microbes and other organisms in the forest. Trees also dominate the hydrological cycle, the soil development process, the microclimate and the ecological characteristics of streams in forest ecosystems. Forest can also be dominated by large plants with woody stems that are not strictly trees, such as bamboo or tree ferns.

An Ecosystem exhibits five attributes:

Structure - there are living and dead plants, animals and microbes arranged in vertical and horizontal patterns in local ecosystem and across regional landscapes. There is a physical environment that is in terrestrial ecosystems consists of soil, geological substrates and an atmosphere. In aquatic ecosystems, the medium is water, and the ecological process may or may not be affected by sediments or geological substrates.

Function- the system of living and dead organisms, together with their abiotic environment, result in the combining of physical(light) or chemical energy with chemical elements (nutrients) from the soil, geological substrates, water or atmosphere to create the complex, high energy, organic molecules that make up living organism and render life as we know it possible. The energy for the creation of the molecules in forest ecosystem is provided almost entirely by the photosynthesis. The chemical raw materials for their synthesis are provided by the circulation of appropriate mixture of different nutrient elements in the ecosystem (nutrient cycling). Which in turn is strongly influenced by temperature and moisture, and hence by climate, and by action of soil animals and microbes.

Complexity- forest ecosystems are characterized by complex assemblage of different plant life forms, from lichens and bryophytes (e.g. mosses) to various types of herbs and shrubs, to climbers and trees. Associated with

these different living plants is an assemblage of animals and microbes that use them as a source of energy and nutrition. Dead plant and animal matter provide the energy resource for a different set of animals and microbes that serve to decompose the organic matter and make the nutrients they contain available again for uptake by a new generation of living plants and microbes. The interaction between the living organisms and between these organisms and both the dead organic matter and the physical environment contribute to the complexity of ecological systems.

Interaction between ecosystem components- as is the case for all systems, a key feature of an ecosystem interaction between the structural components. For example soil affect plants, but plants also influence soil development. Climate determines soil and vegetation development, but plants modify local climate to produce microclimate; vegetation can sometimes influence regional climate features and global vegetation plays a major role in global climate. Animals and microbes affect plants, but plants largely determine which animals and microbes will be affecting them.

Change over time- for humans, “nothing is as certain as death and taxes”. For ecosystems, “nothing is as certain as change. Just as individual animals are born, grow, mature and inevitably die, ecosystems undergo “**renewal**” as a result of ecosystem disturbance caused by humans or non-humans processes or events. Ecosystems develop and mature, and are eventually re disturbed and the processes of renewal are repeated. This change over time is as fundamental to ecosystems as any of their other characteristics, and in many cases is an essential requirements for their long term stability and the maintenance of historical ranges of variation in their structure, function, complexity(including biological diversity) and the interactions of their components.

A **forest ecosystem** is an area of the landscape, varying in size from a local stand (a few hectares or less) to an entire continent, in which the structure,

function, complexity, interaction and patterns of change over time are dominated by trees. Forest ecology is the study of these tree dominated landscape units.

A forest ecosystem community is directly related to species diversity. Generally the more complex the structure, the greater is its species diversity.

2.4.1 Forest ecosystem structure

Forest ecosystem consists of:

Soil or some geological or organic substrate in which the trees and other plants are rooted;

An atmosphere and a regional climate that is modified locally by slope and aspect; a microclimate that results from the shade, the reduced wind speed and the increased humidity created by the trees; and

Organism, including plants. Forest ecosystem structure reflects to a great extent the horizontal and vertical arrangements of living forest plants of different life form. life forms include mosses, liverworts and lichens; grasses and non-grass herbs(forbs); shrub and climbers; and tree of varies types. In addition to the living plants, there are standing dead trees in various stages of decay and collapse; dead tree stems on the ground in various stages of decomposition; and an organic layer on the soil surface (forest floor) made up of varying combination of dead fine roots, above ground litter fall (leaves, branches, reproductive structures), decaying wood, daed fungi, bacteria and animals, the decay resistant faeces of soil animals, and various other types of highly decomposed organic matter.

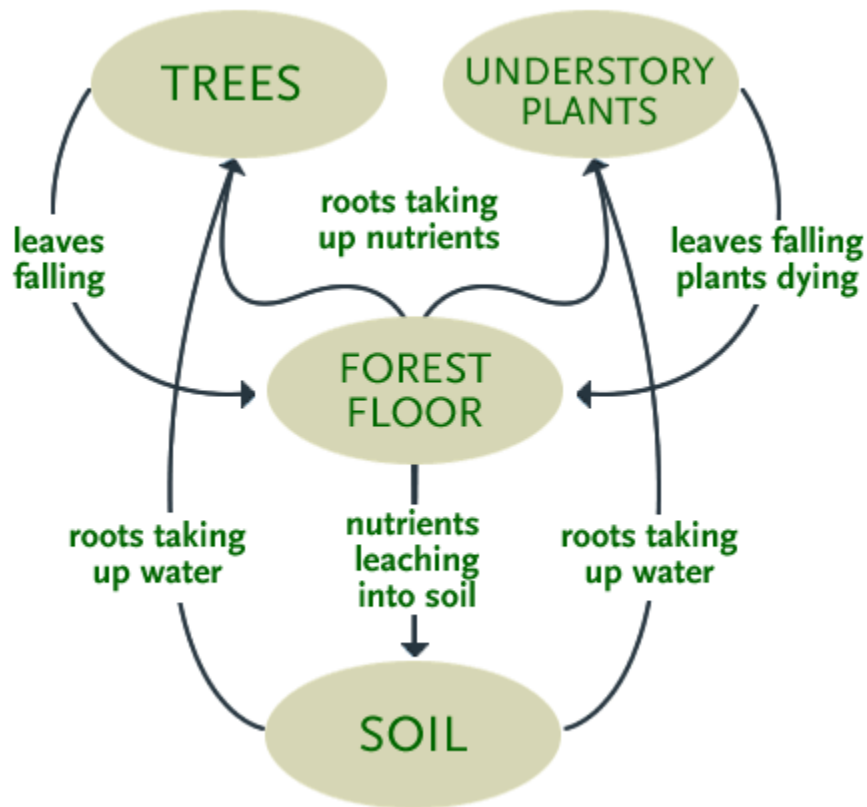


fig 3 components of forest ecosystem

A forested ecosystem, by definition contains trees, so that is our first component. In addition to the various species and layers of trees in a forest, there are other distinct ecosystem components. For example, the understory contains most of the visible plant life found between the sapling layer and forest floor. The forest floor is where one would find most of the plant roots, bulbs, fungi, seeds, years of accumulated leaves and twigs. The soil is the “dirt” under the forest floor and is composed largely of minerals of various grain size (very small grain size = clay...very large grain size = sand) and organic material that has been mixed in with the mineral component. In addition, there are numerous animals that live in the forest.

Forest ecosystems tend to always be moving toward maturity or in to what foresters call a climax forest. This maturing, also called forest succession, of the ecosystem increases diversity up to the point of old age where the systems slowly collapses.

When the ecosystem is exploited and exploitation is maintained or when components of the forest begin to naturally dies, then the maturity of the forest ecosystem declines.

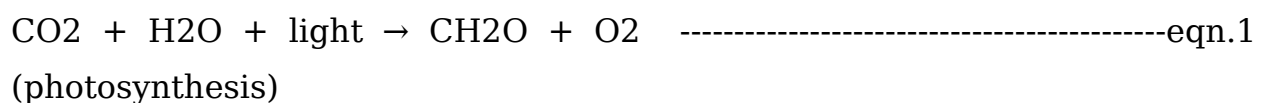
Management of forests for sustainability is desirable when forest diversity is threatened by over use, resource exploitation, old age and poor management. Forest ecosystems can be disrupted and harmed when not properly sustained.

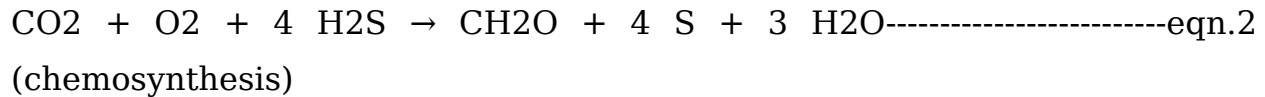
Chapter 3: Production Ecology

3.1 Sources of energy for living things

All living things need energy to survive. Solar radiation from the sun is the source of energy that supports most natural ecosystems. Through photosynthesis, green plants convert light in to chemical energy (carbohydrates) that supports the production of wood, leaves, branches, fruit, seed, and so on. Herbivores get their energy by eating plants, carnivores by eating other animals, and decomposers through the breakdown of plants and animals. Through decomposition, nutrients are made available to the soil flora and fauna and energy (in the form of heat) is realized to the environment. In natural communities this complex chain is called the food web. As energy flows from the sun through an ecosystem, at each step some of the energy is lost to the environment in the form of heat during metabolism and decomposition.

