PREFACE

In the curricular structure introduced by this University for students of Post- Graduate Degree programme, the opportunity to pursue Post-Graduate Degree course in any Subject introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation. I am happy to note that university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade 'A'.

Keeping this in view, study materials of the Post-Graduate Degree level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Cooperation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing and devising of a proper lay-out of the materials. Practically speaking, their role amounts to an involvement in 'invisible teaching'. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials, the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that they may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great deal of these efforts is still experimental—in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

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Post Gaduate Degree Programme
Choice Based Credit System (CBCS)
Subject: P.G. Environmental Science (PGES)
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Course Code: PGES-CC-103

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PGES-CC-103
(New Syllabus)

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Unit 1 □ Life Processes and Characteristics

Structure

1.1 Objectives

- To learn about different theories on origin of life.
- To know the mechanism of evolution
- To perceive the conceptual framework of Gaia hypothesis

1.2 Introduction

The diversity of life on Earth today is the result of evolution. Life began on Earth at least 3.5 to 4 billion years ago, and it has been evolving ever since. Origin of life means the appearance of simplest primordial life from non- living matter. Evolution of life means the gradual formation of complex organisms from simpler ones. At first, all living things on Earth were simple, single-celled organisms. Much later, the first multicellular organisms evolved, and after that, Earth's biodiversity greatly increased through the process evolution. Evolution is a change in the characteristics of living things over time. Evolution occurs by natural selection and genetic drift. Characteristics of organisms are passed from one generation to the next through their genes. The environment of Earth has also evolved. Earth has cooled, the temperature has stabilized, and the composition of the atmosphere has completely changed. Under the current paradigm, the two parallel evolutions, life and its environment, affect each other, but not in any coordinated way. Life consumes resources and discharges waste products; these processes alter the environment. As the environment changes, it presents new challenges to life. Earth is a self-regulating complex system involving the biosphere, the atmosphere, the hydrosphere and the pedosphere, tightly coupled as an evolving system. In this chapter we will discuss about different theories related to origin of life followed by process of evolution and natural selection. Then concept of Gaia hypothesis will introduce about interplay of life and environment and self-sustainability.

1.3 Origin of Life

The origin of life means the emergence of heritable and evolvable self-reproduction. "Origin of Life" is a very complex subject, and oftentimes controversial. Two opposing scientific theories that existed on this complex subject for a long time were the socalled intelligent design and creationism. The big bang theory of the origin of the Universe gave new ideas about the topic of biological evolution. It has been hypothesized that complex life-forms on Earth, including humans, arose over a period of time from simple bacteria like tiny cells by a process of self-organization akin to the evolution of the Universe by self-organization of simple material structures (i.e., fundamental particles produced by the big bang) toward more and more complex structures. There are several theories about the origin of life.

It is a very difficult task to find the theory involves behind the origin of life.

Some important theories have been discussed here:

1.3.1 Special creation:

Life formation on the earth may have been taken place due to supernatural or divine forces. There are different kinds of accreditations by different religions.

HINDU CONCEPT: The whole world, plants, oceans, rivers, humans, animals are created by Lord Brahma.

CHRISTIAN & ISLAM CONCEPT: God created the universe, human beings, plants, oceans and rivers in six days. All the plants and animals were created at once. All the living organisms were created in the same form as they exist today.

The theory of special creation also suggests that Diversity of life form will not change in future. This theory of origin of life has no scientific explanations.

1.3.2 Extra-terrestrial origin:

This theory is given by Richer in 1865 and also known as cosmozoic theory. Panspermia means "seeds everywhere". This hypothesis states that the "seeds" of life exist all over the

Universe and can be propagated through space from one location to another. Some believe that life on Earth may have originated through these "seeds" i.e., Life formation did not take place on earth. It took place somewhere else in the space or on any other planet and carried to the earth. Mechanisms for panspermia include the deflection of interstellar dust by solar radiation pressure and extremophile microorganisms traveling through space within an asteroid, meteorite or comet.

For example, rocks regularly get blasted off Mars by cosmic impacts, and a number of Martian meteorites have been found on earth that it is controversially stated that microbes brought over here, potentially making us all Martians originally. It is also suggested that life might have carried from comets.

Three popular variations of the panspermia hypothesis are:

Litho panspermia (interstellar panspermia) - impact-expelled rocks from a planet's surface serve as transfer vehicles for spreading biological material from one solar system to another.

Ballistic panspermia (interplanetary panspermia) - impact-expelled rocks from a planet's surface serve as transfer vehicles for spreading biological material from one planet to another within the same solar system.

Directed Panspermia - the intentional spreading of the seeds of life to other planets by an advanced extra-terrestrial civilization, or the intentional spreading of the seeds of life from Earth to other planets by humans.

Panspermia does not provide an explanation for evolution or attempt pinpoint the origin of life in the Universe. The panspermia hypothesis gives no explanation for how life that arrived on Earth came to be. Even if we are able to show that life on Earth was a result of panspermia, the question of where and how life originated will be a lot harder to answer.

1.3.3 Spontaneous origin:

Life may have evolved from non-living matter as association with prebiotic molecules under primitive earth conditions, became more and more complex. This theory suggests that life could come from non-living things, decaying, and rotting matter like straw, mud, etc. Several experiments have been conducted to disprove spontaneous generation.

In 1668, Francesco Redi a scientific experiment to test the spontaneous creation of maggots by placing fresh meat in three different jars. He found the maggots in open jar and on the exterior surface of the cloth that covered the jar. No maggots were found in the sealed jar. Redi successfully demonstrated that the maggots came from fly eggs and thereby helped to disprove spontaneous generation.

Louis Pasteur rejected the theory of spontaneous generation and demonstrated that life came from pre-existing life. In his experiment, he kept killed yeast cells in pre-sterilised flask and another flask open into air. The life did not evolved in the former but new living thing evolved in the later flask. Several other experiments like Needham's experiment, Spallanzani's Experiment etc. have been performed which disprove the theory of spontaneous origin. Spontaneous generation is the incorrect hypothesis that non-living things are capable of producing life.

1.3.4 Theory of Biochemical Evolution:

Several models for the origin of life have been suggested. The first 'modern' model for the origin of life was presented in the 1923 independently by the Russian biochemist A. I. Oparin and later supported by the British evolutionary biologist J. B. S. Haldane in 1928. The Oparin and Haldane theory is known as biochemical theory for the origin of life. According to the Oparin-Haldane model, life could have arisen through a series of organic chemical reactions that produced ever more complex biochemical structures. They proposed that common gases in the early Earth atmosphere combined to form simple organic chemicals, and that these in turn combined to form more complex molecules. Then, the complex molecules became separated from the surrounding medium, and acquired some of the characters of living organisms. They became able to absorb nutrients, to grow, to divide (reproduce), and so on.

The biochemical origin of life can be studied in three categories:

1.3.4.1 Chemical Evolution of life:

1. **Formation of Simple inorganic compounds:** The atmosphere of primitive earth had various elements like hydrogen, oxygen, carbon, sulphur, phosphorous, nitrogen etc. These free atoms combine to form molecules and simple inorganic compounds like ammonia, water vapour, HCN etc.
2. **Formation of simple organic molecules:** The simple inorganic compounds formed in atmosphere interacted and combined to produce simple compounds such as simple sugars, purines, pyrimidines, amino acids, etc. The source of energy for chemical reaction might be solar radiations such as UV rays, lightening, radiations from radioactive rocks and heat of earth. The simple organic compounds forms reached the ocean with rainwater.
3. **Formation of complex organic molecules:** The simple organic molecules have undergone polymerization to form complex organic molecules like proteins, nucleic acids, amino acids etc in oceanic water. Formation of these molecules plays a key role in the chemical evolution of life. The oceanic water rich in mixture of organic compounds.

1.3.4.2 Biological evolution of life:

Formation of life initiated from the ocean containing organic compounds.

1. **Formation of Coacervate:** The complex organic molecules of primordial soup in ocean aggregated together through the colloidal system and bounded by water layer were called coacervates. They can grow by absorbing nutrients. They have the power of self-growing and dividing by budding like bacteria. They are intermediate between molecule and organism. Some of the proteins within coacervates acted as enzymes and began metabolic activities.
2. **Formation of primary living organism:** The coacervates presumably obtained energy by fermentation from the oceanic soup. They were anaerobes. They depended on the existing organic molecules for their nutrition.
3. **Origin of Autotrophs:** When supply of existing organic compounds was exhausted, some of the heterotrophs might have evolved into autotrophs. These organisms were capable of synthesizing their own organic compounds by chemosynthesis. They were therefore chemoautotrophs. They develop the chlorophyll through which the autotrophs can prepare the food. Oxygen evolved during the photosynthesis and started to accumulate in atmosphere.

1.3.4.3 Cognogeny:

With gradual increase in the number of heterotrophs as they consumed nutrients of the ocean, there became a declination in organic nutrients. So they began to search other alternatives for obtaining food. During photosynthesis, solar energy was trapped by light trapping pigment called chlorophyll. In this way several other organisms evolved (prokaryotic, anaerobic etc.). With the increase meant in number of photoautotrophs O_2 released in great extent in ocean and came into atmosphere. Now an oxidising type atmosphere has been formed. Then prokaryotes gradually modified to be adapted to the aerobic mode of respiration. Gradually many types of algae, fungi, protozoa and other organic living organisms developed.

1.3.4.4 Simple Beginnings:

Instead of originating from complex molecules like RNA, DNA, life might have begun with small and simple molecules interacting with each other in cycles of reactions. These reactions might have been change a simple capsule to cell membranes and over time more complex molecules or cells. This is the most simple of the standing theories, and is difficult to dismiss.

1.3.4.5 RNA world:

In the formation of life DNA, RNA and proteins play important role. DNA can store genetic information and proteins can catalyze the reactions. But RNA can do both the jobs. RNA has the self-replicating properties. The RNA world theory suggests that life on Earth began with simple RNA molecule that could copy itself without help from any other molecule. The compelling feature of RNA World is that a primordial molecule provided both catalytic power and the ability to propagate its chemical identity over generations. Pieces of RNA have been made that can copy RNA strands longer than themselves, supporting the idea that the first life was based on self-replicating RNA, not DNA.

1.3.4.6 Chilly start:

Ice might have covered the oceans 3 billion years ago, as the sun was three times less luminous than it now. This layer of ice, possibly hundreds of feet thick, might have protected fragile, organic compounds in the water below from ultraviolet light and destruction from cosmic impacts. The cold might have also helped these molecules to survive longer, allowing reactions to happen. The enzyme does not yet copy itself. The main barrier seems to be the folded structure that allows it to copy other RNA. The RNA enzyme's effectiveness at cold temperatures suggests ice was crucial to the first life. When a mix of RNA and metal ions freezes, growing ice crystals suck up the water, leaving tiny pockets of RNA. At cold temperatures, RNA strands often stick together, making it tricky to separate them after the RNA has been copied. Ice freezes and melts all the time, so you can easily see how an RNA replicator could be enclosed, released and allowed to spread.

1.3.4.7 Deep-Sea Vents:

This theory suggests that life arose deep in the ocean within warm, rocky structures called hydrothermal vents. This theory suggests that life may have begun at submarine hydrothermal vents and ejecting hydrogen rich molecules. Their rocky nooks could then have concentrated these molecules together and provided mineral catalysts for critical reactions. These vents are rich in chemical and thermal energy. Deep-sea hydrothermal vents are porous geological structures produced by chemical reactions between solid rock and water. Alkaline fluids from the Earth's crust flow up the vent towards the more acidic ocean water, creating natural proton concentration differences remarkably similar to those powering all living cells.

1.3.4.8 Community Clay:

The first molecule of life, hydrocarbon, might have met on the clay. These surfaces might not only have concentrated these organic compounds together but also helped organize them into patterns much like our genes. Mineral crystals in clay could have arranged organic molecules into organized patterns. Clay minerals played a key role in chemical evolution and the origins of life because of their ability to take up, protect (from UV radiations), concentrate, and catalyse the polymerization of organic molecules. Clay minerals can also store and replicate structural defects and ionic substitutions and act as 'genetic candidates'. So the minerals and organic molecules

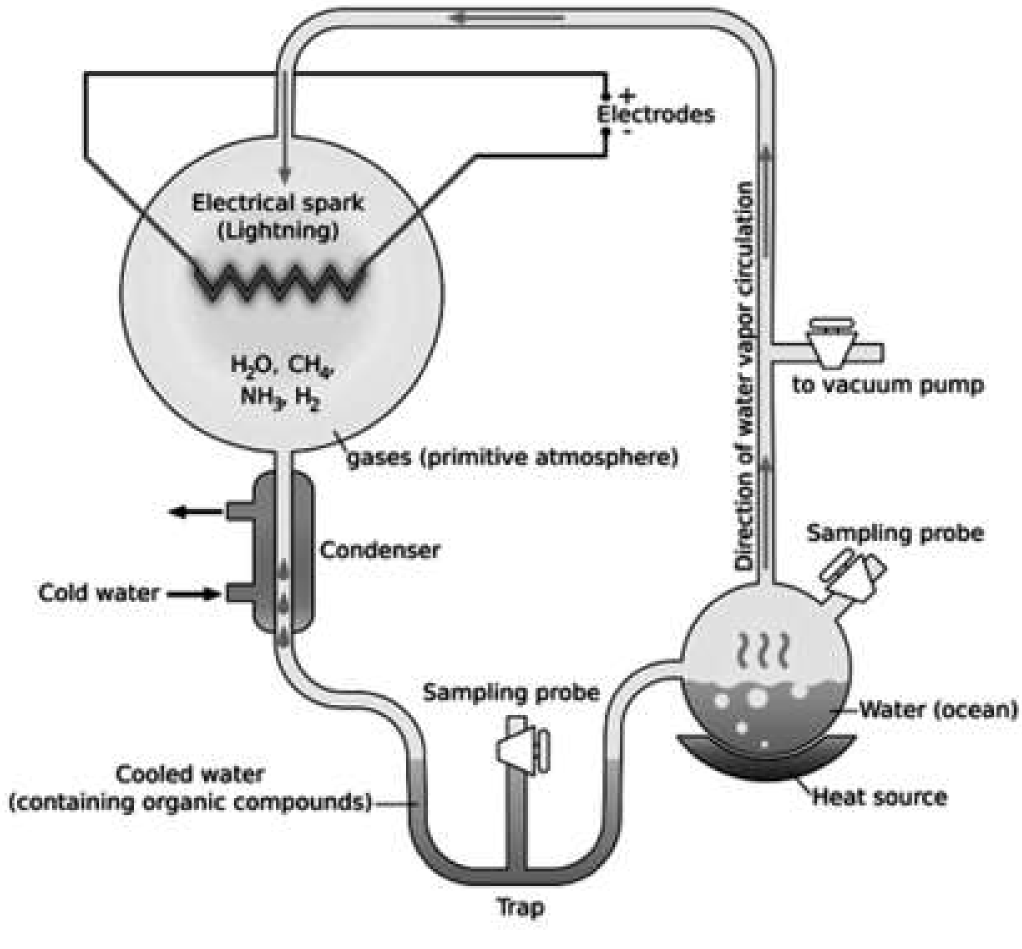


Figure 1.1: Miller Urey experiment

in the layers of clay would favour the formation and replication of biological molecules (e.g. enzymes, polynucleotides) and favour the possibility of origin of life through this theory.

1.3.4.9 Electric Spark:

Lightning may have provided the spark needed for life to begin. There are two distinct versions of the spark of life theory. The first of these versions holds that the first form of life came into existence following "one spark" or on one particular "spark day." The other version argues that life came into existence, or rather emerged, following prolonged sparking rather one specific spark. Electric sparks can generate amino acids and sugars from an atmosphere loaded with water, methane, ammonia and hydrogen, as described in Miller Urey experiment. This suggests that lightning might have helped create the key building blocks of life on Earth in its early days. Over time larger molecules could form as a result of this.

Further reading:

1. The Origins of Life: From the Birth of Life to the Origin of Language By John Maynard Smith, Eörs Szathmáry , 2000

2. Information Theory, Evolution, and the Origin of Life By Hubert P. Yockey

1.4 Evolution of Life Through Ages

The history of life on Earth is an epic tale that unfolds across immense stretches of time, shaped by countless forces, both subtle and cataclysmic. The evolutionary journey, spanning billions of years, has transformed simple, microscopic life forms into the astonishingly diverse and complex array of species that populate our planet today. The story of this transformation is a testament to the relentless force of change, adaptation, and survival. Earth's history is a timeline that stretches over 4.5 billion years, characterized by distinct geological eons, eras, and periods, each marked by unique climatic, geophysical, and biological phenomena. At the dawn of our planet's existence, Earth was a harsh and volatile environment, with its early inhabitants being microbial life forms adapted to extreme conditions. This topic embarks on a journey through this vast expanse of time to unravel the intricate web of life's development, from its humble beginnings to the emergence of modern, complex organisms.

In the sections that follow, we will delve into the milestones of life's evolution, encompassing the Hadean and Archean Eons, where life emerged in the form of simple prokaryotic cells, to the Proterozoic Eon, where the stage was set for the emergence of more complex, eukaryotic organisms. We will then navigate through the Paleozoic, Mesozoic, and Cenozoic Eras, each marked by unique biotic radiations, extinction events, and ecological transitions.

This exploration is framed by the concept of deep time, a concept that allows us to appreciate the vastness of geological and biological timescales. It will reveal that life's evolution is not a linear progression but a complex, branching tree, with countless species appearing, adapting, and often disappearing over millions of years. From the first multicellular organisms to the evolution of terrestrial life, the conquest of the land, and the rise of mammals and, ultimately, humans, the evolutionary history of life is an intricate tapestry of adaptation and survival.

Moreover, the fossil record, comparative genomics, and the understanding of Earth's ever-changing climate and environments will serve as guiding lights in this journey, shedding light on the emergence of key evolutionary innovations and the forces that have driven the transformation of life. This exploration will not only shed light on the origins of the species we share our world with but also deepen our understanding of the profound interconnectedness of all life on Earth. It is a story that challenges us to reflect on our place in this grand narrative, the responsibilities that come with our unique position as stewards of the planet, and the imperative to protect and preserve the precious tapestry of life that has evolved through the ages. This scientific journey invites us to contemplate the origins and interconnectedness of all species on Earth and to appreciate the magnificent tapestry of life woven through the ages.

The evolution of life through the ages is a fascinating journey that spans billions of years. Life on Earth has evolved from simple, single-celled organisms to the complex and diverse array of species we see today. The brief details provided below are an overview of the major events and transitions in the history of life on Earth, from the formation of our planet to the present day. The time laps have been scaled up with Era, Eon, Period, and epoch, which are as follows:

Table 1: Lifeform through geological time Scale

Eon	Era	Period	Epoch	MYA		Life Forms	North American Events
Phanerozoic	Cenozoic (CZ)	Quaternary (Q)	Holocene (H)	0.01	Age of Mammals	Extinction of large mammals and birds	
			Pleistocene (PE)	2.6		Modern humans	Ice age glaciations; glacial outburst floods
		Tertiary (T) Neogene (N)	Pliocene (PL)	5.3			Cascade volcanoes (W) Linking of North and South America (Isthmus of Panama)
			Miocene (MI)	23.0		Spread of grassy ecosystems	Columbia River Basalt eruptions (NW) Basin and Range extension (W)
		Tertiary (T) Paleogene (PG)	Oligocene (OL)	33.9			
			Eocene (E)	56.0			Laramide Orogeny ends (W)
			Paleocene (EP)	66.0		Early primates	
						Mass extinction	
	Mesozoic (MZ)	Cretaceous (K)		145.0	Age of Reptiles	Placental mammals Early flowering plants	Laramide Orogeny (W) Western Interior Seaway (W) Sevier Orogeny (W)
		Jurassic (J)		201.3		Dinosaurs diverse and abundant	Nevadan Orogeny (W) Elko Orogeny (W)
		Triassic (TR)		251.9		Mass extinction First dinosaurs; first mammals Flying reptiles	Breakup of Pangaea begins Sonoma Orogeny (W)
						Mass extinction	
	Paleozoic (PZ)	Permian (P)		298.9	Age of Amphibians		Supercontinent Pangaea intact
		Carboniferous	Pennsylvanian (PN)	323.2		Coal-forming swamps Sharks abundant First reptiles	Ouachita Orogeny (S) Alleghany (Appalachian) Orogeny (E)
			Mississippian (M)	358.9			Ancestral Rocky Mountains (W)
		Devonian (D)		419.2	Fishes	Mass extinction First amphibians First forests (evergreens)	Antler Orogeny (W) Acadian Orogeny (E-NE)
		Silurian (S)		443.8		First land plants Mass extinction	
		Ordovician (O)		485.4	Marine Invertebrates	Primitive fish Trilobite maximum	Taconic Orogeny (E-NE)
		Cambrian (C)		541.0		Rise of corals Early shelled organisms	Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic		Precambrian (PC, W, X, Y, Z)		2500		Complex multicelled organisms Simple multicelled organisms	Supercontinent rifted apart Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean				4000		Early bacteria and algae (stromatolites)	Oldest known Earth rocks
Hadean				4600		Origin of life Formation of the Earth	Formation of Earth's crust

A. Precambrian Era

i. Hadean Eon

The Hadean Eon, which began around 4.6 billion years ago, was a period of extreme heat and geological turmoil. It is believed that the first oceans formed during this time, and the first signs of life may have emerged in the form of simple, single-celled organisms.

ii. Archean Eon

The Archean Eon, spanning from about 4.0 to 2.5 billion years ago, saw the development of more complex single-celled life forms, including cyanobacteria, which are responsible for some of the oldest known fossils. These early organisms began to produce oxygen through photosynthesis, fundamentally altering Earth's atmosphere.

Notable Species: Cyanobacteria, the earliest photosynthetic organisms

iii. Proterozoic Eon

The Proterozoic Eon, lasting from approximately 2.5 billion to 541 million years ago, witnessed the emergence of eukaryotic cells, which are the building blocks of multicellular life. Towards the end of this Eon, complex multicellular organisms began to appear, setting the stage for the explosion of life in the following eras.

Notable Species:

- Ediacara biota, some of the earliest known multicellular organisms.
- Stromatolites are complex layered structures created by microbial communities.

B. Paleozoic Era

i. Cambrian Period

The Cambrian Period, about 541 to 485 million years ago, is often referred to as the "Cambrian Explosion." During this time, a remarkable rapid diversification of life occurred, with the appearance of many major animal groups, including arthropods, molluscs, and chordates.

Notable Species:

- Trilobites, early arthropods.
- Anomalocaris, a top predator of the Cambrian seas.

ii. Ordovician Period

The Ordovician Period, spanning from 485 to 443 million years ago, saw the evolution of early vertebrates, as well as the proliferation of marine life, including diverse coral reefs.

Notable Species:

- Orthoceras, extinct marine cephalopods.
- Agnatha, the first jawless fish.

iii. Silurian Period

The Silurian Period, approximately 443 to 419 million years ago, witnessed the colonization of land by early plants and arthropods, marking a significant transition in Earth's ecosystems.

Notable Species:

- Cooksonia, an early land plant.
- Eurypterus, a large marine arthropod.

iv. Devonian Period

The Devonian Period, from 419 to 359 million years ago, is often called the "Age of Fishes" due to the diversification of fish species. Additionally, the first tetrapod (four-limbed vertebrates) evolved during this time.

Notable Species:

- Dunkleosteus, a giant armored fish.
- Ichthyostega, one of the earliest known tetrapods.

v. Carboniferous Period

The Carboniferous Period, about 359 to 299 million years ago, is known for the lush forests that eventually became the coal deposits we use today. Amphibians were the dominant land vertebrates during this era.

Notable Species:

- Meganeura, a giant dragonfly.
- Dimetrodon, a sail-backed reptile.

a. Mississippian period

The Mississippian (also known as Lower Carboniferous or Early Carboniferous) is a subperiod in the geologic timescale or a subsystem of the geologic record. It is the earlier of two subperiods of the Carboniferous period lasting from roughly 358.9 to 323.2 million years ago.

b. Pennsylvanian period

The Pennsylvanian (also known as Upper Carboniferous or Late Carboniferous) is, in the ICS geologic timescale, the younger of two subperiods (or upper of two subsystems) of the Carboniferous Period. It lasted from roughly 323.2 million years ago to 298.9 million years ago.

vi. Permian Period

The Permian Period, spanning from 299 to 252 million years ago, saw the rise of reptiles as the dominant land vertebrates. It ended with the largest mass extinction in Earth's history, known as the Permian-Triassic extinction event.

Notable Species:

- Cotylorhynchus, a herbivorous reptile.
- Gorgonopsids, a group of mammal-like reptiles.

C. Mesozoic Era

i. Triassic Period

The Triassic Period, from 252 to 201 million years ago, saw the emergence of dinosaurs and the first mammals. It marked the recovery of life after the Permian-Triassic extinction.

Notable Species:

- Plateosaurus, a primitive dinosaur.
- Morganucodon, one of the earliest known mammals.

ii. Jurassic Period

The Jurassic Period, approximately 201 to 145 million years ago, is known for the dominance of dinosaurs, including iconic species like Brachiosaurus and Tyrannosaurus rex. The evolution of primate birds occurs in this period.

Notable Species:

- Brachiosaurus, a massive herbivorous dinosaur.
- Archaeopteryx, an early bird-like dinosaur.

iii. Cretaceous Period

The Cretaceous Period, from 145 to 66 million years ago, witnessed the diversification of flowering plants and the eventual extinction of non-avian dinosaurs, possibly due to a catastrophic asteroid impact.

Notable Species:

- Tyrannosaurus rex, a well-known carnivorous dinosaur.
- Angiosperms, the first flowering plants.

D. Cenozoic Era

i. Paleogene Period

The Paleogene Period, about 66 to 23 million years ago, saw the emergence of modern mammals and the evolution of primates, including the earliest ancestors of humans. This period is also subdivided into three epochs namely, Paleocene (66 to 56 MYA), Eocene (56 to 33.9 MYA) and Oligocene (33.9 to 23 MYA).