Primary production is the synthesis of organic compounds from atmospheric or aqueous carbon dioxide. It is the amount of light energy converted into chemical energy—in the form of organic compounds—by autotrophs during a given time period. It principally occurs through the process of photosynthesis, which uses light as its source of energy, but it also occurs through chemosynthesis, which uses the oxidation or reduction of chemical compounds as its source of energy.





Almost all life on earth is directly or indirectly reliant on primary production. The organisms responsible for primary production are known as primary producers or autotrophs, and form the base of the food chain. In terrestrial ecoregions, these are mainly plants, while in aquatic ecoregions algae are primarily responsible. Primary production is distinguished as either net or gross, the former accounting for losses to processes such as cellular respiration, the latter not.

Net primary production: the amount of biomass that is available to consumers at subsequent trophic levels. Net primary production (NPP) is equal to gross primary production minus the energy used by the primary producers for their “autotrophic respiration.”

$$\text{NPP} = \text{GPP} - \text{Ra}$$

Gross primary production: the total of organic material produced by plants in an Ecosystem—the amount of energy from light (or chemicals, in chemoautotrophic systems) converted to the chemical energy of organic molecules per unit of time. Not all of this production is stored as organic material in the primary producers because they use some of the molecules as fuel in their own cellular respiration. (including that lost to respiration)

3.2 Production ecology at and above primary producer level

Sun light shines down on the canopy of a forest, some is reflected, some is converted to heat energy, some is converted to heat energy, and some is absorbed by chlorophyll. Infrared radiation is absorbed the molecules in organisms, soil and water, increasing their kinetic state and raising the

temperature of the forest. Forest temperature affects the rate of biochemical reaction and transpiration by forest vegetation.

Forest plants use photosynthetically active solar radiation (PAR), to synthesize sugars. The plants use some of this fixed energy to meet their own energy needs. some fixed energy goes directly in o plant growth: to produce new leaves, to lengthen the tendrils of vines, to grow new root hairs, and so forth. Some fixed energy is stored as nonstructural carbohydrates, which act as energy stores in roots, seeds or fruits. Photosynthesis may increase forest biomass.

A portion of the energy fixed by forest vegetation is consumed by herbivores, some is consumed by detritivores, and some ends up as soil organic matter. Energy fixed by forest vegetation powers bird flight through the forest canopy and fuels the muscle contractions of earthworms as they burrow through the forest soil. The forest vegetation is sun light transformed, as are all the associated bacteria, fungi, and animals and all their activities.

Chapter 4: Biogeochemistry

The term "biogeochemical" tell us that biological, geological and chemical factors are all involved. Biogeochemical cycle is any of the natural circulation pathways of the essential elements of living matter. These elements in various forms flow from the nonliving (abiotic) to the living (biotic) components of the biosphere and back to the nonliving again. In order for the living components of a major ecosystem (e.g., a lake or forest) to survive, all the chemical elements that make up living cells must be recycled continuously.

Biogeochemical cycle - The flow of chemical elements and compounds between living organisms and the physical environment. Chemicals absorbed or ingested by organisms are passed through the food chain and returned to the soil, air, and water by such mechanisms as respiration, excretion, and decomposition. As an element moves through this cycle, it often forms compounds with other elements as a result of metabolic processes in living tissues and of natural reactions in the atmosphere, hydrosphere, or lithosphere.

The circulation of chemical nutrients like carbon, oxygen, nitrogen, phosphorus, calcium, and water etc. through the biological and physical world are known as biogeochemical cycles. In effect, the element is recycled, although in some cycles there may be places (called reservoirs) where the element is accumulated or held for a long period of time (such as an ocean or lake for water).

Elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another through biogeochemical cycles. The most well-known and important biogeochemical cycles, for example, include; • the carbon cycle, the nitrogen cycle, the oxygen cycle, the phosphorus cycle, the sulfur cycle, the water cycle and the rock cycle.

4.1 Plant nutrition: energy and nutrients at the primary producer level

Green plants are very effective photochemical factories: they use the energy of light to combine carbon dioxide from the air with water from the soil to make carbohydrates:



This reaction occurs in the chloroplasts of all green plants, using the green pigment chlorophyll to trap the energy from sunlight. The basic building blocks of glucose are then used to build up more complex carbohydrates such as cellulose. The composition of plants is not much different from that of animals, and includes significant amounts of nitrogen and phosphorous, as well as trace amounts of many other elements. Although there is enormous variation between the abundance of the most common element, hydrogen, and the least common, molybdenum, both are very important. For example, plants can only use nitrogen in the form of the ammonium ion. Nitrates are converted to ammonium ions by the enzyme *nitrate reductase*, and as this enzyme cannot function without molybdenum, the presence of molybdenum is essential if the plant is to receive nitrogen in a form that it can use. These trace elements, generally called plant nutrients, normally come from the soil in which the plant is growing. The plants absorb their nutrients from the soil solution (the film of water which covers all the particles in moist soil), usually in very simple forms.

The plant is grown in a solution which contains all the required plant nutrients, in the correct proportions. It is possible to determine just how much of any particular nutrient a plant needs by starting with a balanced nutrient solution, and then varying the amount of each nutrient present, one nutrient at a time. When insufficient of the nutrient is present the plant will not thrive. As the amount of nutrient is increased the growth improves, until all that the plant can utilize is present, when adding more of that nutrient produces no additional growth. If the amount of the nutrient is increased still further, the excess may eventually cause toxic effects, and growth is retarded.

4.2 Nutrient cycling in tropical forests

In tropical rain forests, constant warm temperatures and plentiful rain fall throughout the year mean that the process that govern nutrient cycling never cease.

Nutrients are elements or compounds that are essential for the growth and survival of plants. Plants require large amounts of nutrients such as nitrogen (N), phosphorus (P), carbon (C), hydrogen (H), oxygen (O), potassium (K), calcium (Ca), and magnesium (Mg), but only small amounts of others such as boron (B), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and chlorine (Cl) (micronutrients).

Forest nutrient cycling is defined as the exchange of elements between the living and nonliving components of an ecosystem. The processes of the forest nutrient cycle include: nutrient uptake and storage in vegetation perennial tissues, litter production, litter decomposition, nutrient transformations by soil fauna and flora, nutrient inputs from the atmosphere and the weathering of primary minerals, and nutrient export from the soil by leaching and gaseous transfers.

Each nutrient element is characterized by a unique biogeochemical cycle. Some of the key features of the major nutrients are shown in Table 1. Forest trees make less demand on the soil for nutrients than annual crops because a large proportion of absorbed nutrients are returned annually to the soil in leaf and fine root litter and are reabsorbed after biological breakdown of litter materials. Also, large portions of nutrient requirement of trees are met through internal cycling as compared with agricultural crops.

Table 1 Features of the major nutrient cycles

Element	Uptake by the tree	Major sources for tree uptake	Limiting situations
Carbon	Atmosphere	Atmosphere	Atmospheric concentration may limit growth.
Oxygen	Atmosphere	Atmosphere	Waterlogged soils
Hydrogen	Atmosphere	Atmosphere	Extremely acidic and alkaline conditions.
Nitrogen	Soluble NO_3 and NH_4 ; N_2 for nitrogen fixing species	Soil organic matter; atmospheric N_2 for nitrogen fixing species	Most temperate forests, many boreal forests and some Tropical forests.
Phosphorus	Soluble phosphorus	Soil organic matter; adsorbed phosphate and mineral phosphorus	Old soils high in iron and aluminum, common in subtropical and tropical environment
Potassium calcium magnesium	Soluble K^+ /soluble Ca^{2+} soluble Mg^{2+}	Soil organic matter exchange complex and minerals	Miscellaneous situations and some old soils

Nutrient cycling in forest ecosystems is controlled primarily by three key factors: climate, site, abiotic properties (topography, parent material), and biotic communities. The importance of ecosystem disturbance to nutrient cycling is examined briefly, since some nutrients are added or lost from forest ecosystems through natural (e.g., fire, erosion, leaching) or human activity (harvesting, fertilization).

Nutrient availability is strongly influenced by the quantity and quality of litter produced in a forest. The availability of N, P, and K in soil largely determines the leaf area, photosynthetic rate, and net primary production of forest ecosystems. Forest management practices that produce physical and chemical changes in the soil that accentuate the cycle of nutrients between soil and trees, may increase forest productivity. Nutrient cycling is higher in forests on fertile soil in the wet tropics than on forests on infertile soil.

4.2.1 Nitrogen cycle in the tropics

Nitrogen makes up about 78% of the atmosphere. But it can only enter terrestrial ecosystems through nitrogen fixation or via precipitation (Brady and Weil 2002). Nitrogen gas can be fixed from the atmosphere by microbes living symbiotically with the root of plants in the legume family. It also enters the ecosystem dissolved in rain water. Once in the plant, nitrogen is used in proteins and other compounds. When a leaf or a plant dies it falls to the ground as litter. Some of the nitrogen is converted into ammonium and nitrate and moves into the soil or roots. Under anaerobic conditions, such as those that occur in poorly drained or water logged soils, some nitrate-nitrogen is reduced to nitrogen gases by bacteria called denitrifiers and is then released into the atmosphere.

The high temperatures and humidity of forests of the moist tropics are near optimum for microbes that mediate nitrogen transformation. As organic matter in the soil decomposes, organic nitrogen is decomposed into

ammonia, which can be taken by plants or transformed into nitrite and then nitrate by action of highly specific, aerobic soil bacteria. Nitrate can be leached or taken up by roots or by microbes, or the nitrate nitrogen can be denitrified and returned to the atmosphere (Jackson and Raw 1973).

The microbes that mediate nitrogen transformations are active year round. As a result, the sparse available data suggest that in most tropical ecosystems, more nitrogen is cycled per year than in temperate zones. An exception is tropical forests where nitrogen stocks in the soil are extremely low and therefore limiting, as on spodosols. These are soils that have developed under highly acidic conditions, where organic matter from the top soil dissolves and precipitates down in the soil profile (Brady and Weil 2002).

Biological Transformation of Nitrogen Compounds (microbial mediation)

Nitrogen fixation → enzyme-catalyzed reduction of N_2 to NH_3 , NH_4^+ or any organic nitrogen

Ammonia assimilation → uptake of NH_3 , NH_4^+

Nitrification → oxidation of NH_3 , NH_4^+ to NO_2^- or NO_3^- as a means of producing energy

Assimilatory nitrate reduction → reduction of NO_3^- then conversion to biomass

Ammonification → organic nitrogen to NH_3 or NH_4^+

Denitrification → reduction of NO_3^- to N_2 or N_2O (nitrous dioxide, gaseous forms)

Other chemical elements are cycled through ecosystems in similar ways. These include carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium and potassium. These chemicals are absorbed by plants from the soil or air; the plants are then eaten by animals, and eventually decomposers break them down, returning the elements to the soil or water and carbon dioxide to the air.

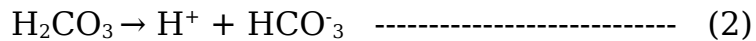
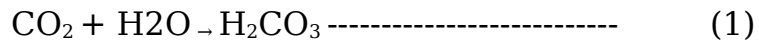
4.2.2 Availability of phosphorus in tropical forest

Phosphorus is frequently the nutrient element most limiting plant growth in oxisols and ultisols, the most common soil types in the tropics. These soils have high concentrations of iron and aluminum. Insoluble iron and aluminum phosphates are formed in the mineral soil. Phosphate in this form is unavailable to plants. In the undisturbed forest, however, phosphorus availability is not generally a problem. Leaf litter provides an energy source for the microbes that carry out decomposition. As the result of their metabolism, the microbes produce organic acids that react with the iron and aluminum. The organic acids use up the binding power that otherwise would be used to bind phosphorus. The organic acids may also solubilize the phosphorus in iron and aluminum phosphates. Because of this microbial activity, more phosphorus is made available for plant growth, plants grow more and as a result, they produce more litter. This cycle can be maintained as long as there is a layer of organic matter on the soil. When this layer is destroyed by forest cutting and cultivation, the availability of phosphorus can fall to levels that are below those that are needed for plant growth.

4.2.2 Leaching and weathering

The high rate of decomposition plus the continues warm temperatures and high rainfall the wet tropics result in optimum year round conditions for leaching of soil nutrients. Positively charged nutrient ion such as calcium

and potassium are held on the surface of clay particles, but when the soil solution is acidic, the nutrients are replaced by hydrogen ions. Hydrogen is formed in the soil when carbon dioxide respired by soil organisms react with soil water to form carbonic acid, which dissociates into bicarbonate and a positively charged hydrogen ion:



Negatively charged anions such as bicarbonate replace negatively charged nutrient ions such as nitrate and sulfate. The nutrients that have been exchanged into the soil solution can then be adsorbed by soil colloids, used by plants, or leached into streams or groundwater.

The reaction in Eqs. (1) and (2) also result in soil weathering. Weathering occurs when hydrogen in the soil solution reacts with minerals in the soil or bed rock, resulting in removal of nutrient elements.

Chapter 5: The physical environment

5.1 Ecological role of solar radiation

Light from the sun, an abiotic factor, makes life possible in almost all ecosystems. Green plants take solar energy and convert it into chemical energy through photosynthesis.

Solar energy powers the **water cycle**. The water cycle is how water moves through the atmosphere and the earth's surface. The sun heats water on the earth. The water **evaporates**— it turns into a gas called **water vapor** and rises into the air to form clouds. The air in the atmosphere is cool. The water vapor **condenses** into liquid water. The water falls from the clouds as **precipitation**—rain, sleet, hail or snow.

5.2 Ecological role of soil

Soil is not a sterile homogeneous material. Soil in its natural state is a living environment, teeming with biological activity functioning in a complex ecosystem. The types of life found in the soil are many, and the numbers of organisms are enormous. Organisms serve a variety of functions in the soil ecosystem. Some of them are:

Recycling of energy and carbon - The decomposition of organic matter releases stored energy and produces carbon dioxide, which can then be reused by plants through photosynthesis.

Recycling of plant nutrients - The decomposition of organic matter transforms plant nutrients into available forms which can be taken up by plants.

Disease transmission and control - Some organisms cause or transmit diseases while others, such as *Penicillium*, produce substances which control disease organisms.

Nutrient/water absorption - Organisms such as fungi and actinomycetes form associations with plant roots and aid the plant in exploring the soil environment for water and nutrients.

Nitrogen fixation - Some organisms take nitrogen from the atmosphere and transform it into organic forms which are then utilized by other organisms in the ecosystem. Such organisms include bacteria in symbiosis with legume plants, blue-green algae, and some actinomycetes.

Soil mixing - Organisms that burrow through the soil mix it through their digging. Subsoil is brought up and mixed with topsoil, recycling the clays and minerals which had eluviated down out of the rooting zone.

Decomposition of chemical materials - Pesticides, petroleum products, and other organic chemicals are degraded by soil microbes; first into other organic materials, ultimately into carbon dioxide and water. Materials which resist microbial action may accumulate and lead to environmental problems.

Microorganisms and organic matter produced by soil organisms are important in the formation of soil structure. Humus and exudates of roots and microorganisms act as a glue, holding soil particles together. Fungal hyphae bind particles together. The surfaces of bacteria carry a net-negative charge, similar to clays, and have a similar effect on soil structure.

Soil organisms are often grouped into five classes:

1. Animals include earthworms, arthropods (insects, spiders, centipedes, etc.), and rodents (moles, gophers, prairie dogs, etc.). Earthworms have an enormous effect on the soil through their mixing of soil material and by ingesting organic matter. The organic matter remaining in their casts is partially digested, so the nutrients in it are more available to plants. Termites digest large amounts of organic matter, some of which is later available to plants, and also affect soil physical properties. Other arthropods are predators, feeding on other organisms. Nematodes are often predators in the soil, feeding on other microorganisms. Many of them have a detrimental effect on plant growth. Microscopic protozoa graze on bacteria, moving within thin films of soil water. When water or food are limiting they encyst, waiting until conditions improve.

Plants have major effects in the soil environment by the cycling of water and nutrients, production of organic matter, formation of pores by root growth, secretion of root exudates which promote soil aggregation, and production of organic acids which influence nutrient availability. Bacteria and actinomycetes that fix atmospheric nitrogen use root exudates for energy; root nodules provide a home for some of these microorganisms. Blue-green algae also fix nitrogen; especially in wet environments such as rice paddies and wetlands.

Bacteria have perhaps the greatest influence in the soil environment of all organisms. Species are either autotrophic or heterotrophic. They perform many functions in the ecosystem, most importantly in enzymatic transformations. They are able to oxidize or reduce many chemical elements in the soil. For example, nitrogen is transformed from ammonium to nitrite and nitrate by two different species. Fixation of nitrogen from atmospheric N_2 into organic forms is also performed by bacteria, either in symbiotic associations with plants or independently. The net-negative electrical

charge on bacteria and organic materials produced by them are important in the formation of soil aggregates and soil structure.