Notable Species:

- Ambulocetus, a semi-aquatic early whale.
- Proconsul, a primitive ape.

ii. Neogene Period

The Neogene Period, spanning from 23 million years ago to 2.58 million years ago, is marked by the continued evolution of mammals, including the appearance of hominins, the group of species that includes humans. This period is also divided into Miocene (23 to 5.3 MYA) and

Pliocene (5.3 to 2.6 MYA).

Notable Species:

- Smilodon, a sabertooth cat.
- Australopithecus afarensis, a hominin species.

iii. Quaternary Period

The Quaternary Period, from 2.58 million years ago to the present day, includes the most recent ice ages and the emergence and spread of Homo sapiens, or modern humans. Pleistocene epoch (2.6 to 0.01 MYA) and Holocene epoch (0.01 to present day) are the subdivisions of the quaternary period.

Notable Species: Homo sapiens, modern humans.

The evolution of life through the ages is a complex and dynamic process that has shaped the Earth's biodiversity over billions of years. From the emergence of simple single-celled organisms to the rise and fall of ancient civilizations, the history of life on Earth is a testament to the adaptability and resilience of living organisms. Understanding this history provides valuable insights into the origins of the species that inhabit our planet today.

1.5 Role of natural selection

1.5.1 Natural Selection

The final force of evolution is natural selection. This is the evolutionary process that Charles Darwin first brought to light, and it is what the general public typically evokes when considering the process of evolution. Natural selection occurs when certain phenotypes confer an advantage or disadvantage in survival and/or reproductive success. The alleles associated with those phenotypes will change in frequency over time due to this selective pressure. It's also important to note that the advantageous allele may change over time (with environmental changes) and that an allele that had previously been benign may become advantageous or detrimental. Of course, dominant, recessive, and codominant traits will be selected upon a bit differently from one another. Because natural selection acts upon phenotypes rather than the alleles themselves, deleterious (disadvantageous) recessive alleles can be retained by heterozygotes without any negative effects. In the case of our primordial ocean cells, up until now, the texture of their cell membranes has been benign. The frequencies of smooth to ruffled alleles, and smooth to ruffled phenotypes, has changed over time, due to genetic drift and gene flow. Let's now imagine that the Earth's climate has cooled to a point that the waters frequently become too cold for survival of the tiny bacteria that are the dietary staples of our smooth and ruffled cell populations. The way amoeba-like cells "eat" is to stretch out the cell membrane, almost like an arm, to encapsulate, then ingest, the tiny bacteria. When the temperatures plummet, the tiny bacteria populations plummet with them. Larger bacteria, however, are better able to withstand the temperature change. The smooth cells were well-adapted to ingesting tiny bacteria but poorly suited to encapsulating the larger bacteria. The cells with the ruffled membranes, however, are easily able to extend their ruffles to encapsulate the larger bacteria. They also find themselves able to stretch their entire membrane to a much larger size than their smooth-surfaced neighbors, allowing them to ingest more bacteria at a given time and to go for longer periods between feedings. The smooth and ruffled traits, which had previously offered no advantage or disadvantage while food was plentiful, now are subject to natural selection. During the cold snaps, at least, the ruffled cells have a definite advantage. We can imagine that the western population that has mostly ruffled alleles will continue to do well, while the eastern population, which has a much smaller proportion of ruffled alleles, will gradually shift toward a higher frequency of ruffled alleles in future generations.

A classic example of natural selection involves the study of an insect called the peppered moth *(Biston betularia)* in England during the Industrial Revolution in the 1800s. Prior to the Industrial Revolution, the peppered moth population was predominantly light in color, with dark (pepper-like) speckles on the wings. The "peppered" coloration was very similar to the appearance of the bark and lichens that grew on the local trees. This helped to camouflage the moths as they rested on a tree, making it harder for moth-eating birds to find and snack on them. There was another phenotype that popped up occasionally in the population. These individuals were heterozygotes that carried an overactive, dominant pigment allele, producing a solid black coloration. As you can imagine, the black moths were much easier for birds to spot, making this phenotype a real disadvantage. The situation changed, however, as the Industrial Revolution took off. Large factories began spewing vast amounts of coal smoke into the air, blanketing the countryside, including the lichens and trees, in black soot. Suddenly, it was the light-colored moths that were easy for birds to spot and the black moths that held the advantage. The frequency of the dark pigment allele rose dramatically. By 1895, the black moth phenotype accounted for 98% of observed moths (Grant 1999). Thanks to new environmental regulations in the 1960s, the air pollution in England began to taper off. As the soot levels decreased, returning the trees to their former, lighter color, this provided the perfect opportunity to study how the peppered moth population would respond. Repeated follow-up studies documented the gradual rise in the frequency of the lighter-colored phenotype. By 2003, the maximum frequency of the dark phenotype was 50% and in most parts of England had decreased to less than 10% (Cook 2003).

Directional, Balancing/Stabilizing, and Disruptive/Diversifying Selection

Natural selection can be classified as directional, balancing/stabilizing, or disruptive/ diversifying, depending on how the pressure is applied to the population.

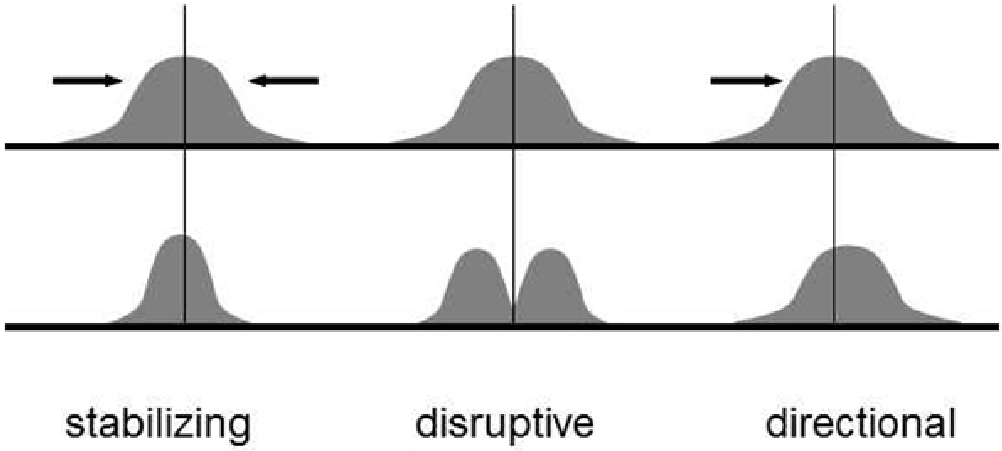


Fig. 1.2. Schematic visualization of different types of natural selection

Both of the above examples of natural selection involve directional selection: the environmental pressures are favouring one phenotype over the other and causing the frequencies of the associated advantageous alleles (ruffled membranes, dark pigment) to gradually increase. In the case of the peppered moths, the direction shifted three times: first, it was selecting for lighter pigment; then, with the increase in pollution, the pressure switched to selection for darker pigment; finally, with reduction of the pollution, the selection pressure shifted back again to favoring light-colored moths.

Balancing selection (a.k.a., stabilizing selection) occurs when selection works against the extremes of a trait and favors the intermediate phenotype. For example, humans maintain an average birth weight that balances the need for babies to be small enough not to cause complications during pregnancy and childbirth but big enough to maintain a safe body temperature after they are born. Another example of balancing selection is found in the genetic disorder called sickle cell anemia.

Disruptive selection (a.k.a., diversifying selection), the opposite of balancing selection, occurs when both extremes of a trait are advantageous. Since individuals with traits in the mid-range are selected against, disruptive selection can eventually lead to the population evolving into two separate species. Darwin believed that the many species of finches (small birds) found in the remote Galapagos Islands provided a clear example of disruptive selection leading to speciation. He observed that seed eating finches either had large beaks, capable of eating very large seeds, or small beaks, capable of retrieving tiny seeds. The islands did not have many plants that produced medium-size seeds. Thus, birds with medium-size beaks would have trouble eating the very large seeds and would also have been inefficient at picking up the tiny seeds. Over time, Darwin surmised, this pressure against mid-size beaks may have led the population to divide into two separate species.

1.6 Genetic Drift

The second force of evolution is commonly known as genetic drift. This is an unfortunate misnomer, as this force actually involves the drifting of alleles, not genes. Genetic drift refers to random changes ("drift") in allele frequencies from one generation to the next. The genes are remaining constant within the population; it is only the alleles of the genes are changing in frequency. The random nature of genetic drift is a crucial point to understand: it specifically occurs when none of the variant alleles confer an advantage. Let's imagine far back in time, again, to that first population of living cells, subsisting and occasionally dividing, in the primordial sea. Many generations have passed, and mutations have created distinct chromosomes. The cells are now amoeba-like, larger than many of their tiny bacterial neighbors, who have long since become their favorite source of nutrients. A mutation occurs in one of the cells that changes the texture of the cell membrane from a relatively smooth surface to a highly ruffled one. This has absolutely no effect on the cell's quality of life or ability to reproduce. In fact, eyes haven't evolved yet, so no one in the world at the time would even notice the difference. The cells in the population continue to divide, and the offspring of the ruffled cell inherit the ruffled membrane. The frequency (%) of the ruffled allele in the population, from one generation to the next, will depend entirely on how many offspring that first ruffled cell ends up having, and the random events that might make the ruffled alleles more common or more rare (such as population bottlenecks and founder effects, discussed below).

1.6.1 Sexual Reproduction and Random Inheritance

Tracking alleles gets a bit more complicated in our primordial cells when, after a number of generations, a series of mutations have created populations that reproduce sexually. These cells go through an extra round of cell-division (meiosis) to create haploid gametes. The combination of two gametes, each containing half a set of homologous chromosomes, is required to produce each new diploid offspring. In the earlier population, which reproduced via asexual reproduction, a cell either carried the smooth allele or the ruffled allele. With sexual reproduction, a cell inherits one allele from each parent, so there are homozygous cells that contain two smooth alleles, homozygous cells that contain two ruffled alleles, and heterozygous cells that contain one of each allele. If the new, ruffled allele happens to be dominant (and we'll imagine that it is), the heterozygotes will have ruffled cell phenotypes, but will have a 50:50 chance of passing on a smooth allele to each offspring. In sexually reproducing populations (including humans and many other animals and plants in the world today), that 50:50 chance of inheriting one or the other allele from each parent plays a major role in the random nature of genetic drift.

1.6.2 Population Bottlenecks

A population bottleneck occurs when the number of individuals in a population drops dramatically due to some random event. The most obvious, familiar examples are natural disasters. Tsunamis and hurricanes devastating island and coastal populations and forest fires and river floods wiping out populations in other areas are all too familiar. When a large portion of a population is randomly wiped out, the allele frequencies (i.e., the percentages of each allele) in the small population of survivors are often much different from the frequencies in the pre-disaster, or "parent," population. If such an event happened to our primordial ocean cell population-perhaps a volcanic fissure erupted in the ocean floor and only the cells that happened to be farthest from the spewing lava and boiling water survived-we might end up, by random chance, with a surviving population that had mostly ruffled alleles, in contrast to the parent population, which had only a small percentage of ruffles. One of the most famous examples of a population bottleneck is the prehistoric disaster that led to the extinction of dinosaurs, the Cretaceous-Paleogene extinction event (often abbreviated K-Pg; previously K-T). This occurred approximately 66 million years ago. Dinosaurs and all their neighbors were going about their ordinary routines when a massive asteroid zoomed in from space and crashed into what is now the Gulf of Mexico, creating an impact so enormous that populations within hundreds of miles of the crash site were likely immediately wiped out. The skies filled with dust and debris, causing temperatures to plummet worldwide. It's estimated that 75% of the world's species went extinct as a result of the impact and the deep freeze that followed (Jablonski and Chaloner 1994). The populations that emerged from the K-Pg extinction were markedly different from their pre-disaster communities. Surviving mammal populations expanded and diversified, and other new creatures appeared. The ecosystems of Earth filled with new organisms and have never been the same.

Much more recently in geological time, during the colonial period, many human populations experienced bottlenecks as a result of the fact that imperial powers were inclined to slaughter communities who were reluctant to give up their lands and resources. This effect was especially profound in the Americas, where indigenous populations faced the compounded effects of brutal warfare, exposure to new bacteria and viruses (against which they had no immunity), and ultimately segregation on resource-starved reservations. The populations in Europe, Asia, and Africa had experienced regular gene flow during the 10,000-year period in which most kinds of livestock were being domesticated, giving them many generations of experience building up immunity against zoonotic diseases (those that can pass from animals to humans). In contrast, the residents of the Americas had been almost completely isolated during those millennia, so all these diseases swept through the Americas in rapid succession, creating a major loss of genetic diversity in the indigenous American population. It is estimated that between 50% and 95% of the indigenous American populations died during the first decades after European contact, around 500 years ago (Livi-Bacci 2006). An urgent health challenge facing humans today involves human-induced population bottlenecks that produce antibiotic-resistant bacteria. Antibiotics are medicines prescribed to treat bacterial infections. The typical prescription includes enough medicine for ten days. People often feel better after less than ten days and sometimes decide to quit taking the medicine ahead of schedule. This is often a big mistake. The antibiotics have quickly killed off a large percentage of the bacteria-enough to reduce the symptoms and make you feel much better. However, this has created a bacterial population bottleneck. There are usually a small number of bacteria that survive those early days. If you take the medicine as prescribed for the full ten days, it's quite likely that there will be no bacterial survivors. If you quit early, though, the survivors-who were the members of the original population who were most resistant to the antibiotic-will begin to reproduce again. Soon the infection will be back, possibly worse than before, and now all of the bacteria are resistant to the antibiotic that you had been prescribed. Other activities that have contributed to the rise of antibiotic-resistant bacteria include the use of antibacterial cleaning products and the inappropriate use of antibiotics as a preventative measure in livestock or to treat infections that are viral instead of bacterial (viruses do not respond to antibiotics). In 2017, the World Health Organization published a list of twelve antibiotic-resistant pathogens that are considered top priority targets for the development of new antibiotics (World Health Organization 2017).

1.6.3 Founder Effects

Founder effects occur when members of a population leave the main or "parent" group and form a new population that no longer interbreeds with the other members of the original group. Similar to survivors of a population bottleneck, the newly founded population often has allele frequencies that are different from the original group. Alleles that may have been relatively rare in the parent population can end up being very common due to founder effect. Likewise, recessive traits that were seldom seen in the parent population may be seen frequently in the descendants of the offshoot population. One striking example of founder effect was first noted in the Dominican Republic in the 1970s. During a several-year period, eighteen children who had been born with female genitalia and raised as girls suddenly grew penises at puberty. This culture tended to value sons over daughters, so these transitions were generally celebrated. They labeled the condition guevedoces, which translates to "penis at twelve," due to the average age at which this occurred. Scientists were fascinated by the phenomenon.

Genetic and hormonal studies revealed that the condition, scientifically termed 5-alpha reductase deficiency, is an autosomal recessive syndrome that manifests when a child having both X and Y sex chromosomes inherits two non-functional (mutated) copies of the SRD5A2 gene (Imperato-McGinley and Zhu 2002). These children develop testes internally, but the 5-alpha reductase 2 steroid, which is necessary for development of male genitals in babies, is not produced. In absence of this male hormone, the baby develops female-looking genitalia (in humans, "female" is the default infant body form, if the full set of the necessary male hormones are not produced). At puberty, however, a different set of male hormones are produced by other fully functional genes. These hormones complete the male genital development that did not happen in infancy. This condition became quite common in the Dominican Republic during the 1970s due to founder effect-that is, the mutated SRD5A2 gene happened to be much more common among the Dominican Republic's founding population than in the parent populations [the Dominican population derives from a mixture of indigenous Native American (Taino) peoples, West Africans, and Western Europeans]. Five-alpha reductase syndrome has since been observed in other small, isolated populations around the world.

Founder effect is closely linked to the concept of inbreeding, which in population genetics does not necessarily mean breeding with immediate family relatives. Instead, inbreeding refers to the selection of mates exclusively from within a small, closed population-that is, from a group with limited allelic variability. This can be observed in small, physically isolated populations but also can happen when cultural practices limit mates to a small group. As with founder effect, inbreeding increases the risk of inheriting two copies of any non functional (mutant) alleles.

1.7 Gaia Hypothesis

The Gaia Theory claims that the Earth is a self-regulating system, maintaining the conditions that support life. Its author, James Lovelock, has proposed since the late 1960s that the explanation of phenomena such as the long-standing constancy of the proportion of oxygen in the atmosphere and of the salinity of the oceans is that the complex system of life on our planet ensures its own continuation, or, latterly, that this is brought about by planetary life together with its environment of atmosphere, rocks and oceans. He does not officially claim that this system, which he calls 'Gaia', acts knowingly or purposively, but he does regard it as a super-organism with wide-ranging capacities for self-repair. The name 'Gaia' is borrowed from that of the ancient Greek goddess of the Earth, the consort of Uranus (Heaven), and the mother of seas, mountains and living creatures. This name was originally suggested to Lovelock by the novelist, William Golding.

1.7.1 Lovelock's developing stance

While researching (with NASA) whether either Mars or Venus could sustain life, Lovelock devised the test of whether their climates reflected the equilibrium that could be predicted to arise from physical forces alone, or deviations from such an equilibrium, which might be generated by the presence of life. He concluded that whereas these other planets displayed just such an equilibrium, our own planet, by contrast, deviates therefrom and maintains an unexpected constancy or homeostasis of the proportions of gases in the atmosphere and salts in the oceans, ascribable to nothing but life itself. These conclusions led him to propound the Gaia Hypothesis that life on Earth keeps these proportions constant and thus hospitable for whatever is the contemporary ensemble of organisms. Later this hypothesis was refined as the Gaia Theory, which represents not just life on Earth but life in conjunction with surface rocks, the ocean and the atmosphere as a self-regulating system, with a goal - 'the regulation of surface conditions so as always to be as favourable as possible for contemporary life' (Lovelock, 2006, 208). Early objections, such as that the oxygen generated by plants and algae is disadvantageous to anaerobic life, and thus that not all life can be included in the Gaian system, were countered by including anaerobic life, together with the conditions that support it, as key regulators in the planetary system of Gaia.

1.7.2 Predecessors

Lovelock was not the first to present the Earth as a super-organism. As Lovelock acknowledges (Lovelock, 1990), James Hutton hit on this intuition in 1788, holding that the Earth could only be studied properly by planetary physiology; this has led Lovelock to propose the study of Gaia as 'geophysiology'.

Much earlier, Plato's Timaeus (fourth century BCE) represented the world as a living organism, albeit one produced by a divine Artificer, and subsequently the Stoics, from Chrysippus (third century BCE) onwards, treated the active substance of the universe as a world-soul or as reason, imposing form on passive matter. These speculative systems, unlike Lovelock's work as a scientist, were much more extensive in scope than Lovelock's theory, and depended neither on empirical evidence nor on thought-experiments. Yet they may have predisposed those familiar with these traditions to the cogency of scientific theories of the Earth such as those of Hutton and of Lovelock, who was himself not slow to gain mileage for his theory by referencing Gaia, the Earth Mother of the ancient Greeks (Lovelock, 2006).

1.7.3 Implications for ecological priorities

Lovelock has long suggested that the current general concern of environmentalists about pollution and the side-effects of technology is exaggerated, partly because of the resilience of Gaia and its ability to withstand such challenges. In particular, he used to doubt whether chlorofluorocarbons were a major problem (diverging here from the international concern which led to the crucial Montreal Protocol of 1987), and he continues to be an advocate of nuclear energy. But he is concerned about human interference with two kinds of global region, continental shelves, whose biota play key roles such as regulating and limiting the sulphur of the oceans, and the tropics, where the burning of grasslands emits 'a huge burden of aerosol particles', together with the bulk of the chlorine now in the atmosphere in the form of methyl chloride. Thus it is not advanced technology that, in his view, causes ecological harm but traditional husbandry and the associated traditional technology. One form of high technology that he favours is the emission of sulphate aerosols into the stratosphere, to reduce incoming solar energy and thus protect Gaia by averting global warming (Lovelock, 2006); yet such 'Solar Radiation Management' could risk the acidification of the atmosphere and thus of rainfall, and could be regarded as an aberration from rather than an implication of Gaia Theory. And while accepting that the planet could support a larger human population, he (perhaps wisely) endorses the view that the optimum number of people is not as large as the maximum that Earth can support (Lovelock, 1979), and that population increase may need to be halted at not far above 10 billion people, or at a still lower level.

1.7.3.1 Key concepts

- James Lovelock hypothesises that the planetary physical and biological system is a self-regulating super-organism.
- There were precedents before Lovelock for ascribing life either to the planet or to the universe.
- James W. Kirchner presents Gaia hypotheses as either unoriginal or untestable.
- Lovelock demonstrates that Gaia theory is both original and testable, albeit indirectly.
- Lovelock's theory can readily escape the charge of circularity.
- Predictions of Gaia theory include the existence of biologically generated mechanisms of planetary regulation.

- Lovelock's discovery of dimethyl sulphide discloses such a mechanism for the regulation of oceanic sulphur.
- Both atmospheric oxygen and atmospheric nitrogen turn out to be biologically generated and maintained.
- Philosophers such as Stephen Clark and Mary Midgley have made Gaia a symbol for the planetary thinking currently needed.
- The Amsterdam Declaration of planetary scientists (2001) accepted aspects of Gaia theory, without explicitly accepting the theory's planetary goal.

1.8 Summary

- Theories on biochemical origin of life is most accepted scientific concepts in origin of life.
- Darwin stated the theory of evolution by natural selection, presenting a great deal of evidence to support his theory.
- Evolution is a change in the characteristics of living things over time. Natural selection helps in adaptive evolution.
- The Gaia hypothesis, proposes that all organisms and their inorganic surroundings on Earth are closely integrated to form a single and self-regulating complex system maintaining the conditions for life on the planet.

1.9 Self-Assessment questions

MCQ questions

1. Miller in his experiment, synthesized simple amino- acid from ______
   a) Methane, ammonia, oxygen, nitrogen
   b) Hydrogen, methane, ammonia, water
   c) Ammonia, methane, carbon dioxide, oxygen
   d) Hydrogen, water, oxygen, helium
2. According to spontaneous generation, life originated _____
   a) From microorganisms
   b) From similar organisms

c) From air

d) Only spontaneously

3. In the natural selection, the production of variations is due to

a) Mutations

b) Meiosis

c) Random mate selection

d) All of them

4. Where selective pressure favors an extreme variation of a trait.

a) Directional selection

b) Stabilizing selection

c) Disruptive selection

d) Sexual selection

5. Gaia hypothesis states, biosphere is capable of keeping the planet healthy by controlling:

a) Physical and Chemical environment

b) Biological environment

c) Marine environment

d) Pedosphere

Short answer type questions

1. Define natural selection with suitable example.
2. What is Panspermia hypothesis?
3. What is founder effect? Give an example.
4. What is Balancing selection? Tall neck of Giraffe is an example of which selection?
5. How community clay promotes origin of life in Earth?

Long answer type questions

1. Describe different types of selection with suitable example.
2. What is Urey-Miller experiment? Write short notes on different theories on biochemical origin of life.
3. Elucidate the role of genetic drift and natural selection on biological evolution.
4. Briefly describe identical charatristico of poleozic era.

1.10 Suggested Readings

Dawkins, Richard (1982) The Extended Phenotype, Oxford and San Francisco: W H Freeman & Co.

Lovelock JE (1979) Gaia: A new look at life on Earth, Oxford and New York: Oxford University Press.

Lovelock JE (1990) Hands Up for the Gaia hypothesis. Nature 344: 100-102.

Lovelock, JE (2006) The Revenge of Gaia: Why the Earth is Fighting Back - and How We Can Still Save Humanity, London and New York: Penguin.

Evolution by Douglas J. Futuyma

Evolution by Monroe Strickberger

Unit 2 □ Ecosystem Structure and Function

Structure

2.1 Objective

- To learn about structure and function of different tropic level.
- To perceive basic concept of productivity, food web and food chain.
- To know about different types of ecological succession.
- Remarks on species diversity and idea about niche, habitat, ecotone, edge effect.
- Elucidating basic idea on ecosystem services.

2.2 Introduction

The ecosystem is the structural and functional unit of ecology where the living organisms interact with each other and the surrounding environment. In other words, an ecosystem is a chain of interaction between organisms and their environment. The term "Ecosystem" was first coined by A.G.Tansley, an English botanist, in 1935. The structure of an ecosystem is characterised by the organisation of both biotic and abiotic components. This includes the distribution of energy in our environment. It also includes the climatic conditions prevailing in that particular environment. The sun is the ultimate source of energy on earth. During photosynthesis light energy is converted into chemical energy and is passed on through successive levels. The flow of energy from a producer, to a consumer and eventually, to an apex predator or a detritivore is called the food chain. All the food chains in a community are related together and known as the food web. But ecosystem is not a static entity, it changes over time. A series of changes over time to community structure that affect community dynamics and encourage the assemblage of plants and animals is known as ecological succession. The richness, or number, of species found in a community refers to species diversity. Every species have specific characteristics, such as availability of nutrients, temperature, terrain, sunlight and predators, which dictate how a species live, and how well, a species survives and reproduces; that boundary known as niche. Generally an area that acts as a boundary or a transition between two ecosystems also known as ecotone contains more species than both the adjacent ecosystem. Ultimately ecosystems provide many of the basic services that make life possible for people. The benefits that natural ecosystems generate for society and to raise awareness for biodiversity and ecosystem conservation is acknowledged as ecosystem services.

2.3 Tropic structure and function in ecosystem

Interaction of biotic and abiotic components result in a physical structure that is characteristic for each type of ecosystem. Identification and enumeration of plant and animal species of an ecosystem gives its species composition. Vertical distribution of different species occupying different levels is called stratification. For example, trees occupy top vertical strata or layer of a forest, shrubs the second and herbs and grasses occupy the bottom layers. The components of the ecosystem are seen to function as a unit when you consider the following aspects:

(i) Productivity
(ii) Decomposition
(iii) Energy flow and
(iv) Nutrient cycling

To understand the ethos of an aquatic ecosystem let us take a small pond as an example. This is fairly a self-sustainable unit and rather simple example that explain even the complex interactions that exist in an aquatic ecosystem. A pond is a shallow water body in which all the above mentioned four basic components of an ecosystem are well exhibited. The abiotic component is the water with all the dissolved inorganic and organic substances and the rich soil deposit at the bottom of the pond. The solar input, the cycle of temperature, day-length and other climatic conditions regulate the rate of function of the entire pond. The autotrophic components include the phytoplankton, some algae and the floating, submerged and marginal plants found at the edges. The consumers are represented by the zooplankton, the free swimming and bottom dwelling forms. The decomposers are the fungi, bacteria and flagellates especially abundant in the bottom of the pond. This system performs all the functions of any ecosystem and of the biosphere as a whole, i.e., conversion of inorganic into organic material with the help of the radiant energy of the sun by the autotrophs; consumption of the autotrophs by heterotrophs; decomposition and mineralisation of the dead matter to release them back for reuse by the autotrophs, these event are repeated over and over again. There is unidirectional movement of energy towards the higher trophic levels and its dissipation and loss as heat to the environment.

2.4 Productivity

Ecological productivity indicates the percentage of energy entering the ecosystem at a specific tropical level as biomass. That constant input of solar energy is the basic requirement for any ecosystem to function and sustain. In simple words, it is the rate of the formation of biomass in the ecosystem. A characteristic percentage of biomass is available at all trophic levels in the ecosystem. Many producers are present in the ecosystem to source energy. Productivity of the ecosystem refers to the rate of biomass production i.e., the amount of organic matter accumulated per unit area per unit time. Therefore, the productivity of ecosystem is being measured through 'Primary Productivity' and 'Secondary productivity'.

Primary Productivity

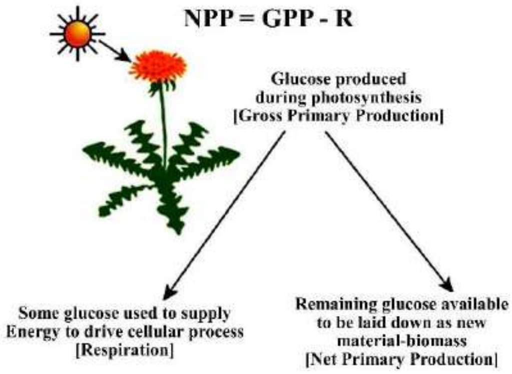
Primary production is defined as the amount of biomass or organic matter produced per unit area over a time period by plants during photosynthesis. It is expressed in terms of weight (g^2) or energy (kcal m^2). The rate of biomass production is called productivity. It is expressed in terms of g^2 yr^1 or (kcal m^2) yr^1 to compare the productivity of different ecosystems. It can be divided into gross primary productivity (GPP) and net primary productivity (NPP).

Gross primary production (GPP)

The total amount of organic matter produced by plants in any community through photosynthesis is referred to as gross primary production (GPP). It includes the whole anabolic synthesis (the process of building complex molecules from simpler ones). It is also referred to as total organic matter formation or even, total solar radiation capture.

Net primary production (NPP)

of an ecosystem is the rate of production of organic matter during photosynthesis. A considerable amount of GPP is utilised by plants in respiration. Gross primary productivity minus respiration losses (R), is the net primary productivity (NPP).



Net primary production accumulates over time as plant biomass, and it is the available biomass for consumption to heterotrophs (herbiviores and decomposers). The amount of accumulated organic matter found in an area at a given time is referred to as the standing crop biomass. Biomass is usually expressed as grams of organic matter per square metre (g/m^2) or as calories per square metre (cal/m^2). Remember that biomass is different from productivity. It is the amount of organic matter present at any given time. Productivity is the rate at which organic matter is created by photosynthesis.

A population ingests food material, which is called ingestion. A part of this food material is processed and used to make new cells or tissues in the body of the animal, and this part is called assimilation. What cannot be assimilated, for example, some parts of the plant stem, or roots exits the body, this is called excretion. Thus, we can calculate assimilation from the following equation:

Assimilation (A)=Ingestion (I) - Excretion (Ex)

Secondary productivity is defined as the rate of formation of new organic matter by consumers. Primary productivity depends on the plant species inhabiting a particular area. It also depends on a variety of environmental factors, availability of nutrients and the photosynthetic capacity of plants. Therefore, it varies in different types of ecosystems. The annual net primary productivity of the whole biosphere is approximately 170 billion tons (dry weight) of organic matter. Of this, despite occupying about 70 percent of the surface, the productivity of the oceans is only 55 billion tons. The rest, of course, is on land. In Table 2, the net primary production and biomass for a variety of terrestrial ecosystems is represented.

Table 2: Net Primary Production and plant biomass of world ecosystem

Ecosystems (In order of productivity)	Area (10^6 Km^2)	Mean net primary production per unit area (G/M^2/Yr)	World net primary production (109 Mtn/Yr)	Mean biomass per unit area (Kg/M^2)
Continental				
Tropical seasonal forest	7.5	1500.0	11.30	36.00
Temperate evergreen forest	5.0	1300.0	6.40	36.00
Temperate decidous forest	7.0	1200.0	8.40	30.00
Boreal forest	12.0	800.0	9.50	20.00
Savanna	15.0	700.0	10.40	4.00
Cultivated land	14.0	644.0	9.10	1.10
Woodland and shrubland	8.0	600.0	4.90	6.80
Temperate grassland	9.0	500.0	4.40	1.60
Tundra and alpine meadow	8.0	144.0	1.10	0.67
Desert shrub	18.0	71.0	1.30	0.67
Rock, ice, sand	24.0	3.3	0.09	0.02
Swamp and marsh	2.0	2500.0	4.90	15.00
Lake and stream	2.5	500.0	1.30	0.02
Total continental	132.0	10462.3	112.69	151.88
Marine				
Algal beds and reefs	0.6	2000.0	1.10	2.00
Estuaries	1.4	1800.0	2.40	1.00
Upwelling zones	0.4	500.0	0.22	0.02
Continental shelf	26.6	360.0	9.60	0.01
Open ocean	332.0	127.0	42.00	0.003
Total marine	361.0	153.0	55.32	0.01
World total	722.0	4940.0	110.64	3.033

Secondary Productivity

It refers to the biomass production rate by herbivores or consumers. Here, the organisms are not able to produce their own food and receive energy from primary productivity's biomass production. In the secondary productivity of an ecosystem, we see different trophic levels, including Herbivores, Carnivores and Omnivores

Here every trophic level uses biomass but dissipates up to just 10% of the biomass into the energy. Further, the remaining unassimilated biomass is released as fecal waste. Additionally, these remains are used by other decomposers or different trophic levels. The total metabolised energy or the energy of assimilation is used for production and maintenance (respiration). The production that occurs in animals over and above respiration is used for growth and reproduction. This growth and reproduction in animals at the secondary consumer level is termed as secondary production. Therefore, the secondary production is greatest when the birth rate of the population and the growth rate of the individuals in a population are at their highest.

The assimilated energy is very useful for or running numerous processes for growth, metabolism, and reproduction, etc. Basically, the secondary productivity of an ecosystem represents the entire energy flow system through various topics levels. It is the energy percentage that each trophic level's consumer tissues store within them.

Primary consumer

Terrestrial-Herbivores (key industry animal) of ecosystem, cow, grazing cattle, rabbit, they are also known as secondary producers as they synthesize complex materials in the cells, by the digestion of food which is obtained from the plant.

Aquatic- common mollusca, tadpole and mosquito, zooplankton

Secondary consumers or primary carnivores

Those animals which feed upon primary consumers and obtain food. Those carnivores which kill and eat the herbivores, are called predators.

Terrestrial- E.g., Dog, cat, snake.

Aquatic-Hydra,frog, whale, and some small fish are secondary consumers. It is an example of a filter because it feeds on plankton.

Top (tertiary) consumers

Those animals which kill other animals and eat them, but they are not killed & eaten by other animals in nature are called tertiary consumers.

Terrestrial- E.g., Lion, man, peacock; Aquatic- large fish

2.5 Decomposition

You may have heard of the earthworm being referred to as the farmer's 'friend'. This is so because they help in the breakdown of complex organic matter as well as in loosening of the soil. Similarly, decomposers break down complex organic matter into inorganic substances like carbon dioxide, water and nutrients and the process is called decomposition. Dead plant remains such as leaves, bark, flowers and dead remains of animals, including fecal matter, constitute detritus, which is the raw material for decomposition. The important steps in the process of decomposition are fragmentation, leaching, catabolism, humification and mineralisation.

Detritivores (e.g., earthworm) break down detritus into smaller particles. This process is called fragmentation. By the process of leaching, water soluble inorganic nutrients go down into the soil horizon and get precipitated as unavailable salts. Bacterial and fungal enzymes degrade detritus into simpler inorganic substances. This process is called as catabolism. It is important to note that all the above steps in decomposition operate simultaneously on the detritus. Humification and mineralisation occur during decomposition in the soil. Humification leads to accumulation of a dark coloured amorphous substance called humus that is highly resistant to microbial action and undergoes decomposition at an extremely slow rate. Being colloidal in nature it serves as a reservoir of nutrients. The humus is further degraded by some microbes and release of inorganic nutrients occur by the process known as mineralisation. Decomposition is largely an oxygen-requiring process. The rate of decomposition is controlled by chemical composition of detritus and climatic factors. In a particular climatic condition, decomposition rate is slower if detritus is rich in lignin and chitin, and quicker, if detritus is rich in nitrogen and water-soluble substances like sugars. Temperature and soil moisture are the most important climatic factors that regulate decomposition through their effects on the activities of soil microbes. Warm and moist environment favour decomposition whereas low temperature and anaerobiosis inhibit decomposition resulting in build-up of organic materials.

2.6 Food chain and Food webs, Energy flow models

2.6.1 Food Chain

A *food chain* is a linear sequence of organisms through which nutrients and energy pass as one organism eats another. Let's look at the parts of a typical food chain, starting from the bottom-the producers-and moving upward.

The flow of energy in one way process and the sequence in which the energy from the lower level of organisms to the higher level of the organisms are called as the food chain. The food chain is of three types -

Grazing food chain, Detritus food chain and Parasitic food chain

- At the base of the food chain lie the **primary producers**. The primary producers are autotrophs and are most often photosynthetic organisms such as plants, algae, or cyanobacteria.
- The organisms that eat the primary producers are called **primary consumers**. Primary consumers are usually herbivores, plant-eaters, though they may be algae eaters or bacteria eaters.
- The organisms that eat the primary consumers are called **secondary consumers**. Secondary consumers are generally meat-eaters-**carnivores**.
- The organisms that eat the secondary consumers are called **tertiary consumers**. These are carnivore-eating carnivores, like eagles or big fish.
- Some food chains have additional levels, such as **quaternary consumers**-carnivores that eat tertiary consumers. Organisms at the very top of a food chain are called **apex consumers.**

2.6.1.1 Types of Food Chain

i. **Grazing Food Chain:** A grazing food chain represents the flow of energy and nutrients through an ecosystem, starting with the primary producers (usually plants) that are consumed by herbivores (grazers). Herbivores are then consumed by carnivores (predators), and the energy transfer continues up the trophic levels. The energy in a grazing food chain flows from the plants to herbivores and then to carnivores. Examples include grass being eaten by a rabbit, which is then eaten by a fox.

ii. **Detritus Food Chain:** In a detritus food chain, the energy flow begins with dead organic matter and the decomposition of detritus (dead plant and animal material) by decomposers such as bacteria and fungi. Detritivores, such as scavengers and detrivorous insects, feed on the decaying organic matter. The energy is transferred from detritus to detritivores and then to organisms that feed on detritivores. This type of food chain is crucial for nutrient recycling in ecosystems, as decomposers break down complex organic matter into simpler forms that can be used by plants. An example is a dead tree being broken down by fungi and then consumed by insects, which are in turn eaten by birds. Detritus food chain is easy to understand prominently in Sundarban mangrove forest of India and Bangladesh. Leaf litters of mangrove vegetation enter the detritus food chain through meiofauna (minute invertebrates generally associated with the benthos, or bottom, of many streams and rivers) namely shrimps, nematodes, snails, bivalves, small crabs and fishes, mudskippers etc.

iii. Parasitic Food Chain: In a parasitic food chain, the energy flow involves a host and a parasite. Parasites are organisms that live on or inside a host organism, deriving nutrients at the host's expense. The energy transfer starts with the parasite feeding on the host's tissues or fluids. The host, in turn, may be part of another food chain (grazing or detritus), creating interconnected relationships in the ecosystem. Examples include ticks feeding on the blood of mammals, or tapeworms living in the digestive system of their host. It is also subdivided into Direct plant parasitic food chain, that's parasites derive nutrient from plants without killing them immediately; and Direct animal parasitic food chain, in which parasites derive nutrient from animal and later release them to the environment and contributes to other food chains.

These three types of food chains illustrate the diversity of ecological interactions within ecosystems. They highlight the pathways through which energy and nutrients move, influencing the structure and dynamics of ecological communities.

One other group of consumers deserves mention, although it does not always appear in drawings of food chains. This group consists of decomposers, organisms that break down dead organic material and wastes. Decomposers are sometimes considered their own trophic level. As a group, they eat dead matter and waste products that come from organisms at various other trophic levels; for instance, they would happily consume decaying plant matter, the body of a half-eaten squirrel, or the remains of a deceased eagle. In a sense, the decomposer level runs parallel to the standard hierarchy of primary, secondary, and tertiary consumers. Fungi and bacteria are the key decomposers in many ecosystems; they use the chemical energy in dead matter and wastes to fuel their metabolic processes. Other decomposers are detritivores-detritus eaters or debris eaters. These are usually multicellular animals such as earthworms, crabs, slugs, or vultures. They not only feed on dead organic matter but often fragment it as well, making it more available for bacterial or fungal decomposers. Decomposers as a group play a critical role in keeping ecosystems healthy. When they break down dead material and wastes, they release nutrients that can be recycled and used as building blocks by primary producers.

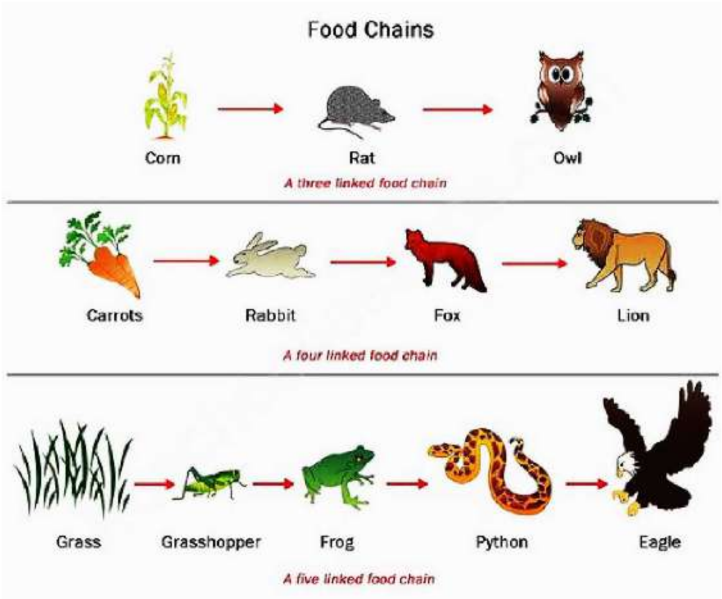


Figure 2.1: Grazing Food Chain

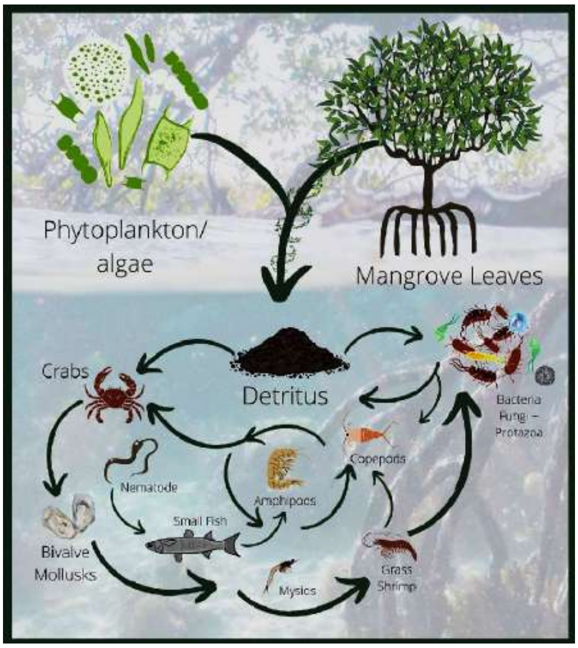


Figure 2.2: Detritus food chain of Mangrove Forest

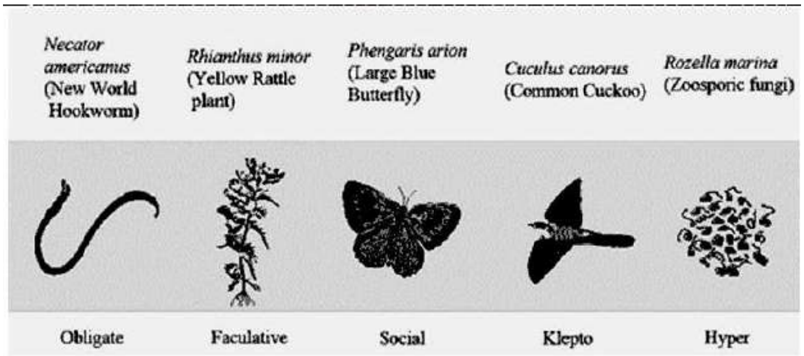


Figure 2.3: Parasitic Food Chain

The green algae are primary producers that get eaten by mollusks-the primary consumers. The mollusks then become lunch for the slimy small fish, a secondary consumer, which is itself eaten by a larger fish, the catfish-a tertiary consumer.

Each of the categories above is called a **trophic level**, and it reflects how many transfers of energy and nutrients-how many consumption steps-separate an organism from the food chain's original energy source, such as light. As we'll explore further below, assigning organisms to trophic levels isn't always clear-cut. For instance, humans are **omnivores** that can eat both plants and animals.

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2.6.2 Food webs

Food chains give us a clear-cut picture of who eats whom. However, some problems come up when we try and use them to describe whole ecological communities. For instance, an organism can sometimes eat multiple types of prey or be eaten by multiple predators, including ones at different trophic levels. This is what happens when you eat a hamburger patty! The cow is a primary consumer, and the lettuce leaf on the patty is a primary producer. To represent these relationships more accurately, we can use a food web, a graph that shows all the trophic-eating-related-interactions between various species in an ecosystem.

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

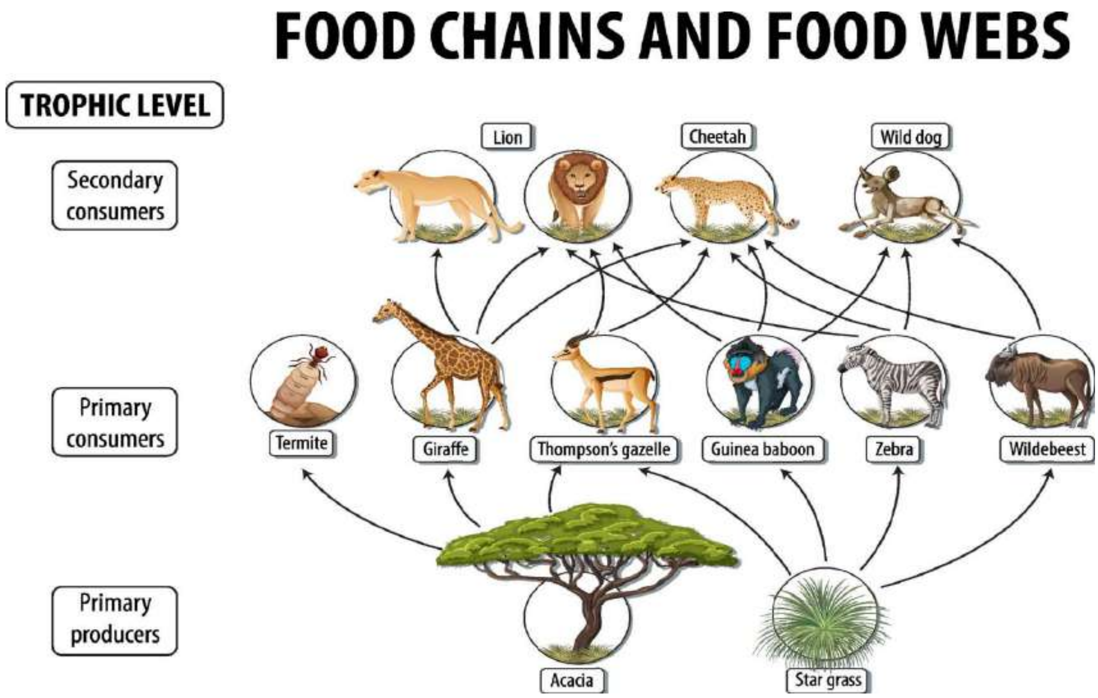

Figure 2.4: Food Chain and Food Webs

2.6.3 Energy Flow Models

The energy flow models link the trophic levels with each other showing the inputs and losses of energy at each trophic level. Lindeman (1942) was the first to propose such model assuming that plants and animals can be arranged into trophic levels and the laws of thermodynamics hold for plants and animals. He emphasized that the amount of energy at trophic level is determined by the net primary production and the efficiency at which food energy is converted into biomass. After that, various models depicting energy flow in ecosystems are described below:

SINGLE CHANNEL ENERGY FLOW MODEL

The flow of energy in an ecosystem takes place through the food chain and it is this energy flow which keeps the system going. The most common feature of this energy flow is that it is unidirectional or one-way flow or single channel flow. Unlike the nutrients (carbon, nitrogen, phosphorus, Sulphur etc.) which move in a cyclic manner and are reused by the producers after moving through the food chain, energy is not reused in the food chain. It flows from producers to herbivores to carnivores and so on.

Two things are clear from this energy flow model.

- Firstly, the flow of energy is unidirectional and non-cyclic. The green plants obtain energy from the sun and it is transformed into chemical energy by the process of photosynthesis. This energy is stored in plant tissues and transformed into heat energy during metabolic activities which then passes to next trophic level in the food chain. The solar energy captured by green plants (autotrophs) never revert back to sun, however, it passes to herbivores and that which passes to herbivores does not go back to autotrophs but passes

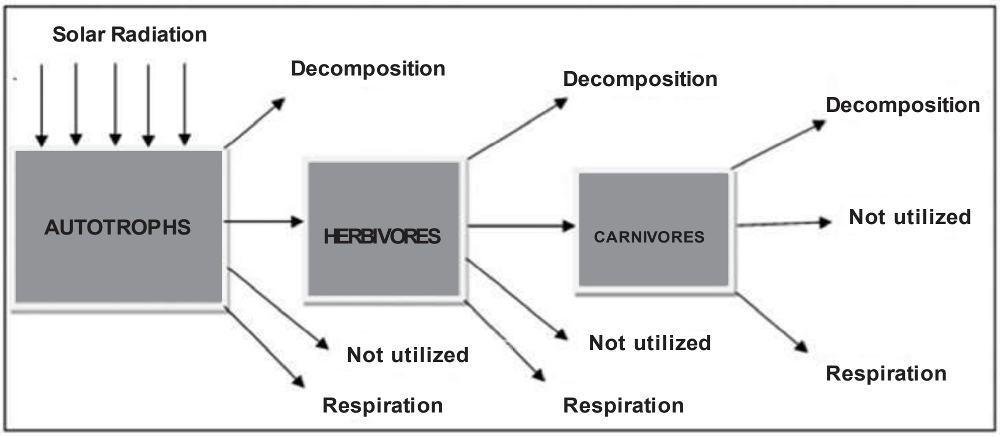

Figure 2.5: Simplified Single Channel Energy Flow Diagram (Modified from Lindeman, 1942)

to consumers. Thus, in biological systems, the energy flows from the sun to green plants and then to all heterotrophic organisms. Due to unidirectional flow of energy, the entire system would collapse if primary source of energy were cut off.

- Secondly, at each tropic level there is progressive decrease in energy as heat in the metabolic reactions and also some of the energy is utilized at each tropic level.

Figure shows the energy flow in three trophic levels in a linear food chain. Here the boxes represent the trophic levels (producers, herbivores and carnivores) and the pipelines depict the energy flow in and out of each trophic level. Size of the box shows energy stored in the form of biomass at that trophic level. There is loss of energy (represented as pipes getting narrower) at every successive trophic level, there is also a corresponding decline in energy stored in standing crop or biomass (represented as decreased size of box) at successive trophic level. Energy inflows in the system balance the energy outflows as required by the first law of thermodynamics and each energy transfer is accompanied by loss of energy in the form of unavailable heat energy (i.e. respiration) as stated by second law of thermodynamics. The energy flow is significantly reduced at each successive trophic level from producers to herbivores to carnivores. Thus, at each transfer of energy from one trophic level to another trophic level, major part of energy is lost in the form of heat or other form. There is successive reduction in the energy flow whether we consider it in term of total flow (I+A) or secondary productivity and respiration component.

DOUBLE CHANNEL OR Y-SHAPED ENERGY FLOW MODEL

The double channel or Y-Shaped energy flow model depicts the simultaneous working of grazing and detritus food chains in an ecosystem. In nature, both grazing and detritus food chains are inter- connected in the same ecosystem. For example, dead bodies of small animals that were once part of grazing food chain become incorporated in the detritus food chain as do the faces of grazing food animals. Functionally, the distinction between the two is of time lag between the direct consumption of living plants and ultimate utilization of dead organic matter. The importance of two food chains may differ in different ecosystems, in some cases, grazing is more important and in others, detritus is more important. It happens in marine ecosystems where primary production at open sea is limited and a major portion of it is eaten by herbivores marine animals. Therefore, very little primary production is left to be passed onto the detritus pathways. On the other hand, in a forest ecosystem, the huge quantity of biomass produced cannot be all consumed by herbivores and a large part of it enters into detritus compartment in the form of litter. Hence the detritus food chain is more important there. In an example given by Singh et al (2015), in a lake open water zone, grazing food chain predominates as phytoplanktons are eaten upon by zooplanktons and other organisms. On the other hand, in the lake bottom, dead organisms are deposited and they are acted upon by detritus feeders and decomposers.