Actinomycetes are a special type of bacteria. They are single-celled and small, but they have filamentous structures (mycelia) like fungi. They have important roles in the decomposition of organic matter, release of plant nutrients, and in some cases form symbiotic relationships with plants including nitrogen fixation. Many of our important antibiotics (all the mycin compounds such as streptomycin) were first discovered through the study of actinomycetes in the soil. *Streptomyces spp.* are responsible for the typical odor of a plowed field.

Fungi are very important in the soil ecosystem. The decomposition of organic matter releases plant nutrients into the ecosystem for other organisms to use. Some fungi form mycorrhizal associations with plant roots - plants provide the fungi with food (sugars and other root exudates) and the mycorrhizae provide the plants with enhanced availability of plant nutrients (P,Zn,Ca,Mg,Mn,Fe, and Cu). Some fungi are important in other ways: mushrooms are important food products; many molds, like *Penicillium*, produce useful materials such as antibiotics. Fungal hyphae also play a role in the development of soil structure.

Chapter 6: Population ecology

6.1. Population growth and Determinants of population size

A population refers to a group of individuals of one kind with no barriers to exchange of genetic material in a given area at a given time. For example, population of human beings in a city, or population of squirrels or of lions in a forest, or pine trees in a given land (Photo 1). The study dealing with structure and dynamics of individuals in a population and their interactions with environment is known as Population Ecology.

Population ecology is a significant branch of ecology that plays an important role in protecting and managing populations, especially those of rare species, through various means including PVA (Population Viability Analysis). PVA helps to determine whether a population would survive or face the risk of extinction (complete disappearance of a species from the biosphere) under a given set of environmental conditions. Further, each population has a minimum viable size - the size at which it can avoid the extinction due to various biotic and abiotic factors.

The subject of population ecology can be divided into 3 sections for the sake of convenience:

- A) Population characteristics
- B) Population dynamics
- C) Population regulation

6.1.1 Population Characteristics

Populations are identified by a number of characteristics. These are: 1. Population size and density, 2. Patterns of dispersion, 3. Age structure, 4. Natality, 5. Mortality, 6. Population growth and dispersal, 7. Biotic potential.

1. Population size and density

Population size is usually determined on the basis of density, i.e. number of individuals per unit area (if it is land) or per unit volume (if it is an aquatic system). For example, 200 trees found in one hectare of land tell us about the density of the tree population, or 15 fishes/m³ water indicates the density of fish population. Density of the population is often of two types - Crude density and Ecological density.

Crude density is that density which takes in account all area of land or aquatic ecosystems under consideration, e.g. number of squirrels in a forest.

Ecological density on the other hand, takes in account abundance of individuals in the actual area occupied by a population. If we consider the above example of squirrels, numbers of squirrels per unit area of the tree dominated patches (areas where squirrels are actually living) constitute ecological density.

The difference in the two types of densities becomes more apparent when the species are clumped together in a small area. However, crude density is studied frequently more than the ecological density because it is very difficult to determine the 'actual area' of inhabitation of a species. Further, the area of inhabitation may vary with developmental stages of species.

2. Patterns of dispersion

Pattern of dispersion means the manner in which individuals of a population are distributed in space and time. Dispersion may be spatial (varying with respect to space) or temporal (varying with time). In the latter, example of migratory birds is well-known. In case of spatial pattern, broadly three types of dispersion patterns are recognized.

Regular or Uniform

Random

Clumped

Regular or Uniform dispersion: In this type, the individuals of a species occur uniformly which is observed in terms of almost equal distances between individuals. This type of dispersion is rare in natural ecosystems but common in manmade ecosystems like agro-ecosystems or tree plantations.

Random dispersion: In random dispersion, position of an individual in a population is unrelated to the positions of other individuals. In other words, individuals do not show any systematic pattern of dispersion. This type of dispersion is also rare in nature.

Clumped dispersion: In this type of pattern, the individuals of a species are clumped together in space in the form of patches. This type of patchy distribution is quite common in nature as individuals of a population occur together because of food availability or better survival rate as in animal populations. In plants, the clumped distribution is very common, and attributed to nutrient availability, specific habitat preference or better environmental conditions. Example of this kind can also be seen in the social aggregations that are formed in response to some environmental suitability.

3. Age structure

A population is comprised of individuals of different age groups that constitute its age structure. Age structure of a population thus derives from the proportion of individuals in different age groups. For the sake of

convenience, the age categories have been divided into three major stages, **Pre-reproductive**, **Reproductive** and **Post-reproductive**. The proportion of different stages in a population is presented graphically in the form of age pyramid. An age pyramid is thus a geometrical model showing the proportions of different age groups of a population. Populations with equal proportion of major three stages are said to be stationary populations. A population with high number of young individuals as compared to the older organisms is increasing or progressive type and the pyramid of such a population would have a broader base. On the other hand, if the number of older organisms is more than the younger ones, the population is said to be retrogressive or declining type. The base of the pyramid of such population would be narrow.

4. Natality

Natality means production of new individuals (offspring) of an organism in a population. The new individuals can be formed through birth (as in human beings), hatching (for example, in chicken eggs), germination (in plants), or cell division (lower organisms). The number of offspring produced per female per unit time is known as *rate of natality*. Natality can be of two types:

Maximum or Absolute natality

Ecological natality

Maximum or Absolute natality also known as *Fecundity rate* means maximum offspring produced under most suitable environmental conditions. This value is theoretical (since the environmental conditions are never static and keep on changing) and constant for a given population.

Ecological natality also known as *Fertility rate*, on the other hand, refers to number of offspring produced under prevailing environmental conditions.

5. Mortality

Mortality refers to death of individuals in a population. Rate of death of individuals referred to as Mortality rate is of two types:

Minimum mortality rate

Ecological mortality rate

Minimum mortality rate, or also known as *Physiological longevity*, refers to the theoretical minimum death rate which occurs under ideal conditions of environment with minimum limiting factors. This value is a theoretical value and constant for a given population. Under actual environmental conditions, the death rate may be more and this actual death rate is referred to as *Ecological mortality*.

The other way of expressing mortality is vital index, which is ratio of birth to death rate and expressed as percentage.

Vital Index = $\frac{\text{Number of births}}{\text{Number of deaths}} \times 100$

Number of deaths

The most popular way to express mortality in a population is to prepare a survivorship curve. A *survivorship curve* for a given population is a graph drawn between numbers of survivors (on a log scale) on Y-axis against age on the X-axis. In general, there are three patterns of survivorship curves (Figure 3).

Type 1 - It is also known as *highly convex curve*. It reflects higher rate of survival or low rate of mortality of younger individuals as compared to the older ones. This type of curve is found in human beings.

Type 2 - This curve shows a steady death of individuals per unit time throughout the life, and is found in some reptiles, corals, honeybees and

rodents. This shows a *straight-line relationship* between age and number of survivors.

Type 3 - This is also known as *highly concave curve*. It shows higher mortality of individuals at young stage as compared to old stage. It is found in plants, sea urchins and fish species.

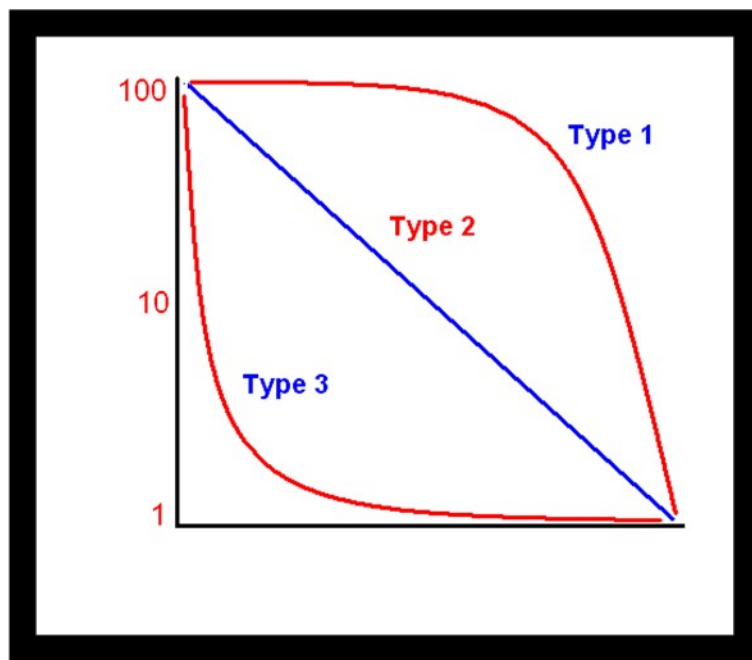


Figure 4 . Different types of survivorship curves found in different populations.

Environment may have significant impact on survivorship curves of a given population. For example, plant population may show one type of survivorship curve under drought and another type of curve under humid conditions.