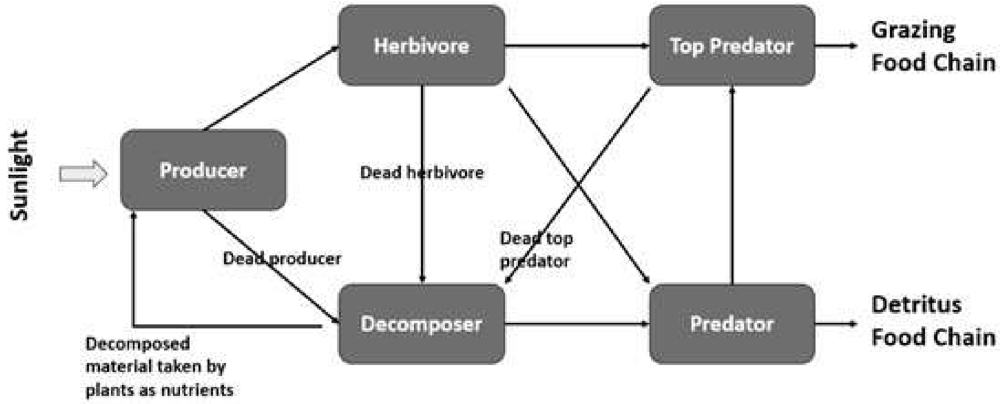

Figure 2.6: The relationship between flow of energy through grazing and detritus pathways.

E.P. Odum (1983) gave a generalized model of Y-shaped or double channel energy flow, which is applicable to both terrestrial and aquatic ecosystems. In energy flow diagram, one arm represents the grazing food chain and another represents detritus food chain. The important point in this model is that both the chains are not separated from each other. Odum regarded this model as more realistic than single channel energy flow model for the following reasons:

a) It confirms to the basic stratified structure of ecosystem by including both grazing and detritus pathways.
b) It separates the grazing food chain from detritus food chain in both time and space as shown by direct consumption of living plants and utilization of dead organic matter respectively.
c) Macroconsumer (animals) and microconsumers (bacteria and fungi) differ greatly in size- metabolism relations.

The two arms differ fundamentally in the way they can influence primary producers. In grazing food chain, herbivores feed on living plants, therefore they directly affect the plant population. Whatever they do not eat is available to the decomposers after death. As a result, decomposers are not able to directly influence the rate of supply of their food. Further, the amount of net production energy that flows down the two pathways varies in different kind of ecosystems and often in the same ecosystem; it may vary seasonally or annually. In heavily grazed grassland, 50% or more of the net production may pass down the grazing pathway. But aquatic systems like marshes or forests operate as detritus systems, for, over 90% of primary production is not consumed by heterotrophs until plant parts die and reach water, sediments and soils. This delay in consumption of primary production increases structural complexity of the ecosystem. Since all the food is not assimilated by the grazers, some is diverted to the detritus route. So, the impact of grazers on the community depends on the rate of removal of living plants and the amount of energy in the food that is assimilated. Marine zooplanktons commonly graze more phytoplanktons than they can assimilate, the excess being egested to the detritus food chain. Thus, energy flow along different path is dependent on the rate of removal of living plant material by herbivores as well as on the rate of assimilation in their bodies.

2.6.3.1 UNIVERSAL ENERGY FLOW MODEL

E.P. Odum (1968) gave Universal Energy Flow Model (Figure 2.7) which represents the basis for a general explanation of ecosystem trophic flows. The model can be applied to any living component, whether it is plant, animal, microorganism, individual, population or trophic group. Such a model may depict food chain as already shown in previous models or the bioenergetics of an entire ecosystem. In the figure, the living structure or biomass of the component is represented as the shaded box. Further, I - is the ingested energy which is solar radiation in case of autotrophs and ingested food in case of heterotrophs. Since not all the energy supplied is utilized, the lost part is called as energy not utilized (NU). The assimilated energy (A) is known as gross production.

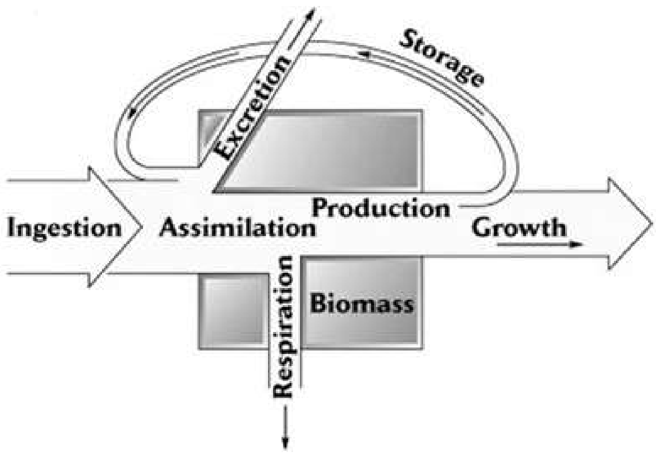

Figure 2.7: Universal Energy Flow Model

Part of assimilation (A) is used for system structural maintenance, that is the respiration (R), and the other part is transformed into organic matter (P), known as net production. P is the energy available for other individuals or trophic levels. Individuals use part of the net production for growth (G) or, in the case of populations or trophic levels, for biomass accumulation (B). A part of net production can be stored (S) to at individual level in the form of organic compounds of higher energetic content (lipids) or, at ecosystem level, as a nutrients deposit or detritus. Some production can be excreted by individuals or, analogously, exported from the ecosystem (E). The universal energy flow, can be used in two ways:

i) The model can represent a species population in which case the appropriate energy inputs and links with other species would be shown as a conventional species-oriented food web diagram.

ii) The model can represent a discrete energy level in which case the biomass and energy channels represent all or parts of many populations supported by the same energy source.

Foxes, for example, usually obtain part of their food by eating plants (fruits etc.) and part by eating herbivores (rabbit, field mice model etc.). A single box diagram could be used to represent the whole population of foxes if to express intrapopulation energetic. On the other hand, two or more boxes may be used if we wish to represent two or more trophic levels. Energy partitioning between P and R is of vital importance to the individual and species. Different organisms have different patterns of energy consumption. Large organisms require more maintenance energy as they have more biomass to maintain. The warm blooded animals (birds and mammals) require more energy than the cold blooded animals. Predators use a large part of assimilated energy in respiration than herbivore, to find and overcoming the prey. The species adapted to unstable, recently derived or under populated area, generally allocate a large portion of their energy to reproduction. The species adapted to stable and more favourable habitats, allocate little energy to reproduction.

2.6.4 Tropic structure and ecological pyramids

The study of trophic structure and ecological pyramids is integral to understanding the intricate dynamics that govern ecosystems. These concepts provide a structured framework for exploring the flow of energy, the distribution of biomass, and the numerical abundance of organisms within ecological communities. As we delve into the intricacies of these concepts, we unravel the tapestry of life, where organisms are intricately linked through a hierarchical system of feeding relationships.

2.6.4.1 Trophic Structure: A Hierarchical Organization

The trophic structure of an ecosystem represents the feeding relationships among its components. At the core of this structure are trophic levels, each characterized by the position an organism holds in the food chain. The journey begins with the primary producers, traverses through herbivores and carnivores, and culminates with the apex predators.

i. Primary Producers: Autotrophic Pioneers

Primary producers, often autotrophic organisms like plants and algae, play a pivotal role in trophic structure. Their ability to capture solar energy through photosynthesis transforms non-organic matter into organic compounds that serve as the foundation of the food web. The process of photosynthesis, however, is not without limitations, and factors such as light availability, temperature, and nutrient levels influence its efficiency.

ii. Primary Consumers: Herbivores and the First Trophic Leap

The trophic structure advances as herbivores, or primary consumers, feed directly on primary producers. This initial transfer of energy from plants to herbivores shapes population dynamics and can significantly impact plant communities. The relationship between herbivores and primary producers is not merely a unidirectional flow but a complex interplay influenced by factors such as herbivore feeding preferences, plant defences, and resource availability.

iii. Secondary and Tertiary Consumers: Carnivores in the Web

As energy moves up the trophic levels, secondary consumers, often carnivores, prey on herbivores, introducing another layer of complexity to the trophic structure. This transition marks another step in the transfer of energy up the trophic levels. Tertiary consumers, situated at the apex, feed on other carnivores, forming the upper echelon of the trophic pyramid. The dynamics within this upper trophic level can have cascading effects on the entire ecosystem.

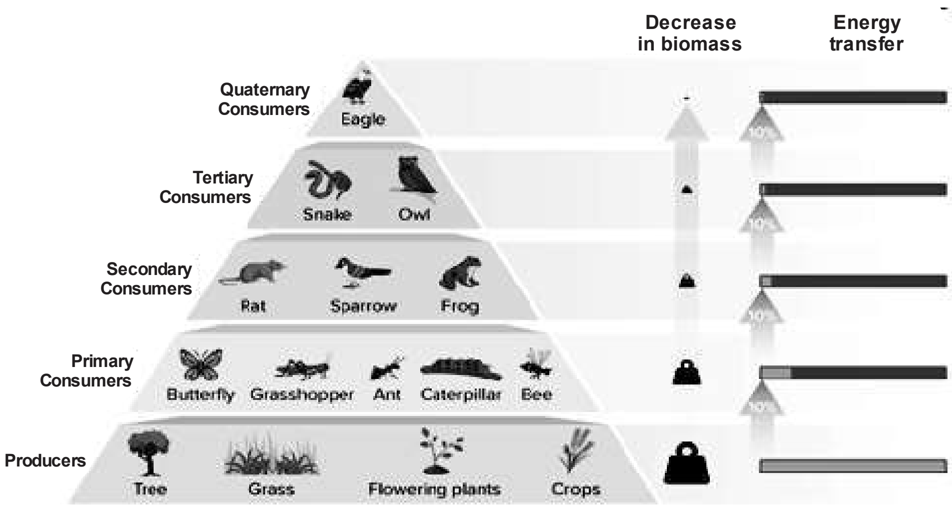

Figure 2.8: Tropic levels

2.6.4.2 Ecological Pyramids: Quantifying Trophic Relationships

To quantitatively understand the trophic structure, ecologists employ ecological pyramids, visual tools that represent various parameters within ecosystems. The three primary types of ecological pyramids-pyramid of numbers, pyramid of biomass, and pyramid of energy, offer insights into the numerical abundance, mass distribution, and energy flow, respectively.

i. Pyramid of Numbers: Counting the Participants

The pyramid of numbers provides a graphical representation of the number of organisms at each trophic level. It may take the form of an upright pyramid, where the base represents primary producers, and each subsequent tier represents a decrease in the number of individuals. However, certain ecosystems, like a tree canopy with numerous insects dependent on a single tree, can invert this pyramid.

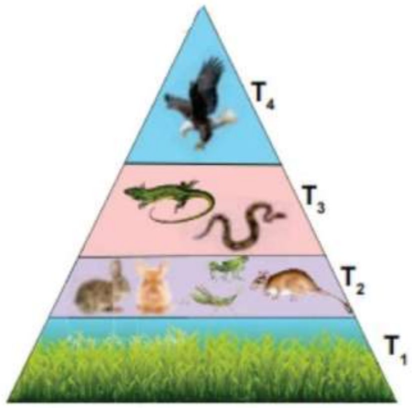

Figure 2.9: Pyramid of Numbers

ii. Pyramid of Biomass: Weighing the Living Matter

In contrast to the pyramid of numbers, the pyramid of biomass illustrates the total mass of living organic matter at each trophic level. This pyramid is typically upright, reflecting the decrease in biomass as energy moves up the food chain. Producers, with their extensive but lightweight structures, form the expansive base, while top predators constitute the narrower peak.

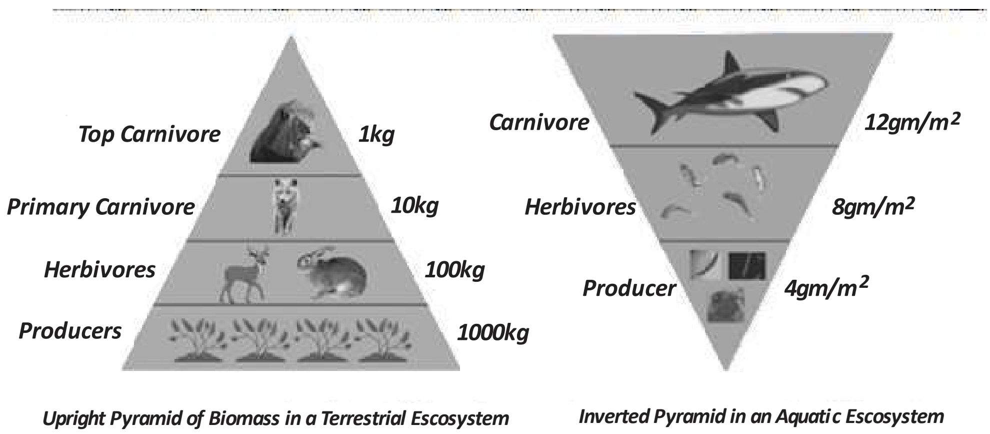

Figure 2.10: Pyramid of Biomass

iii. Pyramid of Energy: Tracing the Vital Currency

The pyramid of energy provides a dynamic view of energy flow through trophic levels. Each tier represents the amount of energy available, with a noticeable reduction at each successive level. This decline is attributable to the second law of thermodynamics, emphasizing the inevitable loss of energy as heat during each transfer. The pyramid of energy is always upright, underlining the unidirectional flow of energy within ecosystems.

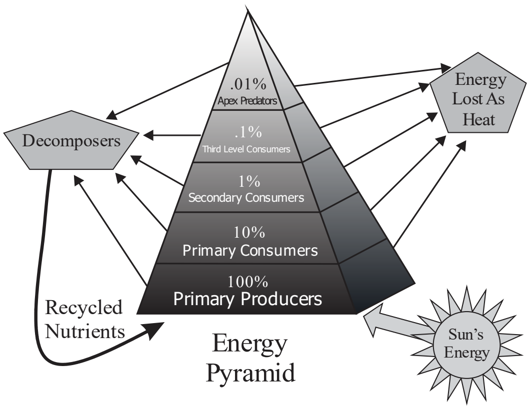

Figure 2.11: Pyramid of Energy

2.6.4.3 Dynamic Interactions: Trophic Cascades and Ecological Resilience

Understanding trophic structure and ecological pyramids is critical for comprehending the dynamic interactions that shape ecosystems. Trophic cascades, where changes in one trophic level have ripple effects throughout the ecosystem, highlight the interconnectedness of species. Predators, for instance, can exert top-down control, influencing not only the abundance of prey but also the structure of vegetation and even the composition of the physical environment. For example:

i. Yellowstone National Park: Wolves, Elk, and Vegetation Dynamics

The reintroduction of wolves to Yellowstone National Park serves as a classic example of trophic structure influencing ecosystem dynamics. The wolves, as top predators, initiated a trophic cascade by controlling the elk population. This, in turn, led to a recovery of vegetation, positively impacting riparian ecosystems and numerous associated species.

ii. Oceanic Food Webs: The Plight of Top Predators

In marine ecosystems, overfishing and the decline of top predators, such as sharks, have disrupted trophic structures. This imbalance can result in an overabundance of herbivores, causing cascading effects on the health of coral reefs and other marine habitats.

It can be concise that trophic structure and ecological pyramids provide a lens through which we can analyze the complex interactions within ecosystems. As we delve deeper into these concepts, it becomes evident that the health and stability of ecosystems depend on the delicate balance maintained by trophic relationships. By unravelling the mysteries of trophic structure and ecological pyramids, we gain valuable insights into the resilience and vulnerability of Earth's diverse ecosystems, ultimately guiding efforts toward their conservation and sustainable management.

2.7 Ecological Succession

An important characteristic of all communities is that their composition and structure constantly change in response to the changing environmental conditions. This change is orderly and sequential, parallel with the changes in the physical environment. These changes lead finally to a community that is in near equilibrium with the environment and that is called a climax community. The gradual and fairly predictable change in the species composition of a given area is called ecological succession. During succession some species colonise an area and their population become more numerous whereas populations of other species decline and even disappear. The entire sequence of communities that successively change in a given area are called sere(s). The individual transitional communities are termed seral stages or seral communities. In the successive seral stages, there is a change in the diversity of species of organisms, increase in the number of species and organisms as well as an increase in the total biomass. The present day communities in the world have come to be because of succession that has occurred over millions of years since life started on earth. Actually, succession and evolution would have been parallel processes at that time.

Succession is hence a process that starts in an area where no living organisms are there - these could be areas where no living organisms ever existed, say bare rock; or in areas that somehow, lost all the living organisms that existed there. The former is called primary succession, while the latter is termed secondary succession. Examples of areas where primary succession occurs are newly cooled lava, bare rock, newly created pond or reservoir. The establishment of a new biotic community is generally slow. Before a biotic community of diverse organisms can become established, there must be soil. Depending mostly on the climate, it takes natural processes several hundred to several thousand years to produce fertile soil on bare rock. Secondary succession begins in areas where natural biotic communities have been destroyed such as in abandoned farm lands, burned or cut forests, lands that have been flooded. Since some soil or sediment is present, succession is faster than primary succession.

Description of ecological succession usually focuses on changes in vegetation. However, these vegetational changes in turn affect food and shelter for various types of animals. Thus, as succession proceeds, the numbers and types of animals and decomposers also change. At any time during primary or secondary succession, natural or human induced disturbances (fire, deforestation, etc.), can convert a particular seral stage of succession to an earlier stage. Also, such disturbances create new conditions that encourage some species and discourage or eliminate other species.

When this process begins in a virtually lifeless area where soil has not yet formed, such as on a new volcanic island or on the rubble (moraine) left by a retreating glacier, it is called primary succession. Often the only life-forms initially present are autotrophic prokaryotes and heterotrophic prokaryotes and protists. Lichens and mosses, which grow from windblown spores, are commonly the first macroscopic photosynthesizers to colonize such areas. Soil develops gradually as rocks weather and organic matter accumulates from the de- composed remains of the early colonizers. Once soil is present, the lichens and mosses are usually overgrown by grasses, shrubs, and trees that sprout from seeds blown in from nearby areas or carried in by animals. Eventually, an area is colonized by plants that become the community's prevalent form of vegetation. Producing such a community through primary succession may take hundreds or thousands of years.

Secondary succession occurs when an existing community has been cleared by some disturbance that leaves the soil intact, as in Yellowstone following the 1988 fires. Sometimes the area begins to return to something like its original state. For instance, in a forested area that has been cleared for farming and later abandoned, the earliest plants to recolonize are often herbaceous species that grow from windblown or animal-borne seeds. If the area has not been burned or heavily grazed, woody shrubs may in time replace most of the herbaceous species, and forest trees may eventually replace most of the shrubs. Early arrivals and later-arriving species may be linked in one of three key processes. The early arrivals may facilitate the appearance of the later species by making the environment more favorable-for example, by increasing the fertility of the soil. Alternatively, the early species may inhibit establishment of the later species, so that successful colonization by later species occurs in spite of, rather than because of, the activities of the early species. Finally, the early species may be completely independent of the later species, which tolerate conditions created early in succession but are neither helped nor hindered by early species.

The final or stable community known as climax community.

2.7.1.1 Characteristics of Climax Community

- The vegetation is tolerant of environmental conditions.
- It has a wide diversity of species, a well-drained spatial structure, and complex food chains.
- The climax ecosystem is balanced.
- Individuals in the climax stage are replaced by others of the same kind.

- It is an index of the climate of the area.

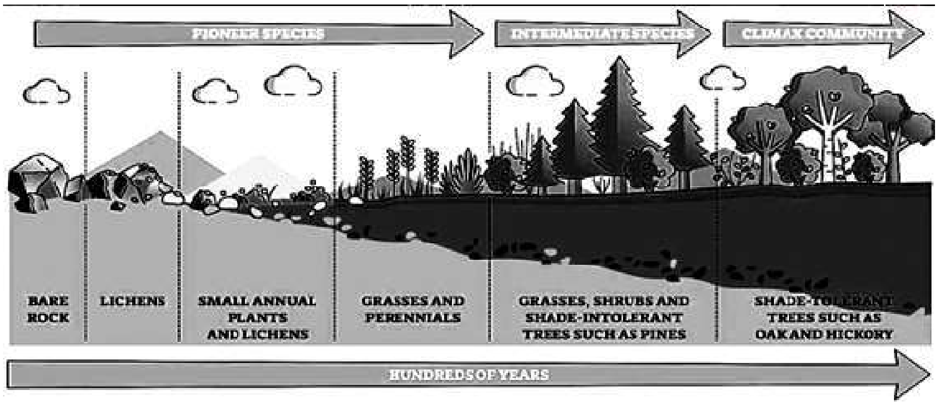

Figure 2.12: Stages of Primary Succession

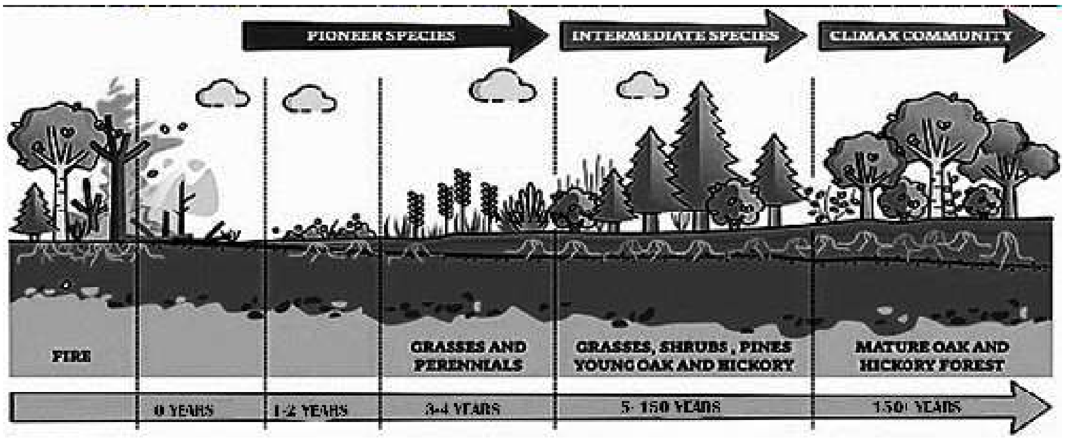

Figure 2.13: Stages of Secondary Succession

2.7.1.2 Types of climax

- Climatic Climax - one of the ecological climaxes possible in a particular climatic area whose stability is directly due to the influence of climate.
- Edaphic Climax -an ecological climax resulting from soil factors and commonly persisting through cycles of climatic and physiographic change.
- Catastrophic Climax -Climax vegetation vulnerable to a catastrophic event such.

2.7.1.3 Disclimax

When a stable community, which is not the climatic or edaphic climax for the given site, is maintained by man or his domestic animals, it is designated as Disclimax (disturbance climax) or anthropogenic subclimax (man-generated).

- Subclimax -The prolonged stage in succession just preceding the climatic climax.
- Preclimax and Postclimax

Preclimax - if the community has life forms lower than those in the expected climatic climax.

Postclimax - a community that has life forms higher than those in the expected climatic climax.

Monoclimax /Climatic Climax Theory– an invention of the American ecologist F.E. Clements. This states that every region has only one climax community, toward which all communities are evolving and that, given sufficient time and freedom from interference.

Polyclimax Theory -. A.G. Tansley - community are controlled by soil moisture, minerals, ions, activity of animals, topography, and other factors.

Climax Pattern Theory - proposed by Whittaker (1953) - recognizes a variety of climaxes governed by responses of species populations to biotic and abiotic conditions. -the total environment of the ecosystem determines the composition, species structure, and balance of a climax community

2.7.2 Succession of Plants

Based on the nature of the habitat - whether it is water (or very wet areas) or it is on very dry areas - succession of plants is called hydrarch or xerarch, respectively. Hydrarch succession takes place in wet areas and the successional series progress from hydric to the mesic conditions. As against this, xerarch succession takes place in dry areas and the series progress from xeric to mesic conditions. Hence, both hydrarch and xerarch successions lead to medium water conditions (mesic) - neither too dry (xeric) nor too wet (hydric). The species that invade a bare area are called pioneer species. In primary succession on rocks these are usually lichens which are able to secrete acids to dissolve rock, helping in weathering and soil formation. These later pave way to some very small plants like bryophytes, which are able to take hold in the small amount of soil. They are, with time, succeeded by higher plants, and after several more stages, ultimately a stable climax forest community is formed. The climax community remains stable as long as the environment remains unchanged. With time the xerophytic habitat gets converted into a mesophytic one. In primary succession in water, the pioneers are the small phytoplanktons, which are replaced with time by rooted-submerged plants, rooted-floating angiosperms followed by free-floating plants, then reed swamp, marsh-meadow, scrub and finally the trees. The climax again would be a forest. With time the water body is converted into land.

In secondary succession the species that invade depend on the condition of the soil, availability of water, the environment as also the seeds or other propagules present. Since soil is already there, the rate of succession is much faster and hence, climax is also reached more quickly. What is important to understand is that succession, particularly primary succession, is a very slow process, taking maybe thousands of to meet with the deficit which occurs due to imbalance in the rate of influx and efflux.

Different types of habitats in which succession takes place:

- **Hydrosere:** succession occurs where water is plenty, e.g. pond.
- **Derosere:** succession occurs on dry soil or rock.
- **Xerosere:** succession occurs in dry habitats like dry deserts or bare rock.
- **Psammosre:** succession which occurs on sand dunes.
- **Halosere:** succession which occurs on saline soil.
- **Lithosere:** Succession on the newly exposed rock surface
- **Oxylosere:** Succession on acidic soil

2.7.2.1 Hydrosere or Hydrarch

This type of succession occurs in the aquatic environment. Such a type of succession does not necessarily lead the aquatic communities toward the development of land communities. If the body of water is large and very deep or very strong wave action and other powerful physical forces are at work, the succession results in a stable aquatic community in which any considerable further change is hardly recognizable.

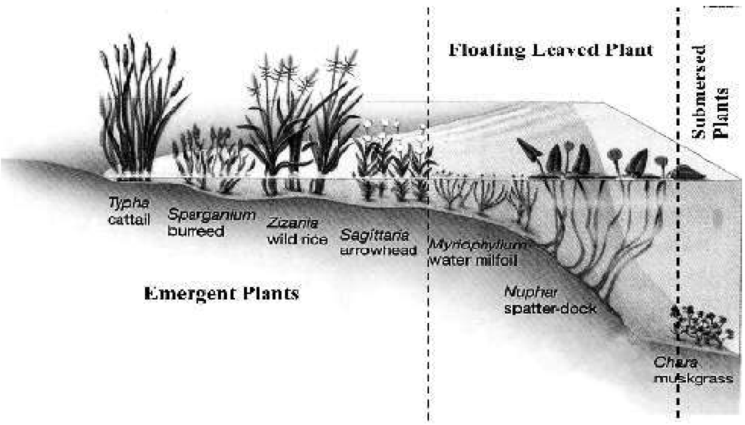

Figure 2.14: Zonation of Aquatic Vegetation (hydrophytes) along the pond with respect of water depth

Succession is recognizable only if the colonization of plant communities takes place in artificial small and shallow ponds, lakes, etc. where wave action speeds up the process by allowing the erosion of soil towards edge regions. In this way, the filling process also speeds up quickly and consequently, the body of water disappears within a few years.

Different types of vegetation at different depths in a pond for example floating plants in the central region, rooted hydrophytes in shallow region, amphibious plants in the marginal mud and trees developing in dry habitat are demonstrated in the **figure 2.14**.

In a new and virgin pond hydrosere succession starts with the colonisation of **phytoplankton** as the pioneer stage and finally terminates in the climax community that is **the forest**.

The process of aquatic succession completes through the following stages (Fig. 2.15):

1. Phytoplankton stage:

In the initial stage of succession, algal spores are brought into the body of water. The simple forms of life like bacteria, algae, and many other aquatic plants (phytoplankton) and animals (zooplankton) floating in water are the pioneer colonizers. All these organisms add large amounts of organic matter and nutrients due to their various life activities and after their death, they settle at the bottom of the pond to form a layer of muck. Muck is a type of organic sediment that can accumulate in lakes and ponds, often consisting of decomposing plant material, algae, and other organic matter.

2. Submerged stage:

The phytoplankton stage is followed by the submerged plant stage. When a loose layer of mud is formed on the bottom of the pond, some rooted submerged hydrophytes begin to appear on the new substratum. The submerged aquatic vegetation develops in the regions of ponds or lakes where the water depth is about 10 feet or more. The pioneers are Elodia, Potamogeton, Myriophyllum, Ranunculus, Utricularia, Ceratophyllum, Vallisnena, Chara, etc. These plants form tangled masses and have marked effects on the habitat. When these plants die their remains are deposited at the bottom of the ponds or lakes. The eroded soil particles and other transported materials are also deposited at the bottom. This gradually raises the bottom of the ponds and lakes. As this process of stratification progresses the body of water becomes more and more shallow, consequently, the habitat becomes less suited for the submerged vegetation but more favourable for other plants.

3. Floating stage:

When the depth of water reaches about 4 to 8 feet, the submerged vegetation starts disappearing from its original place and then the floating plants make their appearance gradually in that area. In the beginning, the submerged and floating plants grow intermingled but over time the submerged plants are replaced completely. The most tolerant species in the area can reproduce and perpetuate. Their broad leaves floating on the water's surface check the penetration of light to deeper layers of water.

This may be one of the main causes responsible for the death of submerged plants. Due to continuous interaction between plant communities and the aquatic environment, the habitat becomes changed chemically as well as physically. More water and air-borne soil and dead remains of plants are deposited at the bottom. Thus, the substratum rises in a vertical direction. Important floating plants that replace the submerged vegetation are

Nelumbmm, Trapa, Pistia, Nymphaea, Limnanthemum etc.

4. Reed-swamp stages:

When the ponds and lakes become too shallow (water depth one to three feet), and the habitat is changed so much that it becomes less suited to the floating plants some other plants which are well adapted to a new environment will then come in. Under these conditions, the floating plants start disappearing gradually and their places are occupied by amphibious plants which can live successfully in aquatic as well as aerial environments Important examples are *Bothrioclova, Typha, Phragmites* (Reed), *etc.*

The foliage leaves of such plants are exposed much above the surface of water and roots are generally found either in mud or submerged in water. The foliage leaves form a cover over submerged and floating plants and thus they cut off light from the plant's underneath them. Under such conditions, neither submerged nor floating plants can survive. Further deposition of soil and plant debris at the bottom reduces the depth of water and makes the habitat less suitable for the pre-existing plants.

When the bottom reaches very close to the water surface many secondary species, such as those of *Polygonum, Sagittaria,* etc. make their appearance. Later, they also bring about such reactions by which the habitat becomes less suitable for most of the existing species, and consequently new successional step follows.

5. Sedge Marsh or Meadow stage:

The filling process finally results in marshy soil which may be too dry for the plants of the preexisting community. Now the plants well adapted to new habitats begin to appear in the preexisting community in mixed state. Important plants that are well suited to marshy habitats are the members of cyperaceae and poaceae. The species of sedge (*Carex*) and rushes (*Juncus*), species of *Themeda, Iris, Dichanthium, Eriophorum, Cymbopogon, Campanula, Mentha, Caltha, Gallium, Teucrium, Cicuta,* etc. are the first invaders of a marshy area.

As these plants grow most luxuriantly in the marshes, they modify the habitats in several ways. They absorb and transpire a large quantity of water and also catch and accumulate plant debris and wind and water-borne soil particles. Consequently, a dry habitat results which may be totally unfit for the growth of normal hydrophytes. Gradually the mesophytes start appearing and after some time the sedge vegetation is totally replaced by them.

6. Woodland stage:

In the beginning some shrubs and later medium-sized trees form open vegetation or woodland. These plants produce more shade and absorb and transpire large quantities of water. Thus, they render the habitat drier. Shade-loving herbs may also grow under the trees and shrubs. The prominent plants of the woodland community are species of *Buteazon, Acacia, Cassia, Terminalia, Salix, Cephalanthus,* etc.

7. Climax Forest:

After a very long time, the hydrosere may lead to the development of climax vegetation. As the level of the soil is raised much above the water level by progressive accumulation of humus and soil particles, the habitat becomes drier and certainly well aerated. In such a habitat, well-adapted self-maintaining and self-reproducing, nearly stable and uniform plant community consisting mostly of woody trees develops in the form of mesophytic forest.

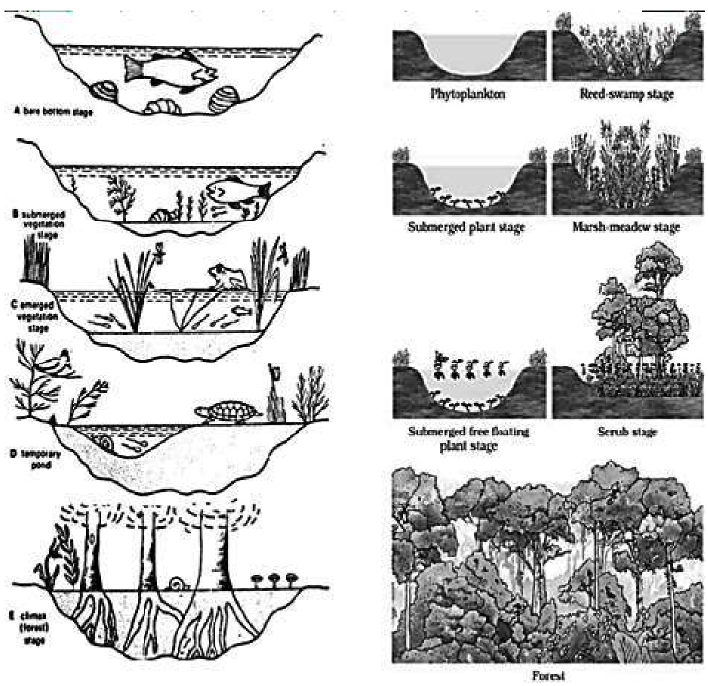

Figure 2.15: Different stages of Hydrosere succession

In the climax forest, all types of plants are met with. Herbs, shrubs, mosses and shade-loving plants represent their own communities. Trees are dominant and they have control over the entire vegetation. Bacteria, fungi, and other micro-organisms are more frequently found in the climax vegetation. They react upon the habitat and make the soil rich in organic materials. At the climax stage, a complete harmony develops between the plant community and habitat.

It is now clear that the whole sere is a continuously but gradually changing complex in which the changes are forced by biotic, topographic or climatic factors. It is a very slow process that cannot be observed in nature. It may require thousands of years to reach the climax stage. One can, however, observe the sequence of hydrosere as he moves in the lake or pond from the deepest region towards the shallower margin. The nature of the climax community (forest) is dependent upon the climate of the region. In tropical climates with heavy rainfall, tropical rain forest develop, whereas in temperate regions mixed forests of *Ulmus, Acer* and *Quercus* develop. In region of moderate rainfall, there develop tropical deciduous forest or monsoon forest.

2.7.2.1.1 Factors Influencing Hydrosere Succession:

a) **Hydrological Factors:** Water depth and flow patterns play a critical role in determining the successional trajectory. Changes in water level influence the availability of nutrients and affect the types of species that can thrive.

b) **Edaphic Factors:** The composition of the substrate, nutrient availability, and sedimentation rates influence the types of plants that can establish themselves.

c) **Biotic Interactions:** Competition, predation, and mutualistic interactions among organisms shape the successional dynamics.

d) **Disturbance Events:** Natural events, such as floods or droughts, can reset the successional clock by altering environmental conditions.

2.7.2.1.2 Ecological Significance of Hydrosere:

- Hydrosere succession plays a vital role in ecosystem development and contributes to biodiversity conservation.
- The final, stable stage provides habitat for a diverse array of plant and animal species, fostering ecological resilience.
- Wetlands formed through hydrosere succession serve as crucial carbon sinks, helping mitigate climate change.

2.7.2.2 Xerosere or Xerarch

Xerosere is a type of ecological succession that occurs in dry or arid environments originating on bare rock surfaces where water availability is limited. The original substratum is deficient in water and lacks any organic matter, having only minerals in a disintegrated unweathered state. The pioneers to colonise this primitive substratum are crustose types of lichens, and through a series of successive seral stages, the succession finally terminates into a forest which constitutes the climax community. In simpler form, Xerosere specifically refers to the succession in dry or desert areas, and it involves a series of stages that ultimately lead to the establishment of a climax community adapted to arid conditions.

The various stages in xerosere can be enumerated as follows-

1. Lichen stage:

Due to great exposure to the sun and extreme deficiency of water, the first pioneers in the bare rock area were a few simple organisms. The most successful of such organisms is crustose lichens. These organisms are well-adapted to harsh conditions, such as low water availability and high temperatures. During the rainy season, they absorb large quantities of water and flourish rapidly.

Migration to distant rocks takes place either by spores or soredia by wind. The common species of crustose lichens are Rhizocarpon, Rinodina, Lecanora etc. Lichens play a crucial role in soil formation, as they can break down rock surfaces through physical and chemical weathering by secreting carbonic acid causing rock disintegration. This helps in the development of a thin layer of soil, albeit nutrient-poor. The lichen Rock particles and dead organic matter of lichens accumulate to provide conditions possible for the growth of higher forms of lichens.

As soon as little soil is formed by the activity of crustose lichens, higher forms of lichens such as foliose lichens appear. These include Dermatocarpon, Parmelia, Umbilicaria etc. These have large leafy thalli which overlap the crustose-lichens and cause their gradual death and decay. In this way more and more humus accumulates and gradually a thin layer of soil is formed which consists of rock particles, remains of lichens, dust particles and moisture. Associated with the lichens a few mites make their appearance. Along with them a few spiders also make their appearance in cracks and crevices of the rock.

2. Moss stage:

As the pioneers, especially lichens, continue to break down rocks and contribute organic matter to the soil, mosses become established. Mosses are better at retaining water and contribute further to soil development. With the accumulation of dust and humus in small quantities the environment is altered enough to allow the establishment of secondary communities in a rather definite sequence. Scattered patches of mosses such as Tortula, Grimmia Byrum and Barbula etc. begin to invade the environment that had so far been dominated by lichens. Later, mosses like Funaria, Sphagnum and Polytrichum make their appearance.

Among the animals, mites become more varied; some small spiders and springtails as well as tardigrades become associated with this secondary community.

3. Herbaceous stage:

As the mats of mosses become more extensive, more soil accumulates; much of the soil is blown in from the surrounding area during windy periods. More mineral material is added to the soil as acid leaches out from the overlying vegetation and increases the depth of the mineral soil layer.

Many annual weeds develop which are, later on, followed by biennial and finally perennial grasses. These plants have deeper root systems, enabling them to access water from deeper soil layers. Andropogon commonly known as broom sedge becomes, the dominant grass in many areas. With the influx of grasses, the fauna (animals) also becomes varied. Nematodes and larval insects, collembola, ants and mites appear in the gradually altered environment.

4. Shrub stage:

Further modification of the environment provides conditions for the germination and growth of shrubs and perennial wood plants such as Acacia, Prosopis, Capparis, Zizyphus etc. Shrubs are more effective in water retention and provide shade, creating a more favorable microclimate for other plants. With the approach of shrubs, the animals also become vivid and numerous, and join hands with the vegetation in altering the environment.

5. Climax Forest:

With the establishment of shrubs, more and more soil is formed and the environment becomes increasingly humid. This favours the growth of woody trees. In the beginning, trees show stunted growth and are sparsely placed. Finally, a climax forest community is established. The climax community is the last aggregation in the successional series. If the climax condition does change.

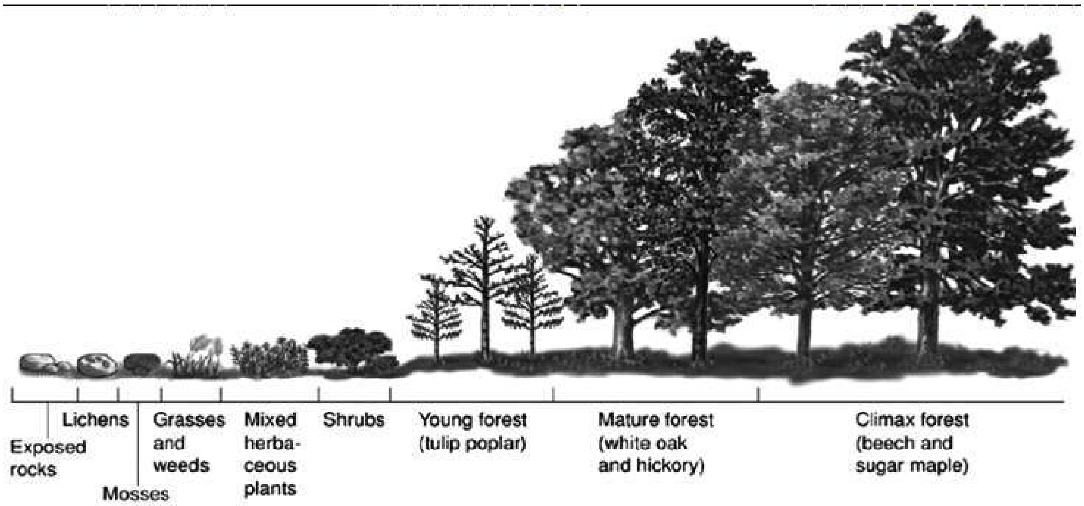

Figure 2.16: Different stages of Xerosere succession

2.7.2.2.1 Factors Influencing Xerosere:

- **Climate:** Arid climates with low precipitation and high temperatures are conducive to xerosere succession.
- **Topography:** The type of substrate, slope, and elevation can influence the rate and direction of xerosere succession.
- **Human Activities:** Human interventions, such as deforestation or overgrazing, can alter the natural succession process in xeroseres.

2.8 Concept of Ecotone, Edge Effect, Ecological Habitats and Niche

2.8.1 Ecotone

The term was coined from a combination of eco(logy) plus -tone, from the Greek tonos or tension (a place where ecologies are in tension). An ecotone is a zone of junction or a transition area between two biomes [diverse ecosystems]. It is where two communities meet and integrate.

For e.g., the mangrove forests represent an ecotone between marine and terrestrial ecosystem. Other examples are grassland (between forest and desert), estuary (between fresh water and salt water) and river bank or marsh land (between dry and wet).

2.8.1.1 Characteristics of Ecotone

- It may be narrow (between grassland and forest) or wide (between forest and desert).
- As it is a zone of transition, it has conditions intermediate to the adjacent ecosystems. Hence it is a zone of tension.
- Usually, the number and the population density of the species of an outgoing community decreases as we move away from community or ecosystem.
- Well-developed ecotones contain some organisms which are entirely different from that of the adjoining communities.

2.8.2 Edge effect

An "edge" is the boundary or interface between two biological communities or between different landscape elements. - refer to the changes in population or community structure s that occur at the boundary of two habitats i.e., ecotone region. As the edge effects increase, the boundary habitat allows for greater biodiversity.

Sometimes the number of species and the population density of some of the species in the ecotone is much greater than either community. This is called edge effect. The organisms which occur primarily or most abundantly in this zone are known as edge species. In the terrestrial ecosystems edge effect is especially applicable to birds. For example, the density of birds is greater in the mixed habitat of the ecotone between the forest and the desert.

2.8.2.1 Types of Edge effect

- Inherent- Natural features stabilize the border location.
- Induced-Transient natural or human related activities, subject borders to successional

changes over time.

- Narrow-One habitat abruptly ends and another begins.
- Wide (ecotone)-Substantial distance separates border from point where physical conditions and vegetation do not differ from interior of patch.
- Convoluted-Border is non-linear.
- Perforated-Border has gaps that host other habitats.

2.8.3 Ecological Niche and Habitat

Niche refers to the unique functional role and position of a species in its habitat or ecosystem. In nature, many species occupy the same habitat but they perform different functions. The functional characteristics of a species in its habitat is referred to as "niche" in that common habitat.

Habitat of a species is like its 'address' (i.e. where it lives) whereas niche can be thought of as its "profession" (i.e. activities and responses specific to the species). It is the surroundings in which an organism lives (home).

A niche is unique for a species while many species share the habitat. No two species in a habitat can have the same niche. This is because of the competition with one another until one is displaced. For example, a large number of different species of insects may be pests of the same plant but they can co-exist as they feed on different parts of the same plant. A species' niche includes all of its interactions with the biotic and abiotic factors of its environment [habitat niche - where it lives, food niche - what is eats or decomposes & what species it competes with, reproductive niche - how and when it reproduces, physical & chemical niche - temperature, land shape, land slope, humidity & other requirement]. An ecological niche describes how an organism or population responds to the distribution of resources and competitors (for example, by growing when resources are abundant, and when predators, parasites and pathogens are scarce) and how it in turn alters those same

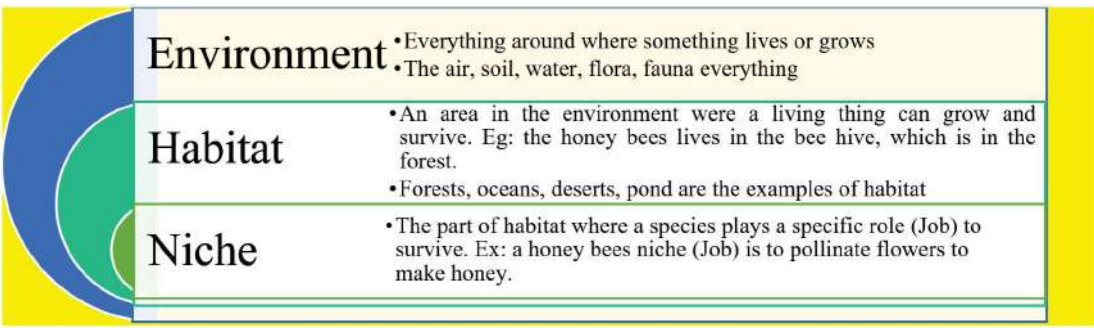

Figure 2.17: Habitat vs Niche

factors (for example, limiting access to resources by other organisms, acting as a food source for predators and a consumer of prey). Niche plays an important role in conservation of organisms. If we have to conserve species in its native habitat we should have knowledge about the niche requirements of the species and should ensure that all requirements of its niche are fulfilled.

Aspects or types of ecological niche: The three aspects of ecological niche are

1) Spatial or habitat niche: According to this, a niche is the "microhabitat in which a species lives". It represents the physical space occupied by an organism. According to this, no two species can occupy the same habitat. e.g., Catla, Rohu, Mrigal live in same pond, but they occupy different niche (surface, mid-column and bottom layer)

2) Trophic niche: According to this, a niche is the "functional status of an organism in its community". Thus, it describes the trophic position of an organism in an ecosystem. E.g., Two weaver birds *Ploceus collaris* and *P. melanocephalus,* live in the same nest but one feeds on seeds and the other on insects.

3) Multidimensional or hypervolume niche: According to this, a niche can be a multidimensional or hyper-volume space. The activity range of any species is dependent on all the dimensions of the environment. These dimensions include physical and chemical parameters such as temperature, humidity, salinity, oxygen concentration etc. and biological factors such as prey species. It led to the concepts of niche breadth and niche overlap.

2.8.3.1 Niche Differentiation

Fundamental niche and realised niche: Fundamental niche are the niche that an organism occupies in the absence of any competitors and predators. Realised niche is referred to as the role an organism actually plays in the community. For example, the outcome of inter-specific competition leads to either extinction or the development of differences allowing coexistence.

2.8.3.2 Advantages of ecological niche:

1) Animals can escape competition by occupying different ecological niches.

2) Segregation of different species in a particular niche result in full exploitation of all available resources.

Table 2-3:Comparison between Habitat and Niche

Basis for Comparison	Habitat	Niche
Meaning	A habitat is an area, where a species lives and interact with the other factors.	A niche is an ideology, of how an organisms lives or survive in the provided environmental conditions.
Consist of	Habitat consist of numerous niches.	Niches does not contains such components.
It includes	Affect of temperature, rainfall and other abiotic factors.	Flow of energy from one organisms to other through ecosystem.
Examples	Desrets, oceans, forest, rivers, mountains, etc. are examples of habitat.	It is a part of habitat only, where shelter for living being can be furnished.
Supports	Habitat supports numerous species at a time.	Niche supports a single species at a time.
What it is	Superset	Subset
Nature	Habitat is a physical place.	Niche is an activity performed by organisms.
Specificity	Habitat is not species specific.	Niche is species specific.

2.9 Ecosystem Services

Healthy ecosystems are the base for a wide range of economic, environmental, and aesthetic goods and services. The products of ecosystem processes are named as ecosystem services, for example, healthy forest ecosystems purify air and water, mitigate droughts and floods, cycle nutrients, generate fertile soils, provide wildlife habitat, maintain biodiversity, pollinate crops, provide storage site for carbon and also provide aesthetic, cultural and spiritual values. Though value of such services of biodiversity is difficult to determine, it seems reasonable to think that biodiversity should carry a hefty price tag. Robert Constanza and his colleagues have very recently tried to put price tags on nature's life-support services.

Ecosystem services are the benefits provided to humans through the transformations of resources (or environmental assets, including land, water, vegetation and atmosphere) into a flow of essential goods and services e.g., clean air, water, and food (Constanza et al.1997).

Historically, humans have modified natural ecosystems to favour those species that yield direct benefits (e.g., agricultural commodities), generally overlooking the unseen but essential ecosystem services (e.g. pollination, soil fertility, insect control and erosion control) that, if lost, are expensive and sometimes impossible to replace. Some ecosystem services, such as the regulation and stabilisation of climate, water flow, and the movement of nutrients have been even less visible until recent times, when disturbance to these systems has exacerbated climate change, soil erosion or eutrophication. Like all complex systems, ecosystems can appear to be working well until they suddenly collapse, as the supporting base may have eroded without obvious warning symptoms. A well-known example is fisheries, which may abruptly collapse even when the level of catch has been stable for years (Mullon et al. 2005). Another example is evident in the landscape where crops and pastures have replaced native vegetation. They have shallow root systems that do not use nearly as much of the rain or irrigation water that percolates into the soil as native plants. The excess water finds its way to the groundwater up to 10 times faster. Consequently, groundwater levels slowly rise, dissolving the natural salt in the weathered soils found over vast areas of Australia. It can take from 10 to 100 years for these changes to bring salt to the land surface or into streams (Australian State of the Environment Committee 2001). When this happens, the result can be devastating to production and to biodiversity. Many ecosystem services have not been easy to observe until they cease to flow, hence they have not been formally counted in economic systems, or the effects of their loss have been counted as 'externalities.' However, when these externalities become a significant cost burden to society, such as restoring degraded river systems, it becomes a priority to understand and value ecosystem services and to integrate them into economic frameworks. Maintenance and restoration of natural ecosystems and the services they provide is therefore essential to sustained community wellbeing, economic prosperity and efficiency. To date, the broad range of biodiversity protection measures, public and private, has been vital in ensuring that ecosystem services continue to flow, even if this has not been their main intention.

Researchers have put an average price tag of US $ 33 trillion a year on these fundamental ecosystem's services, which are largely taken for granted because they are free. This is nearly twice the value of the global gross national product GNP which is (US $ 18 trillion). Out of the total cost of various ecosystem services, the soil formation accounts for about 50 percent, and contributions of other services like recreation and nutrient cycling, are less than 10 percent each. The cost of climate regulation and habitat for wildlife are about 6 percent each.