6. Population growth and dispersal

Individuals of a population keep migrating out (Emigration) or into populations (Immigration). Thus, population size and density keep changing with time. In addition, birth (b) and death (d) of individuals also change population size. Immigration and birth increase population size whereas emigration and death decrease its size. Thus, in a given population if $\text{birth} + \text{immigration} > \text{emigration} + \text{death}$, the size of population would increase. On the other hand, if the $\text{birth} + \text{immigration} < \text{emigration} + \text{death}$, then the size of the population would decrease.

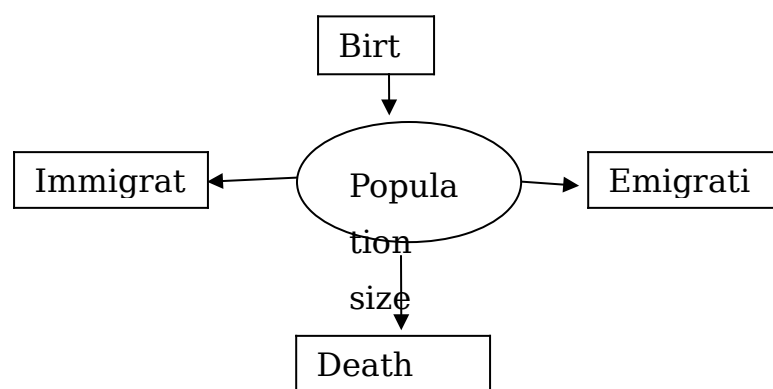


Figure 5. Influence of immigration, emigration, death rate and birth rate on population size.

6.1.2 Population Dynamics

Populations are never static and keep changing in time and space. These changes in population size over time show varied trends. When environment is unlimited (adequate space and food supply) the specific growth rate (population growth rate per individual) of populations becomes maximum and constant under a set of environmental conditions. On the other hand, if the food supply or other resources are limited, the growth rate is typically sigmoid, i.e. increases slowly in the beginning followed by rapid increase and then becomes constant as it approaches the upper limit. To address these growth patterns, there are two types of growth models These are:

a. J-shaped or Exponential Growth Model

b. S-shaped or Sigmoid or Logistic Growth Model

a. J-shaped or exponential growth model

In exponential growth type population increases geometrically or exponentially until there is resource limitation or population growth is limited by other factors. Growth then declines rapidly until favorable period is restored. Mathematically this growth model can be expressed as rate of population increase with time t , i.e.

$$dN/dt = rN$$

Where N = population size, t = time, and r = intrinsic rate of natural increase.

The value of r is the maximum when resources are not limiting. Since the curve drawn between population size (Y-axis) and time (X-axis) is *J-shaped*, it is also known as *J curve* or *J-shaped growth model* (Figure 5a).

b. Sigmoid or S-shaped growth

When population growth occurs at a place where resources are limited, it attains a sigmoid or S-shaped curve showing minimum death during early stages. The population increases in size until it reaches an upper limit. This upper limit is known as the *Carrying capacity*, which is denoted by 'K'. *Carrying capacity thus may be defined as capacity of an ecosystem to support maximum number of individuals of a species*. As the population size increases, population growth rate declines as it approaches carrying capacity. Sigmoid growth is thus density dependent and can be expressed by the following equation:

$$dN/dt = rN (K-N/K)$$

Where N = population size, t = time, r = intrinsic rate of natural increase, and K = carrying capacity.

When N equals K , the growth rate becomes zero and the population reaches equilibrium.

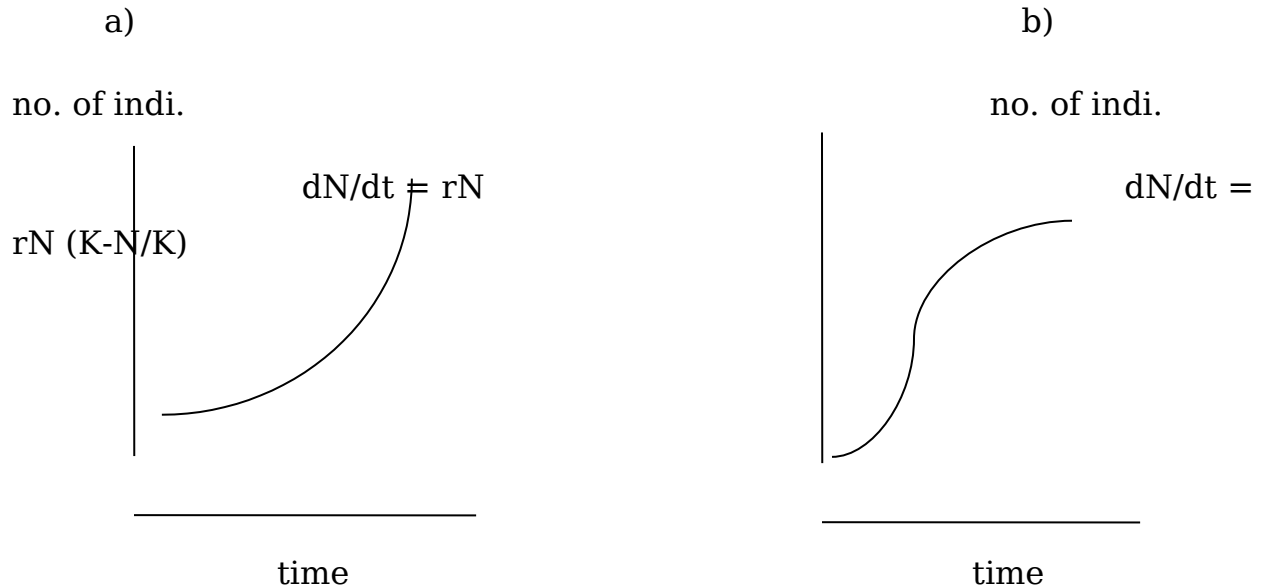


Fig 6. Population Growth Models; a: *J*-shaped or Exponential; b: Sigmoidal or S-shaped.

6.1.3 Population Regulation

A number of factors like availability of food, space, water, and pests may regulate population size. In general, the factors responsible for population regulation can be **density dependent** (competition, predation, parasitism, disease outbreak, or herbivory) or **density independent** (environmental factors). In density dependent factors, competition (particularly intra-specific i.e. between individuals of same species) plays a major role in limiting population size. Among the density independent factors, floods, fire and other natural calamities remove large proportion of the populations and thus decrease their density.

Sometimes individuals of a population release toxic substances in the soil or water, which tend to limit the growth of their own type of plants

(*consepecifics*) and thus control over-crowding of a species at a particular place. This is known as **autoallelopathy or autotoxicity** - a type of interaction where one species releases toxic substances into environment that are detrimental to individualists own growth. Another interesting observation wherein organisms regulate their population prevalent in plants and even in some sessile animals is self thinning. *Self- thinning* results from a specific relationship between density and biomass of individuals.

Chapter 7: Community Ecology

Community ecology has almost similar meaning as that of *Synecology*. A **community**, also known as **biotic community** or **ecological community** or **biocoenosis**, refers to a group of co-existing and interacting populations in a given space and time. For example, a forest community is reflection of co-existence and interactions of a variety of populations - the trees, shrubs, herbs, grasses, animals, and microorganisms. In other words, it is the biological part of the ecosystem distinct from the abiotic part.

Each community has spatial limits or boundaries. The boundaries between communities may be very sharp such as boundary between a forest and a lake or less sharp, e.g. boundary between two types of forests or a forest and a grassland community. Often there is some transitional area between two communities that is known as *Ecotone* where species of both adjacent communities are found. The ecotonal communities are rich in species diversity because of the edge effect (contrasting environmental conditions at the boundaries or the edges supporting a high species richness). For instance, a patch of land between two forest communities will have animals and plants common to both the forest communities.

7.1 Characteristics of Communities

There are various characteristics of communities such as species diversity, structure and composition, dominance, succession (or developmental history) and trophic structure.

7.1.1 Species diversity:

Each community is composed of taxonomically different species. *Species diversity* refers to number of different species in the community including both abundant and rare species. Species diversity is very high in natural communities like tropical rain forests or coral reefs in oceans, whereas it is very low in physically or human controlled communities. Species diversity has two components: species richness and species evenness. In simple words, species richness refers to different types of species and their numerical strength. Technically, it refers to ratio between different species (S) and total number of species (N). Species evenness refers to a measure which qualifies as to how even species are in terms of their number. In a community, it refers to the apportionment of each species. For example, a community is quite even if there are 10 species with 10 or 9 individuals of each species; whereas a community is uneven if there are 10 species of which one species has 90 individuals and the rest 9 species have only 10 individuals.