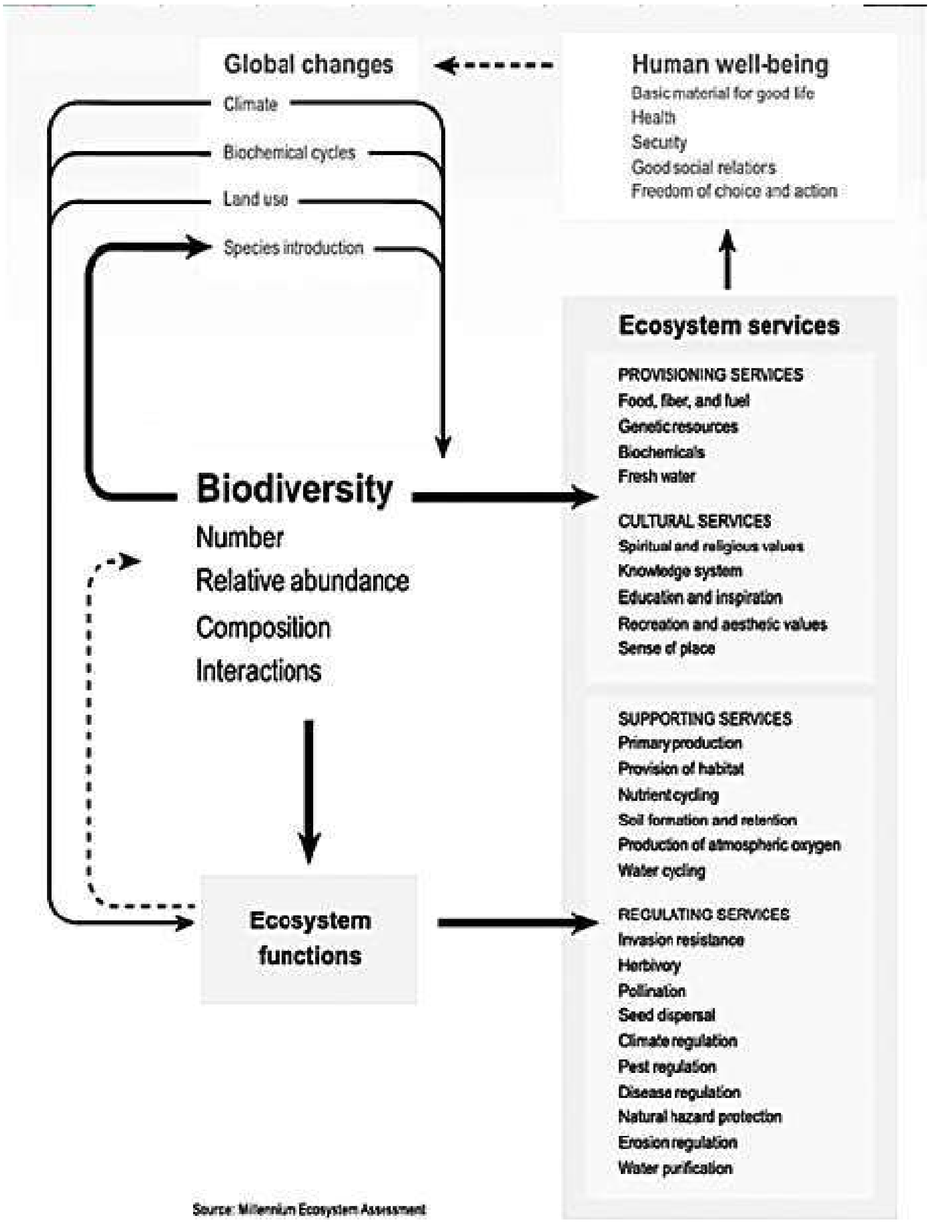

Figure 2.16: Different stages of Xerosere succession

Ecosystem services are the many and varied benefits that people obtain from ecosystems. In 2005, the Millennium Ecosystem Assessment identified and categorised ecosystems and their resulting services, identified the links between these services and human societies, and the direct and indirect drivers and feedback loops. The Millennium Ecosystem Assessment framework identified ecosystem services within four categories:

- **Provisioning Services:** These are the tangible goods that ecosystems provide to humans, directly supporting their livelihoods and well-being, such as food, fresh water, fibre, and raw materials. India's ecological diversity encompasses a range of ecosystems. For instance, the forest ecosystem offers valuable resources like timber, nontimber forest products, and medicinal plants. Additionally, agricultural systems contribute crops, livestock, and fisheries as provisioning services. However, these essential services face growing threats from factors such as deforestation, pollution, and climate change. Sustainable management practices, conservation efforts, and policy interventions are crucial to safeguarding these services and ensuring their continued availability for future generations in India.
- **Regulating Services:** Ecosystems help regulate natural processes, such as climate, water purification, and disease control. Wetlands, for example, regulate water flow and quality, reducing the impacts of floods and acting as natural water filters. Specifically, in India, a riverain country, wetland provides a broad-spectrum service including flood control, maintaining groundwater balance as well as purification of water along with maintaining biodiversity.
- **Cultural Services:** Ecosystems have immense cultural and recreational value, offering opportunities for spiritual, aesthetic, and recreational experiences. In India, Sacred sites, rituals, and festivals often revolve around natural elements, reflecting a profound cultural connection. Biodiversity-rich landscapes like forests and rivers hold spiritual significance and offer peaceful and intellectual spaces for meditation and moments of deep reflection. Preserving these services is crucial, as they nurture cultural identity, promote overall well-being, and contribute to sustainable development in India.
- **Supporting Services:** These services are fundamental to the functioning of ecosystems but are often less visible. These services include functions like nutrient cycling, soil formation, water purification, and pollination. In India, where agriculture is a cornerstone of the economy, these services are particularly crucial for maintaining productive farmland, ensuring water quality, and supporting biodiversity. However, factors like deforestation, pollution, and climate change are threatening these services, necessitating comprehensive conservation and management efforts to safeguard India's ecosystems and the benefits they provide.

Now the question is why these provided services were needed and important to human civilization. Ecosystem services are essential for maintaining human well-being and the functioning of economies. Their significance is multifold:

- **Sustenance of Life:** Provisioning services, for instance food and water, are crucial for human survival. In India, diverse ecosystems contribute to the diets of millions, offering both subsistence and economic livelihoods.
- **Climate Regulation:** Ecosystems are essential for regulating the global climate by absorbing carbon dioxide and emitting oxygen. In India, the forests, grasslands, and wetlands serve as important carbon sinks that help to reduce the impact of climate change.
- **Natural Hazard Mitigation:** Communities are safeguarded from natural disasters through regulating services, such as flood and erosion control. Along India's beaches, mangroves and coastal vegetation function as a natural defence system against storm surges.
- **Cultural and Spiritual Well-being:** Ecosystems hold immense cultural value, serving as spaces for leisure, inspiration, and traditional customs. India's rich cultural heritage is intertwined with sacred sites and natural landscapes.

2.10 Summary

- The components of the ecosystem are seen to function as a unit when you consider the following aspects Productivity; Decomposition; Energy flow; and Nutrient cycling.
- Gross primary productivity of an ecosystem is the rate of production of organic matter during photosynthesis. Net primary productivity is the available biomass for the consumption to heterotrophs.
- Food chain is a linear sequence of organisms which starts from producer organisms and ends with decomposer species. Food web is a connection of multiple food chains.
- The energy flow takes place via the food chain and food web. Total energy decrease on every hierarchical level of ecosystem.
- Ecological succession is the gradual process by which ecosystems change and develop over time. One community replace by another until reaches a climax community.
- Habitat of a species is where it lives whereas niche is how a species interacts within an ecosystem.
- Ecosystem services are the direct and indirect contributions of ecosystems to human well-being.

2.11 Questions

MCQ type questions

1. Which one of the following has the largest population in a food chain?
   a) Producers
   b) Primary consumers
   c) Secondary consumers
   d) Decomposers
2. The 10% energy transfer law of food chain was given by
   a) Tansley
   b) Stanley
   c) Weismann
   d) Lindeman
3. If we completely remove the decomposers from an ecosystem, their functioning will be adversely affected because
   a) Herbivores will not receive solar energy
   b) Energy flow will be blocked
   c) The rate of decomposition will be very high
   d) Mineral movement will be blocked
4. Total primary production in an ecosystem is known as
   a) Gross final production
   b) Net primary production
   c) Gross primary production
   d) Photosynthesis
5. What is true about secondary succession
   a) follows primary succession
   b) takes place on a deforested site
   c) is similar to primary succession except that it has a relatively slower pace
   d) begins on a bare rock

Short answer type questions

1. What is gross primary productivity (GPP) and net primary productivity (NPP)?
2. What is hydrarch and xerarch succession?
3. Give an account of universal energy flow model in an ecosystem.
4. What is ecotone? Explain Edge effect.
5. Compare between habitat and niche.

Long answer type questions

1. Define and elaborate different types of ecosystem services.
2. What is primary and secondary succession? Write down characteristics of different types of climax community.
3. What is the different component of food chain? Write short note on different energy flow model in ecosystem.

2.12 Suggested Readings

1. Fundamentals of Ecology by Eugene Odum
2. Ecology: Theories & Applications by Peter Stiling
3. Elements of Ecology by Smith & Smith

Unit 3 ☐ Population and Human Ecology

Structure

3.1 Objective

- To learn about population dynamics and metapopulation.
- To understand the concept of carrying capacity and population equilibrium.
- To know the role and characteristics of r and k selected species.
- Discussion on human population dynamics

3.2 Introduction

Population ecology is the study of populations in relation to the environment, including environmental influences on population density and distribution, age structure, and population size. A population is a group of individuals of a single species that live in the same general area. Members of a population rely on the same resources, are influenced by similar environmental factors, and have a high likelihood of interacting with and breeding with one another. Populations can evolve through natural selection acting on heritable variations among individuals and changing the frequencies of various traits over time. Here in this chapter, we will discuss about different aspects of population ecology. Human population shows an exponential growth rate and directly or indirectly controls almost everything on earth. We will learn about it in from an ecological perspective.

3.3 Population dynamics

Ecologists use various terms when understanding and discussing populations of organisms. A population is all of one kind of species residing in a particular location. Population size represents the total number of individuals in a habitat. Population density refers to how many individuals reside in a particular area.

Population Size is represented by the letter N, and it equals the total number of individuals in a population. The larger a population is, the greater its generic variation and therefore its potential for long-term survival. Increased population size can, however, lead to other issues, such as overuse of resources leading to a population crash.

Population Density refers to the number of individuals in a particular area. A low-density area would have more organisms spread out. High-density areas would have more individuals living closer together, leading to greater resource competition.

Population Dispersion: Yields helpful information about how species interact with each other. Researchers can learn more about populations by studying the way they are distributed or dispersed. Population distribution describes how individuals of a species are spread out, whether they live in close proximity to each other or far apart, or clustered into groups. Uniform dispersion refers to organisms that live in a specific territory. One example would be penguins. Penguins live in territories, and within those territories the birds space themselves out relatively uniformly. Random dispersion refers to the spread of individuals such as wind-dispersed seeds, which fall randomly after traveling.

3.3.1 Factors controlling population growth

3.3.1.1 Density Dependent and Density Independent Mortality Factors

L. O. Howard and W. F. Fiske (1911) were the first to base a concept of population regulation on functional relationships. They proposed the terms "catastrophic" mortality factors and "facultative" mortality factors. Catastrophic Mortality Factors: factors destroying a constant proportion of a population regardless of the organisms being acted upon. Facultative Mortality Factors: factors destroying a percentage of a population which increases in destruction with increases in the population. They respond to population changes in host or prey density.

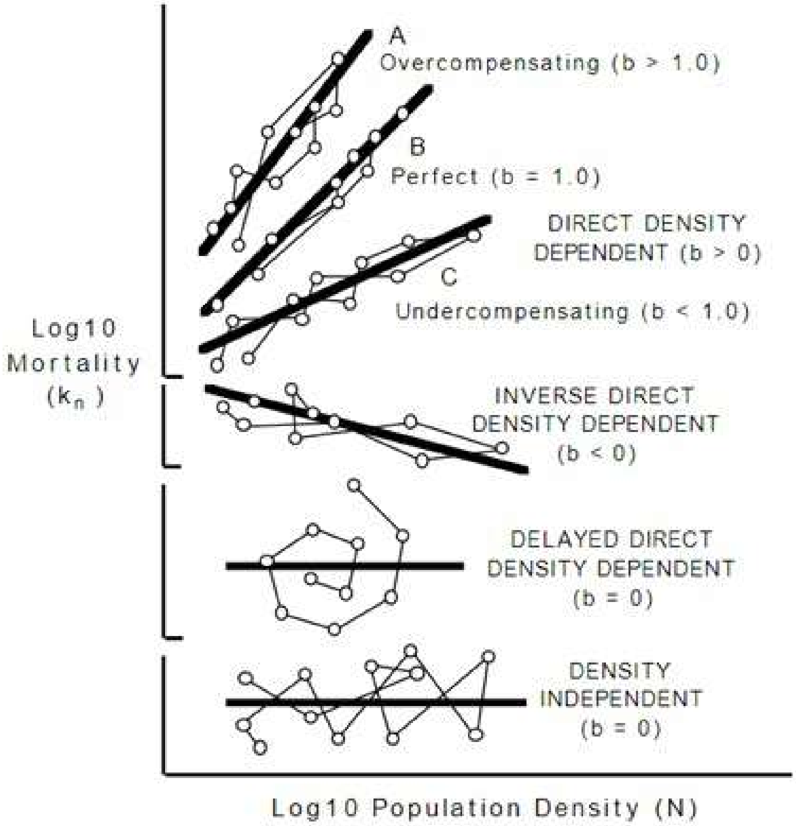

Figure 3.1: Different concepts of population regulation

H. S. Smith (1935) rephrased the terms into "density independent" and "density dependent" mortality factors. Density Independent (Catastrophic) Mortality Factors: those mortality factors that are a function of the non-living (abiotic) physical components of the environment. Density Dependent (Facultative) Mortality Factors: those mortality factors that are a function of biotic agents in the environment. Two types of competition are there i.e., intraspecific competition- competition among a species and interspecific competition- competition between 2 species.

3.3.1.2 Density dependent mortality factors

Reciprocal density dependent mortality: that mortality inflicted on a population by a biotic mortality factor whose own numbers are changed as a consequence (i.e., Vedalia beetle on cottony cushion scale). The different types of reciprocal density dependent mortality are:

a. Direct density dependence
   - overcompensating (b > 1.0) UNSTABLE
   - perfect (b = 1.0)
   - undercompensating (b < 1.0) STABLE

b. Inverse density dependence

c. Delayed density dependence (time lags)

Nonreciprocal density dependent mortality: that mortality inflicted on population by a biotic mortality factor whose own numbers are not changed as a consequence (i.e., solitary wasps competing for a limited number of nest hole sites).

3.3.1.3 Population Equilibrium and Fluctuations

Density dependence tends to push populations toward carrying capacity, K. Because the environment is variable, K is also variable and hence populations often don't rest at K too, which means density dependence doesn't always lead to a static equilibrium. Populations show ups and downs and always try to reach K; these ups and downs are referred as population fluctuations. Population fluctuations can be erratic (irruptive) or they can be periodic (cyclic). Erratic fluctuations are mostly due to variation in density-independent environmental factors that have a large, immediate impact on population size (e.g., fires, catastrophes). While cyclic fluctuations also known as oscillations are the result of time lags in responses of populations to their own density. Populations acquire "momentum" when high birth rates at low densities cause the populations to overshoot K, which causes very low survival and birth rates, consequently population falls below K, recovery occurs when birth rates again increase due to lowered density conditions. Population cycles result from time delays in the responses of birth and death rates to current environmental conditions which try to either under compensate or overcompensate for population size. The nature of the cycle depends on population's resilience. Resilience decides how fast the population will regain the equilibrium. Reproductive rate has very strong influence on resilient capacity of the population. Population fluctuations occur over many different time scales, ranging from millions of years on a geological time scale to years, seasons, or weeks, on a short time scale. Fluctuations at short time scales are important to be studied in population dynamics.

3.3.2 Types of fluctuations

a) Stable

population size fluctuates around carrying capacity slightly above and below and is characteristic of many species living under fairly constant environment, like conditions in

Tropical rainforest.

3.3.2.1 Irruptive

Population is normally fairly stable, it occasionally explodes (irrupts) to peak then crashes to level below carrying capacity. This occurs due to a factor (e.g., a resource availability) that temporarily increases carrying capacity. This is characteristic of short-lived, rapidly reproducing species.

3.3.2.2 Irregular

No apparent recurring pattern is observed an irregular, chaotic behaviour is seen in population size. The cause for this behaviour is poorly understood, some scientists attribute irregular behaviour to chaos in the system.

3.3.2.3 Cyclic

fluctuations occur over a regular time period, generally a multiple year cycle.

3.3.2.4 "Equilibrium Density"

characteristic level of abundance of populations in nature. Concept that developed from the basic premises of the Verhulst-Pearl logistic theory and Chapman's theories. It is theorized that densities of natural populations (though tending to fluctuate in time) attain characteristic levels of abundance, rather than increasing without limit or decreasing to extinction. Steady state is a more appropriate term than equilibrium. This classical view admits that species can deviate from equilibrium, and that the equilibrium state may be unstable in many cases, giving rise to population oscillations about it. Nonetheless, this view attaches fundamental significance to there being such an equilibrium state. It is oriented around equations such as the Lotka-Volterra equations, Leslie's predator-prey equations, the Rosenzweig-MacArthur model, Nicholson- Bailey model, and their many variations, all of which have well-defined mathematical equilibrium points.

3.4 Metapopulation

Populations of many species have a patchy distribution, the most prominent reason of which is spatial heterogeneity of the habitat. It results in many small population sets' establishments, where the sets are linked with different processes and such a group of interacting populations of the same species is known as Metapopulation. Individual population in such case is referred as a local population or deme population. The concept was proposed by an American scientist Richard Levins (1969, 1970). He defined metapopulation as a set of populations linked with significant flow of individuals. The concept was accepted by many scientists. Hanski and Simberloff (1997) modified the definition as Metapopulation is a set of local population within some larger area where typically migration from one local population to at least some other patch is possible. Metapopulations occur naturally as well as are created as a result of human actions. The population and Metapopulation can be differentiated as on the basis of heterogeneity in the area. A population occupies a patch with one set of microclimatic condition while metapopulation comprises many such populations invading the larger area in the local environment conditions.

3.4.1 Types of Metapopulations

a) Classical Metapopulation / Levins Metapopulation:

It has a large network of similar small patches with local dynamics occurring at a much faster rate than the metapopulation dynamics. This metapopulation indicates higher risk of extinction at all the local population sets.

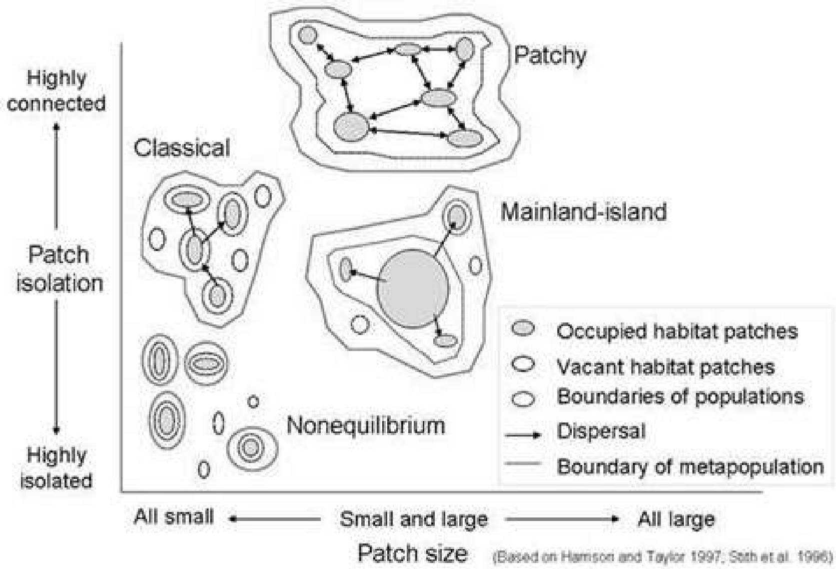

Figure 3.2: Different types of Metapopulation Models

3.4.1.1 Mainland- Island Metapopulation / Boorman- Levitt Metapopulation:

This defines a system of habitat patches located within dispersal distances from a very large habitat patch, the large patch behaves as mainland (source population) from where dispersal to small island patches (sink populations) is possible. Source populations produce excess individuals that emigrate to other patches and Sink populations are maintained by immigration into unfavourable habitats, in this type of system the local population never goes extinct and it is an ideal population type.

3.4.1.2 Source Sink Metapopulation/Patchy Metapopulation:

It is a system where sub populations have much low density and may show negative growth in absence of dispersal and positive growth in presence of dispersal. Thus, every patch can function as Source as well as Sink.

3.4.1.3 Non- Equilibrium Metapopulation:

It is a system in which long term extinction rates exceed colonization rates or vice - versa. Populations are isolated and communication among patches is highly diffused, such metapopulations at high risk of extinction.

3.4.2 Metapopulation Dynamic

As in population, birth and death rates play important role in population growth, the three key processes which are important in Metapopulation dynamics are colonization, extinction, and turnover. Metapopulations are characterized by repeated extinctions and colonization. Extinction occurs in already occupied area while Colonization is possible in already occupied area and in vacant area which is suitable for the species growth.

Extinction: It is the disappearance of a species. It starts with thinning of population and then ultimate disappearance of the population. The causal processes for extinction are high mortality rate, low natality rate poor immigration, high emigration and low resilience to fluctuation and the distribution of species. The response of the species varies, the threat is more too rare and endemic species as compare to wide spread species. In metapopulation dynamics extinction is usually a constant risk at occupied patches.

Colonization: It is the appearance and establishment of a species at a patch. It depends on number of occupied and vacant patches. Colonization is affected by the proximity of the mainland and process of migration / dispersal.

Turnover: Turnover is related to extermination of local populations and establishment of new local populations in vacant habitat patches by nomad from existing local populations. It is process of reappearance.

3.5 Concept of carrying capacity

Carrying capacity is typically defined as the maximum population size that can be supported indefinitely by a given environment. The simplicity of this definition belies the complexity of the concept and its application. There are at least four closely related but nonetheless different uses of the term in basic ecology, and at least half a dozen additional definitions in applied ecology.

Carrying capacity is most often presented in ecology textbooks as the constant K in the logistic population growth equation, derived and named by Pierre Verhulst in 1838, and rediscovered and published independently by Raymond Pearl and Lowell Reed in 1920.

Of historical interest is that neither Verhulst nor Pearl and Reed used 'carrying capacity' to describe what they called the maximum population, upper limit, or asymptote of the logistic curve. In reality, the term 'carrying capacity' first appeared in range management literature of the late 1890s, quite independent of the development of theoretical ecology (see below). Carrying capacity was not explicitly associated with K of the logistic model until Eugene Odum published his classic textbook Fundamentals of Ecology in 1953.

The second use in basic ecology is broader than the logistic model and simply defines carrying capacity as the equilibrial population size or density where the birth rate equals the death rate due to directly density dependent processes.

The third and even more general definition is that of a long-term average population size that is stable through time. In this case, the birth and death rates are not always equal, and there may be both immigration and emigration (unlike the logistic equation), yet despite

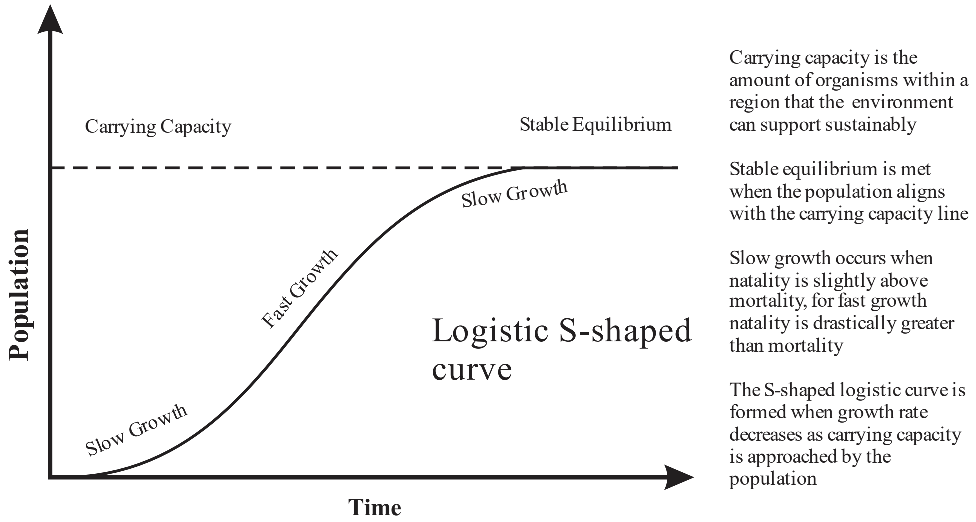

Figure 3.3: Carrying Capacity

population fluctuations, the long-term population trajectory through time has a slope of zero.

The fourth use is to define carrying capacity in terms of Justus Liebig's 1855 law of the minimum that population size is constrained by whatever resource is in the shortest supply. This concept is particularly difficult to apply to natural populations due to its simplifying assumptions of independent limiting factors and population size being directly proportional to whatever factor is most limiting. Moreover, unlike the other three definitions, the law of the minimum does not necessarily imply population regulation.

Note that none of these definitions from basic ecology explicitly acknowledges the fact that the population size of any species is affected by interactions with other species, including predators, parasites, diseases, competitors, mutualists, etc. Given that the biotic environment afforded by all other species in the ecosystem typically varies, as does the abiotic environment, the notion of carrying capacity as a fixed population size or density is highly unrealistic. Additionally, these definitions of carrying capacity ignore evolutionary change in species that may also affect population size within any particular environment.

3.6 Mechanism of Population Equilibrium

The concept of population equilibrium was relevant in different context, one being its use for the mathematical description of predator-prey oscillations. Here the work of Lotka and Volterra inspired biologists because it provided opportunity to calculate the nature of equilibria in a community. The mechanism that was attached to the concept of equilibrium at this stage in community ecology was rebounding behaviour. The epistemic value was stability and the concept of equilibrium provided a way to explain the stability of predator-prey interactions. Regarding equilibrium in populations, the epistemic value was control of population size (N), which meant that N limited the growth rate (r). The logistic curve provided a mathematical justification for this through its modelling of the relationship between r and N. Assumptions that were inherent in the logistic curve were discussed among population ecologists, especially concerning the role of the variable r. Andrewartha and Birch, for example, emphasized the importance of discriminating between an innate r and an actual r. They rejected the epistemic value of control and thus rejected the concept of equilibrium as well. According to their metaphysical framework, the environment determined population size, which was reflected by their methodology of life-table analysis. This assumed exponential growth of populations with a stable age distribution, density-dependence not being the primary concern. Both elements made them reject the logistic curve with its simplistic assumption of linear density-dependence. A certain ambiguity can be found in their work because they claimed on one hand that a stable age distribution could rarely be found in nature. On the other hand, they used it as a theoretical assumption to be able to compare different populations based on their intrinsic r.

Despite Andrewartha and Birch's critique, the concept of density-dependent regulation leading to an equilibrium state is still in use. Because the logistic provided a simple model for population control it became very influential and served as an inspiration to ecological research. Ecologists, however, have modified assumptions made in the logistic curve. The logistic and the predator-prey equations were discussed in this chapter as a form of mathematical justification of the equilibrium concept. The equilibrium state, defined as setting the growth rate to zero and subsequently solving the equations, provided important insight into the dynamics of predator and prey. These relations could also be described in graphical form, which was done by ecologists to summarize the behaviour of the two populations. Regarding population growth, the logistic curve was influential in illustrating a certain growth pattern of populations and then providing the mathematical description of it. Both elements were important for the justification of the concept of equilibrium. Even if it was later discovered that the logistic was not clear on the exact form of density-dependence, the mathematical justification of equilibrium concept was successful. However, this justification did not follow established rules. Volterra's laws, for example, were not laws for population dynamics but rather descriptions of what would happen if the laws were correct, although he himself initially was not aware of this. Other biologists, however, were less tdng of his predictions because some of the assumptions involved did not seem to be realistic (Israel 1993). Mathematical justification took many forms and was much debated. Thus, it is not useful to refer to a certain context of discovery which can be separated from a context of justification because there is no evidence for any a priori rules for justifications of the concept of equilibrium. Volterra's and Lotka's approach to mathematical justification used deterministic methods. This caused criticism by Andrewartha and Birch, and 'equilibrium' was increasingly discussed in probabilistic terms following the 1950s when it was suggested that statistical thinking be incorporated into ecology.

3.7 Concept of "r" and "k" species

An organism's Darwinian fitness is calculated as the number of offspring it leaves behind that, themselves, survive to reproduce. In evolutionary terms, it is of no consequence if an organism is a fine, fully mature, physical specimen, or the dominant member of the herd, or even that an individual produces a lot of young but none of them survive. In the relay race of evolution, getting as many copies of your genes into the next generation as possible is the only goal. As you might imagine, there are many ways to be reproductively successful. One way is to become the dominant animal in a pack, and to monopolize mating opportunities, but another way is to be submissive and sneaky, mating with others when the dominant animal is not around to stop you. There are no moral judgements. It's just biology. Now imagine that you're an animal faced with the following choice: given limited resources, should you put them all into producing one or a few offspring, and protect them with great ferocity, or should you put a small amount of effort into a much larger number of offspring, and let them each take their chances? Should you measure out your reproductive effort over many seasons, or save it all up for a one-time mating frenzy as soon as you're able? These trade-offs relate to the r/K selection theory of life history strategies.

3.7.1 r-selection:

On one extreme are the species that are highly r-selected. r is for reproduction. Such a species puts only a small investment of resources into each offspring, but produces many such low effort babies. Such species are also generally not very invested in protecting or rearing these young. Often, the eggs are fertilized and then dispersed. The benefit of this strategy is that if resources are limited or unpredictable, you can still produce some young. However, each of these young has a high probability of mortality, and does not benefit from the protection or nurturing of a caring parent or parents. r-selected babies grow rapidly, and tend to be found in less competitive, low-quality environments. Although not always the case, r-selection is more common among smaller animals with shorter lifespans and, frequently, no overlapping generations, such as fish or insects. The young tend to be precocial (rapidly maturing) and develop early independence.

3.7.2 k-selection:

On the other extreme are species that are highly K-selected. K refers to the carrying capacity, and means that the babies are entering a competitive world, in a population at or near it carrying capacity. K-selected reproductive strategies tend towards heavy investment in each offspring, are more common in long-lived organisms, with a longer period of maturation to adulthood, heavy parental care and nurturing, often a period of teaching the young, and with fierce protection of the babies by the parents. K-selected species produce offspring that each have a higher probability of survival to maturity. Although not always the case, K-selection is more common in larger animals, like whales or elephants, with longer lifespans and overlapping generations. The young tend to be altricial (immature, requiring extensive care). You can see r- and K-selected strategies clearly by looking at different organisms within a phylogenetic group, such as the mammals. For example, elephants are highly K-selected, whereas mice are much more r-selected. Among the fishes, most, like the salmon, are r-selected. Some species will even inadvertently eat their own young if they are not immediately dispersed, but a few species, such as the cichlids, are K selected and provide prolonged care and protection of the eggs and hatchlings. Even among humans, there are a range of strategies toward one or the other extreme. In one family, with ten children, for example, there is no way for the parents to put as much time, energy, or resources into all of them as could be done with an only child. But, with humans, it gets complicated by the fact that others, including siblings, grandparents, blood-relatives, and the larger community all play a role in the nurturing and education of children. Even plants are capable of r- and K-selected reproductive strategies. Wind pollinated species produce much more pollen that insect pollinated ones, for example, because the pollen has to be carried at random by the wind to a receptive female flower. Eggs too, can be r- or K-selected. The amount of nutrient energy placed in an egg gives it a lesser or greater ability to survive in adverse conditions. One can even compare the reproductive stragies of males and females within a species, when sperm and egg represent different levels of energy investment. Often sperm are resource poor, and produced in large quantities, while eggs are resource rich and produced in smaller numbers. This can lead to differences in behaviour between the sexes, often with the result that the female is the choosier sex when it comes to reproduction. This trend is further extended if the female also carries the young (in the case of internal fertilization) or has a greater role in parental care once the babies are born. There are some interesting exceptions that illustrate the rule. Male seahorses are the choosier sex, and they are the ones that incubate the young. In a small fish called the stickleback, the male is also choosier, it is believed, because the female lays her eggs in a nest he constructed and then leaves. The male guards the nest and tends the young for an extended period. It should be noted that r- and K-selection are the extremes at both ends of a continuum and that most species fall somewhere in between.

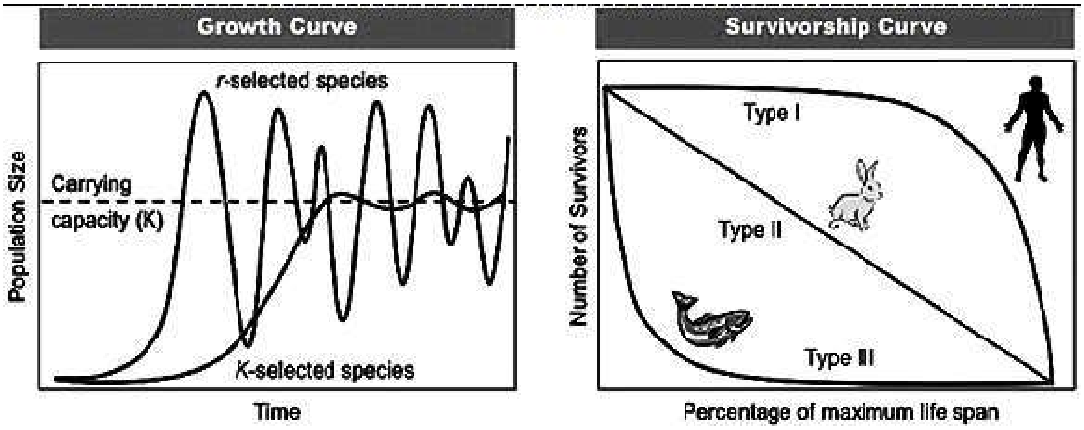

Figure 3.4: Type I survivorship curve is most K-selected, Type III survivorship curve is most r-selected and Type II fall in somewhere in between. Example of Type I curve is most large mammals like elephant, Type III is mouse, insects, bacteria etc and Type II shown by some bird species.

Table 3.1: Comparisons between 'r' and 'k' selection

Characteristics	r-Selected	k-Selected
Number of offspring	High	low
Parental care	Low	high
Reproductive maturity	Early	late
Size of offspring	Small	large
Independence at birth	Early	late
Ability to learn	Low	high
Lifespan	Short	long
Early mortality	High	low
Acclimatization ability	Low	high

3.7.3 Keystone species concept

The keystone species concept has proved both promising and elusive in theoretical and applied ecology. The term has its origins in Robert Paine's studies of rocky shore communities in California. When the top predator (a starfish) was removed the species assemblage collapsed, prompting the architectural analogy with the keystone of an arch. By definition keystone species are those whose effect is large, and disproportionately large relative to their abundance. They include organisms that (i) control potential dominants, (ii) provide critical resources, (iii) act as mutualists, and (iv) modify the environment. Identifying keystone species can be problematic. Approaches used include experimental manipulations, comparative studies, natural history observations, and natural experiments', but no robust methodologies have been developed. Our inability to monitor and manage all aspects of biodiversity has led to the development of paradigms that focus on either single-species (e.g., indicators, umbrellas, or flagships) or whole ecosystems (ecological processes and habitats). Not surprisingly, both have their advocates and detractors. The keystone species concept, which retains a species focus while avoiding the need to examine every species, and emphasises processes that directly (e.g., predation, competition) rather than indirectly (e.g., nutrient cycling) control biodiversity, may allow managers to combine the best features of both these paradigms. By itself however, the concept is unlikely to provide a panacea for biodiversity managers.

3.8 Human Population

After centuries of very slow and uneven growth, the world population reached one billion in 1800. The modern expansion of human numbers started then, rising at a slow but more steady pace over the next 150 years to 2.5 billion in 1950. During the second half of the twentieth century, however, growth rates accelerated to historically unprecedented levels. As a result, world population more than doubled to 6.5 billion in 2005 (United Nations 1962, 1973, 2007). This population expansion is expected to continue for several more decades before peaking near 10 billion later in the twenty-first century. Around 2070, the world's population will be 10 times larger than in 1800. The recent period of very rapid demographic change in most countries around the world is characteristic of the central phases of a secular process called the demographic transition. Over the course of this transition, declines in birth rates followed by declines in death rates bring about an era of rapid population growth. This transition usually accompanies the development process that transforms an agricultural society into an industrial one. Before the transition's onset, population growth (which equals the difference between the birth and death rate in the absence of migration) is near zero as high death rates more or less offset the high birth rates typical of agrarian societies before the industrial revolution. Population growth is again near zero after the completion of the transition as birth and death rates both reach low levels in the most developed societies. During the intervening transition period, rapid demographic change occurs, characterized by two distinct phases. During the first phase, the population growth rate rises as the death rate declines while the birth rate remains high. In the second phase, the growth rate declines (but remains positive) due to a decline in the birth rate. The entire transition typically takes more than a century to complete and ends with a much larger population size. The plot of world population size over time in shows the typical S-shaped pattern of estimated and projected population size over the course of the transition. Population growth accelerated for most of the twentieth century reaching the transition's midpoint in the 1980s and has recently begun to decelerate slightly. Today, we are still on the steepest part of this growth curve with additions to world population exceeding 75 million per year between 1971 and 2016. Contemporary societies are at very different stages of their demographic transitions. Key trends in population size, fertility and mortality during these transitions are summarized below. The focus is on the century from 1950 to 2050, covering the period of most rapid global demographic change. The main source of data is the United Nation's 2006 world population assessment, which provides estimates for 1950-2005 and projections from 2005 to 2050 (United Nations 2007).

3.8.1 Future Population Trends

The projected rise in world population to 9.2 billion in 2050 represents an increase of 2.7 billion over the 2005 population of 6.5 billion. Nearly all this future growth will occur in the 'South'-i.e., Africa, Asia (excluding Japan, Australia and New Zealand), and Latin America-where population size is projected to increase from 5.3 to 7.9 billion between 2005 and 2050. In contrast, in the 'North' (Europe, Northern America, Japan and Australia/ New Zealand), population size is forecast to remain virtually stable, growing slightly from 1.22 to 1.25 billion between 2005 and 2050. The difference in trends between these two world regions reflects the later stage of the transition in the North compared with the South. The global demographic transition began in the nineteenth century in the now economically developed parts of the world (the North) with declines in death rates. Large reductions in birth rates followed in the early part of the twentieth century. These transitions are now more or less complete. But trends for the two principal regions in the North are expected to diverge between 2005 and 2050: an increase from 0.33 to 0.45 billion in Northern America, and a decline from 0.73 to 0.66 billion in Europe. In fact, several countries in Europe (e.g., Russia) and East Asia (e.g., Japan) face significant population declines as birth rates have fallen below death rates. The demographic transitions in Africa, Asia and Latin America started later and are still underway. In 2005, Asia had a population of 3.94 billion, more than half of the world total, and its population is expected to grow by 34 per cent to 5.27 billion by 2050. Africa, with 0.92 billion inhabitants in 2005, is likely to experience by far the most rapid relative expansion, more than doubling to 2.0 billion by 2050. Latin America, with 0.56 billion in 2005, is the smallest of the regions of the South; its projected growth trend is similar to that of Asia. It may seem surprising that population growth continues at a rapid pace in sub-Saharan Africa, where the AIDS epidemic is most severe. This epidemic has indeed caused many deaths, but population growth continues because the epidemic is no longer expanding and the birth rate is expected to remain higher than the elevated death rate in the future (UNAIDS 2007; Bongaarts et al. 2008). The epidemic's demographic impact can be assessed by comparing the standard UN population projection (which includes the epidemic's effect) with a separate hypothetical projection in which AIDS mortality is excluded (United Nations 2007). In sub-Saharan Africa, the former projects a 2050 population of 1.76 billion and the latter a population of 1.95 billion. The difference of 0.2 billion in 2050 between these projections with and without the epidemic is due to deaths from AIDS as well as the absence of the descendants from people who died from AIDS. According to these projections, the population of sub-Saharan Africa will grow by one billion between 2005 and 2050 despite the substantial impact of the AIDS epidemic. In fact, no country is expected to see a decline in its population size between 2005 and 2050 due to high AIDS mortality. Most populations in sub-Saharan Africa will more than double in size, several will triple and Niger is expected to quadruple by 2050 (United Nations 2007). Transitions in the developing world have generally produced more rapid population growth rates in mid-transition than historically observed in the North. In some developing countries (e.g., Kenya and Uganda), peak growth rates approached four percent per year in recent decades (implying a doubling of population size in two decades), levels that were very rarely observed in developed countries except with massive immigration. Two factors account for this very rapid expansion of population in these still largely traditional societies: the spread of medical technology (e.g., immunization, antibiotics) after World War II, which led to extremely rapid declines in death rates, and a lag in declines in birth rates. In 2005, China (1.31 billion) and India (1.13 billion) were by far the largest countries, together accounting for nearly half the South's total. The top 10 include six Asian countries and only one country each in Latin America and Africa. By 2050, the ranking is expected to have shifted substantially, with India's population exceeding China's, and with Ethiopia and DR Congo rising to the top 10, replacing Japan and the Russian Federation. To simplify the presentation of results, all projections discussed in this study are taken from the medium variant of the UN projections (United Nations 2007). The UN has a good record of making relatively accurate projections (National Research Council 2000), but the future is of course uncertain and actual population trends over the next half century will likely diverge to some extent from current projections. The UN makes an effort to capture this uncertainty by publishing separate high and low projections. For the world, the high and low variants reach 7.8 and 10.8 billion, respectively, in 2050, indicating a rather wide range of possible outcomes.

3.8.2 Drivers of Population Growth:

The world's population increases every year because the global birth rate exceeds the death rate. For example, in 2000-2005 population size increased at a rate of 1.17 per cent per year, which equals the difference between a birth rate of 2.03 per cent and a death rate of 0.86 per cent. At the country level, population growth is also affected by migration, but for the regional aggregates of population used in this analysis, migration is usually a minor factor, and it will therefore not be discussed in detail. The annual birth and death rates of populations are in turn primarily determined by levels of fertility and mortality experienced by individuals. The most widely used fertility indicator is the total fertility rate (TFR), which equals the number of births a woman would have by the end of her reproductive years if she experienced the age-specific fertility rates prevailing in a given year. Mortality is often measured by the life expectancy (LE) at birth, which equals the average number of years a new born would live if subjected to age-specific mortality rates observed in a given year.

a) Fertility

The UN's past estimates and future projections of fertility levels by region for the period 1950-2050 are presented in figure 2. In the 1950s, the TFR in the South was high and virtually stable at around six births per woman on average. This high level of fertility reflects a near absence of birth control, a condition that has prevailed for centuries before the middle of the twentieth century. In the late 1960s, a rapid decline in fertility started nearly simultaneously in Asia and Latin America. In contrast, Africa has experienced only limited reproductive change. As a result of these divergent past trends, fertility levels in 2000-2005 differed widely among regions from as high as 5 births per woman (bpw) in Africa, to 2.5 bpw in Asia and Latin America. Average fertility in the North was already low in the early 1950s and has since declined to 2.0 bpw in Northern America and to 1.4 bpw in Europe. The decline in the average fertility in the South from 6 to 3 bpw over the past half century has been very rapid by historical standards. This reproductive revolution is mainly due to two factors. First, desired family size of parents has declined as the cost of children rose and child survival increased. Second, government intervention played a key role. In China this took the form of a coercive and unpopular one-child policy, but most other countries implemented voluntary family planning programmes. The aim of these programmes is to provide information about and access to contraceptives at subsidized prices so that women who want to limit their childbearing can more readily do so. UN projections for the South assume that the TFR will eventually reach and then fall slightly below the so-called 'replacement' level in all regions. Replacement fertility is just above 2 bpw and it represents the level at which each generation just replaces the previous one, thus leading to zero population growth (in the absence of mortality change and migration). Below-replacement fertility produces, in the long run, population decline. Africa is assumed to be on a much slower trajectory towards replacement fertility because of its lower level of socio-economic development. High fertility therefore remains a key cause of future population growth in this region. In contrast, the already low fertility of the North is expected to remain below replacement and is no longer driving population growth.

b) Economic Development

- **Industrialization:** Economic development and industrialization often lead to improved living standards, increased access to education, and better healthcare. As these factors improve, fertility rates may initially rise due to improved child survival rates and later decline as education and career opportunities for women increase, leading to lower birth rates.
- **Urbanization:** The shift from rural to urban living is associated with changes in lifestyle, education, and employment opportunities. Urban areas typically have lower fertility rates than rural areas, which can contribute to slowing population growth.

c) Education and Empowerment

- **Female Education:** Education, particularly for women, plays a crucial role in reducing birth rates. Educated women often choose to have fewer children and may delay childbirth to pursue career and personal goals.
- **Empowerment of Women:** Women's empowerment, including access to reproductive rights and family planning, can significantly impact population growth. When women have the autonomy to make decisions about their reproductive health, it often leads to smaller family sizes.

d) Cultural and Religious Factors

- **Cultural Practices:** Cultural norms and practices can influence attitudes toward family size and contraceptive use. In some cultures, large families are valued, while in others, smaller families may be preferred.
- **Religious Beliefs:** Religious beliefs can also shape attitudes toward family planning. While some religions may encourage large families, others may promote responsible parenthood and family planning.

e) Government Policies

- **Family Planning Programs:** Government policies that promote family planning, provide access to contraceptives, and educate the public about the benefits of smaller family sizes can have a significant impact on population growth.
- **Social and Economic Policies:** Policies that address poverty, unemployment, and social inequalities can indirectly influence population growth by improving overall living conditions and providing individuals with more opportunities for education and employment.

3.8.2.1 Mortality and life expectancy

Mortality levels have also changed rapidly over the past several decades. The South experienced exceptional improvements in Life Expectancy (LE) from an average of 41 years in 1950-1955 to 64 years in 2000-2005. By the early 2000, Latin America reached mortality levels similar to those prevailing in the North in the 1970s, and Asia was just a few years behind. Africa experienced the highest mortality and improvements in LE stalled in the 1990s due to the AID Sepidemic. As a result, Africa's LE, at 52 years in 2000-2005, was still substantially below that of Asia (68) and Latin America (72). As expected, Europe and Northern America already achieved relatively low levels of mortality by 1950, but they have nevertheless seen signi?cant further improvements since then. Europe's LE (74) is now lower than North America's (78) because of a rise in mortality in Eastern Europe after the break-up of the Soviet Union. Projections of future LEs by the UN assume continued improvements over time in all regions. The North is expected to reach 82 years in 2050 despite the increasing dif?culty in achieving increments as countries reach ever higher levels of LE. Asia and Latin America are expected to continue to close the gap with the North, and Africa will continue to lag, in part because the continent remains affected by the AIDS epidemic. It should be noted that the assumptions made by the UN about future trends in fertility and mortality are not based on a firm theoretical basis. Instead, the UN relies on empirical regularities in past trends in countries that have completed their transitions, mostly in the North, where fertility declined to approximately the replacement level, and increases in LE became smaller over time. This is a plausible approach that unfortunately leaves room for potential inaccuracies in projection results.

3.8.2.2 The age-dependency ratio

A changing age distribution has significant social and economic consequences, e.g., for the allocation of education, healthcare, and social security resources to the young and old. Assessments of this impact often rely on the so-called age-dependency ratio (DR) that summarizes key changes in the age structure. The DR at a given point in time equals the ratio of population aged below 15 and over 65 to the population of age 15-64. This ratio aims to measure how many 'dependents' there are for each person in the 'productive' age group. Obviously, not every person below 15 and over 65 is a dependent and not every person between ages 15 and 65 is productive. Despite its crudeness, this indicator is widely used to document broad trends in the age composition. Over the course of a demographic transition, the DR shows a characteristic pattern of change. This pattern as observed in the South from 1950 to 2005 and projected from 2005 to 2050. Early in the transition, the DR typically first rises slightly as improvements in survival chances of children raise the number of young people. Next, the DR falls sharply as declines in fertility reduce the proportion of the population under age 15. This decline has important economic consequences because it creates a so-called 'demographic dividend', which boosts economic growth by increasing the size of the labour force relative to dependents and by stimulating savings (Birdsall et al. 2001). Finally, at the end of the transition, the DR increases again as the proportion of the population over age 65 rises. From 1950 to 2010 it showed a slight decline, but after 2010 it rises steeply as very low fertility and increasing longevity increases the proportion 65+. This ageing of the North poses serious challenges to support systems for the elderly (OECD 1998, 2001).

3.8.2.3 Population momentum

At the end of the demographic transition natural population growth reaches zero once three conditions are met:

i) Fertility levels-off at the replacement level of about 2.1 bpw (more precisely, the net reproduction rate should be 1). If fertility remains above replacement, population growth continues.

ii) Mortality stops declining. In practice, this is not likely to happen because improvements in medical technology and healthcare as well as changes in lifestyles, etc. will probably ensure continued increases in LE.

iii) The age structure has adjusted to the post-transitional levels of fertility and mortality.

The adjustment of the age structure at the end of the transition takes many decades to complete. A key implication of this slow adjustment process is that population growth continues for many years after replacement fertility is reached if, as is often the case, the population is still relatively young when fertility reaches the replacement level. The tendency of population size to increase after a two-child family size has been reached is referred to as population momentum; it is the consequence of a young population age structure ('young' is de?ned relative to the age structure in the current life table) (Bongaarts & Bulatao 1999). The population momentum inherent in the age structure of a particular population at a given point in time can be estimated with a hypothetical population projection in which future fertility is set instantly to the replacement level, mortality is held constant and migration is set to zero. Since such a variant is not directly available from UN projections, it will not be presented here. However, the UN does provide 'instant replacement' projections in which mortality and migration trends are the same as in the standard projection. This projection gives an approximation of the combined effect on future growth of population momentum and declining mortality in the South because the role of migration is small. The difference between this hypothetical projection and the standard medium UN projection is a measure of the impact of high fertility on future population growth. Three results are noteworthy. First, the two projections differ most in Africa (+117% versus +50%) which is as expected because fertility is still very high in this region. Second, in all regions of the South outside China, populations would be expected to rise by 50 per cent (62% in West Asia) if fertility were set to replacement in 2005. This implies that momentum and declining mortality are responsible for nearly half of the projected future population growth in Africa and for the large majority of growth in Latin America, and South and West Asia. Third, in East Asia and in Latin America the replacement projection exceeds the medium UN projection. This ?nding is explained by the fact that fertility in these regions is assumed to average below the replacement level over the next half century.

Conclusion

The world and most countries are going through a period of unprecedentedly rapid demographic change. The most obvious example of this change is the huge expansion of human numbers: four billion have been added since 1950. Other demographic processes are also experiencing extraordinary change: women are having fewer births and LEs have risen to new highs. Past trends in fertility and/or mortality have led to very young populations in high fertility countries in the South and to increasingly older populations in the North. Still other important demographic changes which were not reviewed here include rapid urbanization, international migration, and changes in family and household structure.

Global population growth will continue for decades, reaching around 9.2 billion in 2050 and peaking still higher later in the century. The demographic drivers of this growth are high fertility in parts of the South, as well as declining mortality and momentum. This large expansion in human numbers and of the accompanying changes in the age structure will have multiple consequences for society, the economy, and the environment as discussed in the subsequent chapters in this issue.

3.9 Summary

- Relation between mortality and population density is the key player behind population growth pattern.
- The carrying capacity of an environment is the maximum population size of a biological species that can be sustained by that specific environment.
- A metapopulation is a set of local populations within some larger area, where migration from one population to another is possible.
- r and K selection are concepts in ecology used to describe life history traits in the fluctuation of a population or population dynamics. They show three types of survivorship curve.
- Keystone species are those which have an extremely high impact on a particular ecosystem relative to its population.
- Global human population growth is around 75 million annually due to higher birth rate of 2.03% whereas death rate of 0.86%. Total population will reach 9.2 billion in 2050 as per future projection.

3.10 Self-Assessment Questions

MCQ type questions

1. The collection of individuals which belongs to the same species when live together

in a region is known as ____________

a) Keystone species

b) Community

c) Guild

d) Population

2. Which of the following survivorship curve is suitable for the organisms who breeds several times during the course of their life span?

a) Type IV

b) Type III

c) Type II

d) Type I

3. Human population growth curve is a

a) S shaped curve

b) J shaped curve

c) Parabola curve

d) Zig-zag curve

4. The carrying capacity of a population defined by

a) Mortality rate

b) Natality rate

c) Population growth rate

d) limiting resources

5. Exponential growth curve occurs when there is

a) a great environmental resistance

b) no environmental resistance

c) no biotic potential

d) a fixed carrying capacity

Short answer type questions

1. Write difference and characteristics of r and k selected species.
2. What is density dependent and inversely density dependent population growth control?