For a community to be stable, it requires two components - **Resilience** and **Resistance**. *Resilience* is the ability of a community to recover after facing a disturbance or displacement. *Resistance*, on the other hand, is the ability of a community to avoid disturbance (any event that alters structure of a community) or displacement (shifting of the community to some other

place). One of the reasons for the species rich complex communities acquiring stability is that any change in one or a few species would be compensated by the other species. Some other studies, however, have indicated that greater complexity in a community leads to instability. Thus, it remains controversial whether complexity of a community leads to stability or unstable conditions. However, ecologists have successfully found a relationship between competition and diversity or stability. If the competition is severe, there is low diversity because only those species survive what are able to withstand harsh conditions by suitably adapting themselves. On the other hand, if the competition is weak and the requirements of species do not overlap, the species will not fight for resources and thus more and more species can coexist. The competition becomes intense if the resources for the life support system – food, air, water, space, sunlight (in case of plants, especially) are scarce and the requirements of the species overlap.

7.1.2 Community Structure and Composition:

Each community has its own structure and composition. The forest communities are highly stratified (forming distinct vertical storeys). In a typical forest, there are five different vertical storey viz. subterranean part (deep in soil), forest floor, herbaceous vegetation, shrubs, and trees. In contrast, grasslands show poor vertical stratification. It has only two layers - a subterranean part with roots and rhizomes and herbaceous part consisting of grasses, herbs and weeds.

7.1.3 Dominance:

A community is a heterogeneous assemblage of species. Not all species present in it are equally important and thus only a few of them have a major controlling influence based on their number, size or productivity. Such groups of species are not taxonomically related and influence the energy flow and affect the environment of other species. These are known as **Ecological Dominants**. In land communities, some plants have a major influence over the others by virtue of their greater number (Numerical dominance). These protect and provide shelter to the organisms and are capable of influencing physical environment.

7.1.4 Trophic Structure:

In addition to above, each community has its own trophic structure or organisms grouped based on feeding habits. Trophic structure of a Forest consists of a variety of organisms as producers, consumers and decompose. The consumers may be primary (herbivores that directly feed on green plants), secondary (carnivores that feed on herbivores) or tertiary (feeding on other carnivores).

In a forest, the autotrophs or the producers are the trees, which are also the dominant species. Additionally, the forests also have shrubs, herbs and grasses that are autotrophic and form a distinct understorey, but their role is lesser than that of trees. The type of the trees in the forests varies from place to place depending upon environmental conditions.

7.1.5 Succession:

Succession is the orderly process of community development and refers to the continuous, unidirectional and sequential change in the species composition of a given community over time. It involves various stages during which a specific set of species occupy the area and replaced by the next group of species. All these stages of succession are known as seral stages. The first stage of succession when the bare area is colonized for the first time is known as Pioneer stage and such species are referred to as Pioneer species. The final, mature, stable and long lasting community is known as Climax community.

Chapter 8: Ecological Succession

Plant communities keep changing with time and space. These changes in the communities may either be due to changing environmental conditions or communities themselves such as their mutual interactions. Thus, in an area, one community may replace the other, and in turn, may be got replaced by another community. This change in community structure and composition over a period until there is a formation of a stable community is known as **Ecological succession**. It is predictable and orderly process. The final stable community formed at the end of succession exists for a longer period and is in harmony with the existing environmental conditions. This final stable community is known as **Climax community**, whereas the communities that appear for a shorter time, and are replaced in succession are termed as **Seral communities** or **Seral stages**. The plant community that colonizes an area for the first time is termed as **Pioneer community** and such plants as **Pioneers** or **Primary colonizers**.

8.1 Types of Succession

The different types of succession are:

Primary and Secondary Succession-- If the succession starts from the primary substratum free of any living or organic matter (unoccupied habitat), it is termed as primary succession. It may occur in terrestrial or aquatic ecosystems and is slow in nature. Secondary succession, on the other hand starts from already build-up substratum. In such areas, plant community earlier occupying the area get altered due to disturbances like sudden changes in climate, fire, floods or some biotic interference. The succession starting from such a substratum is termed as secondary succession and it is comparatively rapid.

Autogenic and Allogenic Succession: During the process of succession, the mutual interactions among the living organisms of the community change the environment. These changes make the environment unfavourable for the existing community and thus cause its replacement. This type of succession where the community replacement occurs due to reasons created by community itself is known as Autogenic succession. If during the succession, the replacement of one community by the other may be caused by environmental factors and not by living organisms, then the succession is termed as Allogenic succession.

Autotrophic and Heterotrophic Succession: A succession in which green plants or the autotrophs dominate, so that there is a continuous energy flow during the whole process, is known as Autotrophic succession. In contrast, succession wherein heterotrophs such as bacteria, fungi, actinomycetes or even animals dominate and there is a continuous decline in the energy flow is known as Heterotrophic succession

Chapter 9: Regeneration methods and Silvicultural systems

9.1 Silvicultural systems

Silvicultural system is the process of tending, harvesting, and regenerating a forest. There are different types of silvicultural systems and a broad classification can be made based on the pattern of regeneration and how the tree canopy is removed. Generally forest managed using clear felling and shelter wood system tend to be even aged (only possess one or two canopy strata) and those managed using selection systems are un-even aged (have three or more canopy).

9.2 Natural forest management and regeneration

Natural forest management has been defined as a controlled and regulated harvesting, combined with silvicultural and protective measures, to sustain or increase the commercial value of future stands, all relaying on natural regeneration of native species.

9.2.1 Sustainable forest management

According to the United Nations Environmental Program (UNEP), sustainable development “meets the needs of the present generation without compromising the ability of the future generations to meet their own needs. It implies the maintenance, rational use, and enhancement of the natural resource base that underpins ecological resilience and economic growth.

Sustainable forest management (SFM) Is management of natural forests in such away as to minimize the problem associate with timber extraction. It aims at maintain the productivity of the forest for timber and other human

needs through preservation of soil fertility and hydrological stability. And it also maintains level of biodiversity that occur naturally in the forest (Dawkins and Philip 1998).

9.2.2 Systems used in management of natural forests in tropics

9.2.2.1 Natural regeneration method

The success of management systems based on natural regeneration depends on the number of individuals of desirable species left after harvest.

Natural regeneration consists of seedlings (small plants of tree species originating from seed), vegetative resprouts (stems that have originated from a dead or cut tree stem or from roots), and saplings (young trees that have not attained a given dbh or height (Husch *et al.* 2003).

Natural regeneration from seed

When regeneration obtained from seed forms a crop, it is called a seedling crop it neither planted nor of coppice or root-sucker origin but originating in situ from natural regeneration. When this seedling cop grows in to a forest, it is called a high forest.

Natural regeneration from seed depends on: Seed production, seed dispersal, seed germination, seedling establishment.

Natural regeneration from vegetative part

When regeneration obtained by coppice forms a crop, it is called coppice crop and when it develops in to a forest, it is called coppice forest.

Natural regeneration by coppice can be obtained either by:

Seedling coppice- coppice shoots arising from the base of seedlings that have been cut or burnt back. This method of obtaining natural regeneration

is not making any progress so that they may produce vigorous shoots and soon develop in saplings.

Stool coppice- coppice arising from the stool or a living stump of tree is called stool coppice. In this method regeneration is obtained from the shoots arising from the adventitious buds of the stump of felled trees.

Vegetative reproduction can be obtained by any of the following method:

Coppice- vegetative reproduction in which the tree plants or the seedling of a species when cut near the ground level produce shoots.

Root sucker- a shoot rising from the root of a woody plant. vegetative reproduction in which a root of a plant is partially or wholly cut to produce a shoot called root sucker.

Cutting- vegetative propagation in which a portion of the stem branch or stem is placed in the soil or other medium, in order that it may develop in a plant.

Layering - inducing development of roots on branches while they are still attached to the trees is called layering

Chapter 10: Mensuration and stand measurement

10.1 Measuring individual trees

10.1.1 Age

For some conifers, age estimates can be obtained by counting the number of branch whorls, although this method is less accurate in older trees because it can be difficult to determine where branches have been abscised. In some broadleaved trees and tree ferns it is possible to estimate ages by counting the number of leaf scars on the terminal shoot, although again this method is only useful with younger trees and branches.

Age estimates are generally obtained by counting the number of annual rings in a stem cross-section. Total tree age is obtained by counting rings at ground level; if measurements are made higher up the stem, then the number of years that the tree takes to grow to this height should be added to the total (Avery and Burkhart, 2003).

Dendrochronology: the study of tree rings

Dendrochronology means the measuring of time using trees - dendro = trees, and chronology = system of measuring time. Dendrochronology was recognized as an important source of information on age and climate as early as the 1700s in Europe and in the early 1800s in the United States.

10.1.2 Stem diameter

The two most commonly used instruments for measuring tree stem diameters are calipers and diameter tapes. *Calipers* are usually used when the trees are less than 60 cm dbh; although larger calipers are available, they can be difficult or unwieldy to use in the field. Calipers are usually constructed out of metal, wood, or plastic, and enable the diameter to be read directly off a scale when the arms of the caliper are placed around the tree stem. The caliper arms should be pressed firmly against the tree stem with the main beam of the caliper placed perpendicular to the axis of the

tree stem, and the arms parallel and perpendicular to the beam (Husch *et al.* 2003).

10.1.3 Height

Total tree height can be defined as the distance along the axis of the tree stem from ground level to the top of the canopy. Other terms commonly used by foresters include *bole height*, which refers to the distance between ground level and the first crown-forming branch, and *crown length*, which is the distance on the axis of the tree stem between the first crown-forming branch and the top of the canopy.

The heights of relatively short trees can be readily measured by using a graduated pole. Height measurements of tall trees are generally made by means of *hypsometers*, which use trigonometric relations to estimate height. Bole height and crown length can be measured, as well as total tree height, by measuring the heights of the appropriate locations on the tree stem. Commonly used types of hypsometer include the Abney level and the Suunto clinometers

10.2. Characterizing stand structure

A forest stand may be defined as a group of trees that occupy a given area, which share some characteristics such as species composition, size, or age. *Stand structure* refers to the distribution of species or tree sizes within the stand. Canopy characteristics and leaf area can also be considered as structural variables.

10.2.1 Age and size structure

Stands are commonly differentiated into those that are *even-aged*, where all trees are of approximately the same age, and those that are *uneven-aged*, where trees display a variety of different ages. In even-aged stands, the age of the stand is usually determined as the mean age of those trees that dominate the canopy (i.e. the largest individuals), and sampling may be restricted to these. Age distributions are typically illustrated by plotting a

frequency distribution or histogram of the number of trees within each age class.

The diameter (dbh) of a stand can be expressed a mean of the diameters of the trees present. Often, basal area is calculated to provide a measure of stand density and to provide a basis for calculating stand volume. Basal area can be calculated from measurements of stem diameter by using the following equation (assuming that trees are circular in cross-sectional area):

$$g = \frac{\pi r^2}{4}$$

Where g is cross-sectional area of the tree and d is the diameter of the cross-section.

10.2.2 Height and vertical structure

The vertical structure of a forest stand refers to its structural complexity, which is influenced by the presence of different plant life forms (such as vines and epiphytes), the arrangement of leaves on branches, and the amount and distribution of leaves, branches, and twigs, at different heights (Brokaw and Lent 1999). Vertical structure has a major influence on the provision of habitat for wildlife. Foresters traditionally classify the crown position of trees according to the following simple scheme (Oliver and Larson 1996):

- *Dominant*, where tree crowns extend above the general canopy level and are

Not physically restricted from above

- *Co-dominant*, where crowns from the general level of a forest canopy and are

Somewhat crowded by other adjacent trees

- *intermediate*, where trees are shorter, but their crowns extend into the general canopy that is primarily composed of the crowns of dominant and co-dominant trees
- *suppressed (overtopped)*, where crowns lie entirely below the general level of the canopy and are physically restricted from above.

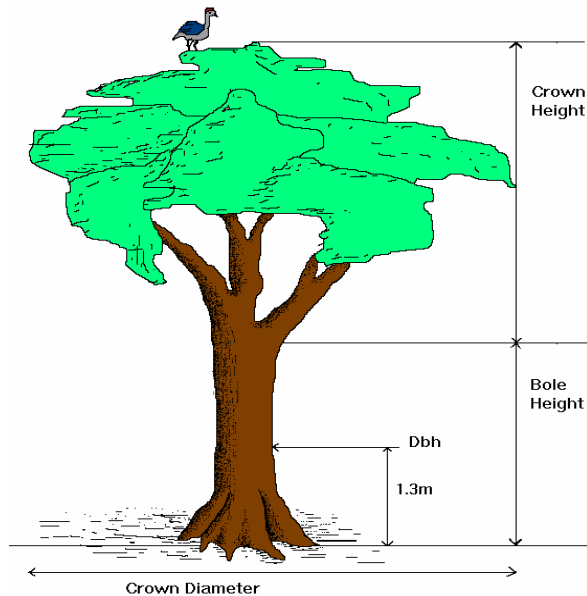


Fig.

10.3 Stand volume

Measurement of the volume of wood produced by a forest stand is of fundamental importance to forestry, and consequently foresters have developed a variety of methods for estimating it. Particular efforts have been directed towards developing functions for stem volume and taper that allow estimates to be made from relatively simple measurements.

The main method used to measure tree stem volume is the *sectional method*, which involves measuring the stem in relatively short sections, determining the volume, and each then summing these values to produce an estimate of total volume. The volume of a stem section is determined by measuring its length, and the stem diameter at the lower end of the section

(‘large end diameter’), the upper end (‘small end diameter’) and/or at the midpoint of the section.

10.4 Stand density

Stand density refers to the number of trees within a given area. This can be most simply obtained by counting the number of trees present within a stand and measuring its area, then dividing the former by the latter. However, basal area and the extent of crown cover can also be used as measures of stand density. Stand density is of great importance to forest management, primarily because of its importance in determining the volume of timber likely to be obtained from a particular stand. Consequently foresters have developed a range of metrics for describing it, including various measures of relative spacing, stand density indices, crown competition factors, and stocking diagrams. Details are provided by forest mensuration textbooks such as Avery and Burkhart (2003) and Husch *et al.* (2003).

Chapter 11: The basics of Forest and woodland inventory

11.1 Forest inventory

Forest inventory is an accounting of trees and their related characteristics of interest over a well-defined land area.

Forest inventory refers to the process of collecting information about the extent and condition of forest resources within a specified area. Traditionally, forest inventories were primarily carried out to determine the quantity of available timber, but increasingly the scope of such inventories has been expanded to include ecological variables such as measures of the quality of habitat provided for different species. A forest inventory may

therefore be carried out to obtain a range of different information. For estimating potential timber supplies, the key variable to estimate is timber volume, which requires forest area to be measured together with a sample of some or all of the trees in the area. Other information relevant to the development of forest management plans includes descriptions of forest ownership, access and transport infrastructure, topography, hydrology, and soils.

Unlike human or animal populations, trees are sessile organisms and there is no immigration or emigration to consider. However, tree populations vary widely in their species composition, age, size, site requirements, potential value, longevity and growth - all factors that may influence the design of a forest inventory.

11.2 Types of Inventory

National Forest Authority (NFA) carries out various types of inventories aimed at inventories addressing management needs at specific levels/needs. Broadly the following types of inventories are currently being carried out.

- Exploratory Inventory (EI)- is normally undertaken when a reserve is first being brought under management or when management is being reintroduced after a lapse of many years. The intention is to have an idea of possible annual allowable cut, the felling series and information on the major commercial species in the reserve.
- Integrated Stock Survey and Mapping Inventory (ISSMI)- is an inventory done to guide

silvicultural decisions and forest management and control at compartment level.

- Yield Monitoring and Growth Modeling. (Permanent Sample Plots-PSPs)- *Permanent Sample Plots in Natural Forests* Estimates of allowable cut and sustainable yield, and assessment of forest response to different diameter limits, felling cycles, and silvicultural treatments depends critically on growth, mortality and recruitment rates

- Management Plantation Inventory-

- Biodiversity Inventory-designed specifically to provide data necessary for assessing the

biological value of the country's principal forests, as a basis for Nature Reserve site selection

- Biomass Survey- the National Biomass Study of NFA adopted a two-stage sampling technique

in the assessment of the biomass resource.

Mapping stage- Remotely sensed data from SPOT satellite imageries are used to map the location and distribution of LUC and eventually the quantification of areas of each LUC. Geographical Information System (GIS) is intensively used in the mapping process. The following are the steps applied:

- Land use cover stratification
- Preliminary interpretation of satellite imageries
- Ground truthing and
- Final Delineation

b) Biomass Inventory- It involves the measurement of tree parameters for the determination of single tree weights and aggregation of standing stock

of biomass per unit area. The purpose is to finally quantify the total standing stock of biomass.

11.3 Purpose of Forest Inventory

The prevailing reason for conducting a forest inventory is to make informed decisions about forest management. The primary need has been the quantification of volumetric product yield and structural composition of the forest. The volume of the timber resource is typically categorized by species, product and size. In addition, quantities like the number of trees and basal area per unit area are often desired. While collection of data on other components of the ecosystem is increasing, the timber resource still remains the main focus for most forest inventories.

Both spatial and temporal scales are normally addressed in the planning of an inventory. The most obvious dichotomy is in time: a forest inventory may be initiated for an assessment of current conditions (growing stock), or it may be repeated at future periods in time, yielding estimates of change in volume or basal area and possibly other components of growth, mortality and removals (due to harvest).

There are numerous reasons or objectives for conducting a forest inventory; the most common of these include:

Silvicultural prescriptions: Inventories conducted in connection with stand examinations that focus specifically on making stand-level decisions over a short planning horizon of say 10 years with specific regard to the prescription of silvicultural treatments such as thinnings or regeneration harvests.

Regeneration surveys: Assessing the adequacy of regeneration stocking following a regeneration treatment. Such efforts may be repeated to estimate survival rates.

Harvest or operational inventory: Often required to more precisely estimate volume and value of

an area prior to a commercial harvest. Postharvest inventories assess damage on residual trees and assess whether the amounts of remaining material conform to local laws and to the overall management plan.

Appraisal surveys: Surveys conducted for the valuation of land and timber to be purchased, sold or exchanged.

Strategic inventories: Large-scale inventories for forest-level strategic planning such as determining allowable harvest rates or optimal harvest scheduling plans.

Regional and national surveys: Often mandated by law in the case of countrywide surveys, these inventories are commonly used for making high level policy decisions and broad-scale resource monitoring. Surveys of this scale may also be augmented with other localized data to provide specific information, such as identifying a site for a new mill.

The design of the inventory or forest survey (sometimes referred to as a cruise or enumeration) will vary according to the specific information needs. For example, ecologists may be interested in variables such as the structure and composition of the stand, the extent and pattern of natural regeneration, and those variables that describe the quality of the forest as habitat for wildlife, such as the amount of deadwood.

Most inventories are implemented at the scale at which forest management decisions are typically taken, the *forest management unit* (FMU) or stand level. Regardless of which scale the inventory is designed to address, and which variables are selected for measurement, an appropriate sampling design needs to be implemented, and a choice must be made regarding which type of sampling unit to use. The methods described here are those

used for field survey; typically these will be supported by use of aerial photographs or other remote sensing data

11.3.1 Choosing a sampling design

It is rarely possible to measure all of the trees in a particular forest. Therefore, a *sample* must be taken from the complete *population* of all sample units. The most important basic principle is to ensure that the sample is representative. Otherwise, the information obtained will be biased in some way, and the inferences drawn from the data are likely to be invalid. The first step is to divide the forest area to be surveyed into sampling units, for example by dividing it into grid squares or forest stands or patches. The next step is to decide which sample units to include in the survey, according to an appropriate design. Four basic sampling designs are used in forest surveys: *simple random*, *stratified random*, *systematic sampling* and *cluster sampling*.

11.3.2 Choosing sampling intensity

How many samples should be taken? Enough to obtain the level of precision required. It is therefore important to specify an acceptable level of precision before the survey is initiated.

11.3.3 Locating sampling units

Sample location can be determined by using a hand compass to identify direction and by pacing to estimate distance. It is helpful to calibrate the length of your stride over different terrain, by measuring the number of paces required to cover a set distance marked out with a measuring tape or marker poles.

The development of satellite navigation systems has proved to be of enormous value to forest surveys (Kleinn 2003), enabling sampling locations to be located and relocated relatively easily. GPS receivers can now be obtained relatively cheaply, and are reasonably user friendly. Although models made by different manufacturers vary in the details of their

operation, typically they can be used to determine a location, to navigate from one location to another, and to store both individual locations and tracks. GPS is particularly useful where available maps are of poor quality, or where there are few features that can be identified from a map. As different models vary in their accuracy, the type of GPS unit used in collecting a set of information should be reported (Johnston 1998). One of the main problems with use of GPS in forest survey is that it can sometimes be difficult to obtain an accurate location fix from underneath a forest canopy, which can prevent communication between the GPS unit and the satellites. To solve this problem, it may be necessary to locate the nearest canopy gap in order to obtain a measurement. The second main problem is the degree of accuracy obtained with a typical hand-held GPS unit, which is typically 5–10 m at best (Longley *et al.* 2005), especially under forest canopies.

11.3.4 Sampling approaches

There are two main types of sampling unit that might be selected. The commonest approach is to use a *fixed area* method, which involves establishment of a field plot that may be square, rectangular, or circular in shape. Alternatively, a *distance based* sampling approach might be adopted, where the area sampled varies but the number of individuals sampled is fixed.

Reference

- Adrian C. Newton.2007. Forest ecology and conservation. Techniques in Ecology and Conservation Series, Oxford University press, Newyork.
- Avery, T. E. and Burkhart, H. E. 2002. Forest measurements, 5th edition. McGraw-Hill, NY.
- Begon, M., Harper,J.L. and Townsend,C.R. 1996. Ecology: Individuals, populations and Communities. 3rd end. Black well Scientific, Oxford.
- Begon, M., Harper,J.L. and Townsend,C.R. 1996. Ecology: Individuals, populations and Communities (3rd ed.). Black well Scientific, Oxford.
- Bettinger, P. and Wing, M.G. 2004. Geographic Information Systems: Applications in Forestry and Natural Resource Management. McGraw-Hill
- Bettininger, P., Boston, K., Siry, J.P. and Grebner, D.L. 2009. Forest management and planning. Elsevier Inc.
- Brokaw, N. V. L. and Lent, R. A. 1999. Vertical structure. In Maintaining biodiversity in forest ecosystems, ed. M. L. Hunter, pp. 373-399. Cambridge University Press, Cambridge.
- Burley, J, Evans, J. and Youngquist J.A. 2004. Encyclopedia of Forest Sciences. Elsevier Ltd.
- Chapman, J.L. and Reiss, M.J. 1999. Ecology - Principles and Applications. Cambridge University Press, Cambridge, England. Pp. 330.
- Cotgreave, P. and Forseth, I. 2002. Introductory Ecology. Blackwell Publishing, England. Pp. 288.

- Cunningham, W.P. and Cunningham, M.A. 2002. Principles of Environmental Science. Tata McGraw-Hill Publishing Co., New Delhi, India. Pp. 418.
- Davis, L.S., and Johnson, K.N. 1987. Forest Management (3rd ed.). McGraw-Hill Evans, & Younquist, 2004
- Etherington, J.R. 1975. Environment and Plant Ecology. Wiley Eastern limited, New Delhi.
- Forbes, R.D. and Meyer, A.B. 2001. Forestry Handbook : Section 1- 4. Greenwood publishers
- Hamito, D. 2001. Research Methods in Forestry: Principles and Practices with Particular Reference to Ethiopia.
- Higman, S., Mayers, J., Bass, S., Judd, N. and Nussbaum, R. 2005. The Sustainable Forestry Handbook (2nd ed.). Earthscan
- Hill, M.O. 1973. Diversity and its evenness, a unifying notation and its consequences. Ecology 54: 427-432.
- Husch, B., Beers, T. W., and Kershaw, J. A. 2003. Forest mensuration. Wiley, New York. Oliver, C. D. and Larson, B. C. (1996). Forest stand dynamics. Wiley, New York.
- Johnston, C. A. 1998. Geographic information systems in ecology. Blackwell Science, Oxford
- Kangas, A. and Maltamo, M. 2006. Forest Inventory: Methodology and Applications. Springer. The Netherlands
- Kent, M. & P. Coker .1992. Vegetation description and analysis: a practical approach. John Wiley and Sons, U.S.A.

Kimmins, J. P. 1997. Forest Ecology: A foundation for sustainable management. Prentice hall international, 596pp.

Kimmins, J. P. 1997. Forest ecology. A foundation for sustainable management. (2nd ed.).

Kleinn, C. 2003. New technologies and methodologies for national forest inventories.

Kohl, M., Magnussen, S.S. and Marchetti, M. 2006. Sampling Methods, Remote sensing and GIS Multirecourse Forest Inventory, Springer-Verlag, Berlin Larestein University of Professional Edition, Deventer, The Netherlands.

Longley, P. A., Goodchild, M. F., Maguire, D. J., and Rhind, D. W. 2005. Geographical information systems and science, 2nd edition. Wiley, New York.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical Ecology, A Primer on Methods and computing. John Wiley and Sons, New York, 337 p.

Perry, D. A.1994. Forest Ecosystems. The Johns Hopkins University press, USA. Prentice Hall, Englewood Cliffs, NJ.

Shiver, B.D. 1996. Sampling Techniques for Forest Resource Inventory. John Wiley and Sons Inc.

Spurr, S. H. & Barnes, B. V. 1980. Forest Ecology. John Willey and Sons Inc. Newyork. Unasyuva, 53, 10-15.