3. What is keystone species? Give one example.
4. What is Equilibrium Density in population growth?
5. Write about different types of population fluctuation.

Long answer type questions

1. Explain different types of survivorship curve in relation with r and k selected species.
2. Discuss about drivers of human population growth. Comment on its current trends.
3. Write short notes on different types of metapopulation. Explain metapopulation dynamics.

3.11 Suggested Readings

1. Fundamentals of Ecology by Eugene Odum
2. Ecology: Theories & Applications by Peter Stiling
3. Elements of Ecology by Smith & Smith
4. Ecology: Principles and Applications by JL Chapman and MJ Reiss
5. Ecology by Ricklefs & Miller

Unit 4 □ Biomes

Structure

4.1 Objective

- To learn about what is biome.
- Discuss on salient features and characteristics of different biomes.

4.2 Introduction

Biomes are both climatically and geographically defined. Biomes are regions of Earth that have similar climates and other abiotic (non-living) factors such as elevation, humidity, and soil type. The Biome of any biotic settlement depends on its abiotic resources. Biomes can be divided into types depending on climatic conditions and precipitation. No matter where they occur on the planet, biomes have similar types of vegetation and animal life, or ecological communities. In this chapter, we will study the major types of biomes around the world.

4.3 Biomes and biome types

A biome is a large ecological area or region that is characterized by its climate, soil type, and vegetation; the dominant plants and animals that live there. In another words biome is defined as the world's major communities, classified according to the predominant vegetation, and characterized by adaptations of organisms to that particular environment. A biome is determined mainly by its climate-like temperature and rainfall. Each biome has a different climate, which in turn affects the soil. There are five major categories of biomes on earth. In the five biomes, there are many sub-biomes. The climate and geography of a region determines what type of biome can exist in that region. The major types of biomes are; forest, grassland, tundra, desert and aquatic. In these, Forests are classified into tropical, temperate, and taiga; grasslands are divided into savanna and temperate grasslands; and the aquatic biome is split into freshwater, marine and brackish. Each biome consists of many ecosystems whose communities have adapted to the small differences in climate and the environment inside the biomes.

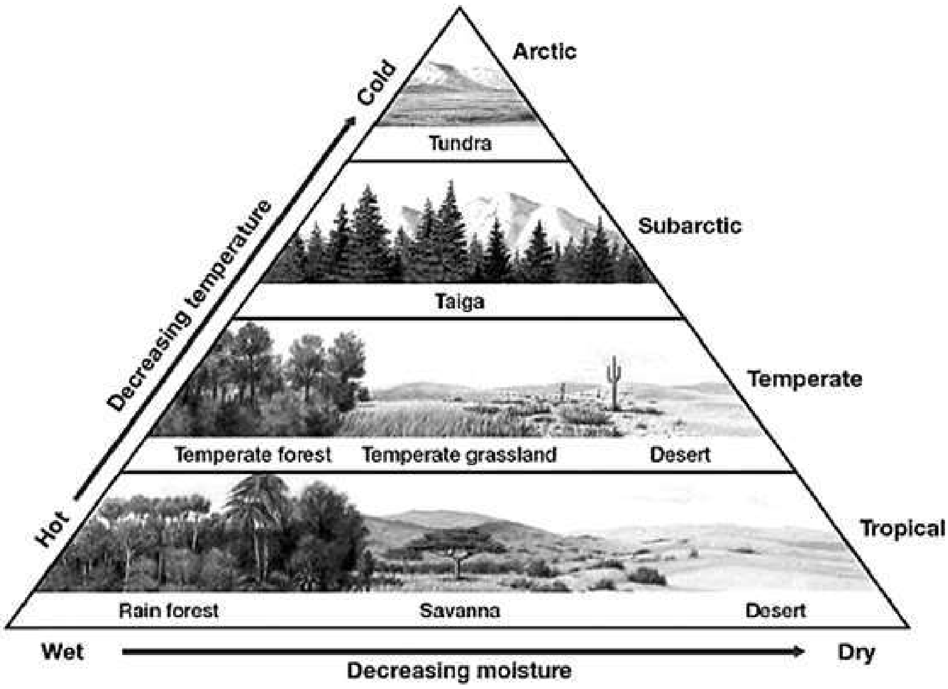

Figure 4.1: Biome pyramid

4.4 Characteristics of different biomes: forest, grassland, highland icy alpine biome, tundra, and desert

4.4.1 FOREST

A forest may be defined as a large uncultivated tract of land covered with trees of different species growing close together. The conditions such as temperature, ground moisture (rainfall), soil type and topography are responsible for the establishment of forest communities and their distribution. Forests occupy approximately one-third of Earth's land area. Forests are becoming major casualties of civilization as human populations have increased over the past several thousand years, bringing deforestation, pollution, and industrial usage problems to this important biome. The forest biomes can be classified according to the vegetation, climate, and latitude. There are three major types of forests classified according to distributional patterns of plants, world climate and latitude; Tropical, Temperate and Taiga.

4.4.1.1 TROPICAL FOREST

Earth's most complex land biome is tropical forest in terms of both structure and species diversity. Tropical forests are characterized by the greatest diversity of species. Tropical forests occur near the equator, tropical region, within the area bounded by latitudes 23.5 degrees N and 23.5 degrees S. There are two seasons - rainy and dry. More than ½ of the tropical forests have been already destroyed.

4.4.1.2 TROPICAL EVERGREEN RAIN FOREST/ EQUATORIAL FOREST.

These forests are found in warm and humid areas. They are having a heavy rainy season, the annual precipitation is above 200 cm and the average temperature is about 20-25 ^{0}C. Normally, it extends between 10 degree N and 10 degree S latitude. While covering less than 6 percent of Earth's land surface, rain forests are home to more than 50 percent of the world's plant and animal species. There is no definite time for trees to shed their leaves, so they are appearing green all the year round. The trees are having an average height of 45-60 m or even more. Many of the trees have straight trunks that don't branch out for 100 feet or more. The topsoil of tropical rainforest is heavily leached due to the rain and so poor in nutrients. Due to this regeneration of the tree cover is diìcult when it is cleared. Because of these poor nutrients (in the surface), rainforest trees have very shallow roots to get more nutrients and they are having buttressed trunks to support. The tropical evergreen forests are well stratified. They are having a multi-layered continuous canopy; growing in layers; 5 layers. The stratification results from competition between species for favourable locations for the sunlight. First layer: uppermost canopy of the tallest trees. The tall trees grow so close together that their crowns interlock to form a continuous canopy, likes an umbrella or crown which blocks out the sunlight to the next layers. They are in an average height of 30 m- 60 m. Second layer: This layer is at a height of 25 m-30 m. Third layer: Have lower and smaller trees, height of 15-20 m. Fourth layer: It is the shrub layer, also some stunted plants and trees of less than 5 m height are there. Fifth layer: It is the ground layer having herbaceous plants and ferns.

Tropical evergreen rain forest biome accounts for the largest number of plant species. The fora is highly diverse here; one square kilometre may contain as many as 100 different tree species. Tree is the most significant floral member, second is the Creepers (climbers) like herbaceous plant climber, lianas and epiphytes (they do not need to have their roots on the surface). They are forest of tall and large trees like ebony, mahagony, rosewood, palms; and creepers like vines, lianas, epiphytic orchids; bromeliads, shrubs, herbs, ferns, mosses, etc. Like the vegetation, animal life in this region is also found in abundance and variety. The most of the animals found are arboreal animals (creatures, which spend the majority of their lives in trees). Some examples of animals in the evergreen forest are howler monkeys, brocket deer, lemur, elephants, one horned rhinoceros, bats, sloth, scorpions, snails, oatimundis, agoutis, curassows, tinamous, plenty of birds, humming birds, butterflies, lizards, silky ant eaters, woolly oppassum, kinkajous, armadillos, jaguars, owls, parrots, parakeets, tree frog, etc. The primary ecological productivity of the tropical rain forest is the highest of all biome type of the world. It accounts 40 percent of the total net productivity of the world, approximately 5000 dry grams per square meter per year. They are found in South America, West Africa, Australia, Southern India, and Southeast Asia.

4.4.1.3 TEMPERATE FORESTS

The forest found in the temperate region, about 48 N latitude. Temperate forests occur in eastern North America, northeastern Asia, and western and central Europe. Well-defined seasons with a distinct winter characterize this forest biome. The temperature ranges from 20 - 30 ^{0}C. Rainfall is evenly distributed throughout the year about an average of 75-150 cm. The soil is fertile, enriched with decaying litter. It has deep soil layers, rich in nutrients, so is good for agriculture. Climate and amount of sunlight can vary tremendously between each season. Temperate forests have moderately dense broadleaved trees - mostly deciduous & some evergreen; with less diversity of plant species. Trees adapt to varied climate by becoming dormant in winter. Deciduous forest has more diversity than that of coniferous forest, but less diversity of plant species than that of tropical rain forest. Deciduous forests also grow in layers but not as much that of evergreen. More sunlight reaches the ground compared to a rainforest so more ground dwelling plants can see there. The main plant species are Oak, Beech, Maple, hickory, hemlock, basswood, cottonwood, Elm, Willow, spring flowering herbs, etc. The main fauna are: Squirrels, rabbits, skunks, birds, black bears, mountain lions, deer, bobcat, timber wolf, fox, Bald Eagles, raccoon, elks, White tailed deers, coyotes, American buffalos, beavers, wolves, Cougar, owl, rodent, opossum.

4.4.1.4 TAIGA OR BOREAL FOREST

The taiga is the biome of the needle leaf forest. A lot of coniferous trees grow in the taiga. Cold-tolerant evergreen conifers like Pine, Fir, Spruce and Larch are the major trees seen here. The roots are long to anchor trees. The needles are long, thin and waxy. Low sunlight and poor soil keep plants from growing on forest floor. Taiga has a thin soil cover and poor in nutrients and acidic. The seasons are divided into short moist rainy moderately warm summers and long cold snowfall dry winter. They have a very low temperature. The precipitation is mostly snowfall and is ranging 40-100 cm. extreme annual variation of temperature ranging between -40^{0}C to 25^{0}C. The animals are adapted for cold winters. The main fauna are: Caribou, moose, timber wolf, lynx, bears, wolverines, capercaillies, red squirrels, crossbill, pine marten, mink, beaver, woodpeckers, owl, hawks, bears, deer, hares, bats etc. It is also called as temperate coniferous forest, because of a few species of temperate deciduous trees have also developed in this biome. E.g., Aldar, Birch and Poplar. Boreal forests, or taiga, represent the world's largest terrestrial biome. Found only in Northern Hemisphere, occurring between 50 and 60 N latitudes just below the tundra biome. And it stretches over Eurasia and North America, parts of Siberia, Alaska, Canada and Scandinavia. The average net primary productivity is 800 dry grams per square meter per year.

4.4.2 GRASS LANDS

Grassland biomes are large, lands of grasses, flowers and herbs. Latitude, soil and local climates for the most part determine what kinds of plants grow in particular grassland. The rainfall is less here, that not enough to support a forest, but it is more than that of the desert. Due to the less precipitation, drought and fire prevent large forests from growing. The soil of most grassland is also too thin and dry for trees to survive. Grassland biomes can be found in the middle latitudes, in the interiors of continents. There are two real seasons: a growing season and a dormant (not growing-too cold) season. There are mainly two types of grassland biomes; Tropical (savanna) and temperate grasslands.

4.4.2.1 SAVANNA (TROPICAL GRASSLANDS)

It is a variety of grassland with scattered shrubs and individual isolated trees (deciduous). The trees are having a flat crown, umbrella shaped. Savanna can be found between tropical deciduous rainforest and desert biome. Savanna is found in the tropics, near equator. Savannas cover Africa (generally central and east Africa) and large areas of Australia, South America (Venezuela, Brazil, Columbia), and India. Climate is the most important factor in creating a savanna. Savannas are always found in warm hot climates where the annual rainfall is from about 50 - 125 cm per year. It has only

2 very different seasons; a dry and warm one and a rainy (wet) hot one. In tropical grasslands the length of the growing season is determined by how long the rainy season lasts. Amount of precipitation supports tall grasses but only occasional trees. It appears greenish and well-nourished in the rainy season and turns in to yellow in dry season. The soil has porous with a thin layer of humus (the organic portion of soil created by partial decomposition of plant or animal matter), which provides vegetation with nutrients. Savanna contains the greatest number of grazing animals on Earth. Plants of the savannah are highly specialised to the long period of drought. They have long tap roots, thick barks to resist annual fire, trunks that can store water, and the leaves that can drop off during the dry season to conserve water. Many plants have thorns and sharp leaves to protect against predation. The main floras are Acacia, baobab, bottle trees, grass, etc. Most of the animals on the savannah have long legs or wings for long migrations. The animals are adapted for short rainy season, they migrate as necessary. They reproduce during rainy season and ensure more young survive. The fauna are Hawks, buzzards, Kangaroo, Giraffes, zebras, buffalos, elephants, antelopes, gazells, marsupials, uanaco, mice, moles, snakes and worms, Lion, leopards, cheetah, jackals, hyenas, gophers, ground squirrels, termites, beetles, ostrich, etc. Average net primary productivity is 900 dry grams per square meter per year.

4.4.2.2 TEMPERATE GRASSLANDS

Temperate grasslands are characterized as having grasses as the dominant vegetation. Trees and large shrubs are absent. Temperate grasslands have hot summers and cold winters. The amount of rainfall is less in temperate grasslands than in savannas. The annual average is about 50-90 cm. The amount of annual rainfall influences the height of grassland vegetation, with taller grasses in wetter regions. In the temperate grasslands the length of the growing season is determined by temperature. The soil of the temperate grasslands is deep and dark, with fertile upper layers. The rotted roots hold the soil together and provide a food source for living plants. Some non-woody plants, specifically a few hundred species of flowers, grow among the grasses. The various species of grasses include purple needle-grass, blue grama, buffalo grass, and galleta. Flowers include asters, blazing stars, coneflowers, goldenrods, sunflowers, clovers, psoraleas, and wild indigos. The appearance of the temperate grasslands varies with seasons. In spring, the grass appear, green, fresh and blooming with small, colourful flowers. The light rainfall that comes in late spring and early summer greatly stimulates their growth and there is plenty for the animals to graze. In summer, there is so much heat and evaporation that the grass is scorched. The bluish-green grass turns yellow and soon brown. Towards autumn, the grass withers and dies, but the roots remain alive and lie dormant throughout the cold winter. The average net primary productivity is 600 dry grams per square meter per year. The fauna found here are gazelles, zebras, rhinoceroses, wild horses, lions, wolves, prairie dogs, jack rabbits, deer, mice, coyotes, foxes, skunks, badgers, blackbirds, grouses, meadowlarks, quails, sparrows, hawks, owls, snakes, grasshoppers, leafhoppers, and spiders. The temperate grass lands are found in South Africa, Hungary, the pampas of Argentina and Uruguay, the steppes of the former Soviet Union, and the plains and prairies of central North America. Temperate grasslands can be further subdivided; prairies and steppes. They are somewhat similar. Prairies are grasslands with tall grasses about 11 feet.

4.4.2.3 STEPPES

The Steppe biome is a dry, cold, grassland that is found in all of the continents except Australia and Antarctica. It is mostly found in the USA, Mongolia, Siberia, Tibet and China. Steppes occur in the interiors of North America and Europe. There isn't much humidity in the air because Steppe is located away from the ocean and close to mountain barriers. The Steppe biome is usually found between the desert and the forest. Steppe has warm summers and really cold winters. All the Steppes experience long droughts and violent winds due to few trees. The steppe is differing only in the density and quality of the grass. Their greatest difference from the tropical savanna is that they are practically treeless and the grasses are much shorter. The grasses are greater than 30cm tall. They include blue grama and buffalo grass, cacti, sagebrush, spear grass, and small relatives of the sunflower.

4.4.3 DESERT

These are the driest places on earth. Deserts cover about one fifth of the Earth's surface and occur where rainfall is less than 25 cm. Evaporation rates regularly exceed rainfall rates. The environment, so lacking in moisture and so excessive in heat, is most unfavourable for plant growth. Desert soil is rich in nutrients with little or no organic matter. Even though nutrients are present in the soil due to the less rainfall the productivity is less. Most desert shrubs have well-spaced long roots to gather moisture, and search for ground water. Plants have few or no leaves and are either waxy, leathery, hairy or needle-shaped to reduce the loss of water through transpiration. Some of them are entirely leafless, with pricks or thorns. Others like the cacti have thick succulent stems to store up water for long droughts. Major deserts on earth: sahara, thar, Kalahari, Arabian, namib, Iranian, Turkestan, takia makan gobi, Australian, Patagonian, Atacama, north American. Desert Biomes can be classified as follows:

4.4.3.1 HOT AND DRY DESERT

In these types of deserts seasons are generally warm throughout the year and very hot in the summer. The winters usually bring little rainfall. The average rainfall is less than 1.5 cm. Some years are even rainless. Inland Sahara also receives less than 1.5 cm a year. The mean annual temperature range is 20-45 ^{0}C. Most Hot and Dry Deserts are near the Tropic of Cancer or the Tropic of Capricorn. E.g., Sahara, Kalahari, Marusthali, Rub-el-Khali. The four major North American deserts of this type are the Chihuahuan, Sonoran, Mojave and Great Basin. The plants need some adaptations to survive. Some of them are the ability to store water for long periods of time and the ability to stand the hot weather. Plants are mainly ground hugging shrubs, the leaves are with water conserving characteristics. Some examples of plant are Turpentine Bush, Prickly Pears, and Brittle Bush, yuccas, ocotillo, false mesquite, sotol, ephedras and agaves. The animals include small nocturnal (active at night) animals. Some examples of the animals are Borrowers, kangaroo rats, Mourning Wheatears, and Horned Vipers.

4.4.3.2 SEMI ARID DESERT

Semi-arid desert are found in the marginal areas of hot deserts. They are having a temperature of 21-38 ^{0}C. The summer is moderately long and dry, like hot deserts. The winters normally bring low concentrations of rainfall. The average rainfall ranges from 2-4 cm annually. Semiarid plants include: Creosote bush, bur sage, white thorn, cat claw, mesquite, brittle bushes, lyciums, and jujube. The animals include the kangaroo rats, rabbits, and skunks; lizards and snakes; burrowing owls and the California thrasher. The major deserts of this type include the sagebrush of Utah, Montana and Great Basin. They also include the North America, Newfoundland, Greenland, Russia, Europe and northern Asia.

4.4.3.3 COSTAL DESERT

These deserts occur in moderately cool to warm areas. A good example is the Atacama of Chile. The temperature range is 15-35 ^{0}C. The cool winters of coastal deserts are followed by moderately long, warm summers. The average rainfall measures 8-13 cm in many areas. The plants living in this type of desert include the salt bush, buckwheat bush, black bush, rice grass, little leaf horsebrush, black sage, and chrysothamnus. Animals include: coyote, badger, toads, great horned owl, golden eagle, bald eagle, lizards, snakes, insects etc.

4.4.3.4 COLD DESERT

They are found near to the tundra regions. Cold deserts are near the Arctic part of the world. The temperature range is 2-25 ^{0}C. These deserts are characterized by cold winters with snowfall and high overall rainfall. The precipitation is of 15-26 cm. They have short, moist, and moderately warm summers. The animals in Cold deserts also have to burrow but in this case to keep warm, not cool. Widely distributed animals are jack rabbits, kangaroo rats, kangaroo mice, pocket mice, grasshopper mice, and antelope ground squirrels, badger, kit fox, and coyote.

4.4.4 TUNDRA

The word tundra means a barren land. The ground is permanently frozen 25-100 cm down so that trees can't grow there. The tundra is the world's coldest and driest biomes. They have little precipitation, poor nutrients, short growing seasons and low biotic diversity. Temp rarely higher than 10 ^{0}C. They are bitterly cold and covered with snow and ice. They have short growing seasons. Very short warm season that is very wet. Many insects are there during warm season. Below a thin layer of tundra soil is its permafrost, a permanently frozen layer of ground. Only certain small plants such as mosses, shrubs, sedges, lichens, and grasses can grow. The plants here are growing close to the ground. And they are having shallow roots to absorb the limited water resources. The animals are shrews, hares, rodents, wolves, arctic foxes, polar bears, lemmings, wolverine, reindeer, deer, harp seal, penguins of Antarctica, muskox. Black flies, deer fies, mosquitoes and noseeums (tiny biting midges) can make the tundra a miserable place to be in the summer. Migratory birds like the harlequin duck, sandpipers and plovers are found in tundra. The average net primary productivity is 140 dry grams per square meter per year. Tundra Biomes can be classified as follows:

4.4.4.1 ARCTIC TUNDRA

Arctic tundra is located in the northern hemisphere, encircling the North Pole. The growing season ranges from 50 to 60 days. The average winter temperature is -34°C. The average summer temperature is 3-12°C which enables this biome to sustain life. Yearly precipitation, including melting snow, is 15 to 25 cm. There is no deep root system of vegetation. They are having low shrubs, sedges, reindeer mosses, liverworts, grasses, 400 varieties of flowers, crustose and foliose lichen. The animals are: lemmings, voles, caribou, arctic hare, squirrels, arctic foxes, wolves, polar bears, Migratory birds: ravens, snow buntings, falcons, loons, sandpipers, terns, snow birds, gulls. It occupies the northern fringe of Canada, Alaska, European Russia, Siberia and island group of Artic Ocean.

4.4.4.2 ALPINE TUNDRA

Alpine tundra is located on mountains throughout the world at high altitude, above the tree line and just below the snow line of the mountain. In the summer average temperature ranges from 10-15 ^{0}C. In the winter the temperature are below freezing. The winter season can last from October to May. The summer season may last from June to September. The growing season is approximately 180 days. The major vegetation's are tussock grasses, dwarf trees, small-leafed shrubs, heaths. Animals living are pikas, marmots, mountain goats, sheep, elk, grouse like birds, springtails, beetles, grasshoppers, butterflies, etc Alpine animals have to deal with two types of problems; the cold and too much high UV rays. This is because there are fewer atmospheres to filter UV rays from the sun light. There are only warm-blooded animals in the Alpine biome. Alpine animals adapt to the cold by hibernating, migrating to lower warmer areas, or insulating their bodies with layers of fat. Alpine animals also have larger lungs, more blood cells and haemoglobin because of the increase of pressure and lack of oxygen at higher altitudes.

4.4.5 HIGHLAND ICY ALPINE BIOME

Alpine biome describes an ecosystem that does not contain trees due to its high altitude. These biomes are found in mountainous regions across the globe. Their elevation normally ranges between 10,000 feet (3,000 meters) and the area where a mountain's snow line begins.

Alpine biomes are home to only about 200 plant species, as their dynamic conditions are not favorable for plant growth. These regions are characterized by cold and windy conditions, as well as harsh sunlight. Moreover, there's a minimal supply of carbon dioxide for photosynthesis at high altitudes. Let's take a deeper look at alpine biome, including its climate, geographical location, as well as various flora and fauna you can find there.

The climate of alpine biomes is somewhat dynamic. You can't describe the climate of this kind of biome using a simple climate scheme. Temperatures normally drop by about 10 ^{0}C for every 1000 meters as you go up a mountain. The biome experiences a long, cold winter season, lasting about nine months. Summer temperatures normally range from 40 to 60 ^{0}F. However, these temperatures can normally drop from warm to freezing within a day.

Precipitation varies considerably in alpine biomes, but they're usually fairly dry. In fact, the regions receive about one foot (30 cm) of precipitation annually. Nevertheless, snow may remain on the ground for an extended period of time, thanks to the consistently low temperatures.

Alpine biomes occur at high altitudes within any latitude worldwide. Parts of montane grassland and shrubland ecosystems across the globe include alpine biome. Extensive areas of alpine biome are found in the following regions: the Himalayas in Asia, the Scottish Highlands, the Scandinavian Mountains, American Cordillera in North and South America, the Rift Mountains of Africa, Carpathian and Pyrenees Mountains in European, the Caucasus Mountains, a substantial extent of the Tibetan Plateau.

Alpine biome occupies summits and slopes of high mountains. It can also be found in high-mountain ridges above timberline. The treeline normally occurs at high altitude on warmer equator-facing slopes. In light of the fact that alpine region is found only on mountains, the biome is characterized by a rugged and wrecked landscape, with rock-strewn, snowcapped peak, and cliffs. Other remarkable features include talus slopes. It's worth noting that some areas of this biome feature gently rolling to virtually flat terrain. Across various locations, the treeling rises about 75 meters as you move one degree south from 70°N to 50°N, and 130 meters a degree as you move from 50°N to 30°N. The treeline virtually remains constant between 30°N and 20°S, at 3,500 meters to 4,000 meters.

The alpine biome is characterized by unfavourable conditions for plants to thrive, including strong winds, unfavourably low temperatures, low carbon dioxide levels, and strong sunlight. With low carbon dioxide, plants have a hard time carrying out photosynthesis. As a result of the windy weather, alpine biomes are characterized by small groundcover plants. These plants take longer to grow and reproduce. They shield themselves from the cold and windy conditions by staying as close to the ground as possible. Moreover, these plants decompose slowly after they die, thanks to the low temperatures. This results in poor soil conditions. Most plants that are found in alpine biomes are adapted to thrive in rocky and sandy soil. You should also realize that plants in the alpine biome have an anti-freeze chemical, which coats and protects the plants from the low temperatures. This ensures the plants don't die from freezing. They also have specialized root system.

The roots don't grow vertically downward but rather spread and grow horizontally. This kind of root growth prevent the roots from getting to the permafrost soil, which would result in the death of the plants due to water loss. It's also worth noting that alpine plants have limited transpiration. Transpiration is the process by which plants lose water through their leaves. Limited transpiration, therefore, ensures that alpine plants don't dry out as a result of excessive water loss. These plants need all the water they can get in a bid to survive the cold, dry alpine conditions. Here are some of the plants that thrive in alpine biomes: Bear Grass, Moss Campion, Pygmy Bitterroot, Wild potato, Bristlecone pine etc.

Animals that live in the alpine biome should be adapted to contend with two types of problems: 1. the cold, 2. high UV light exposure. This region is home to many warm-blooded animals and a couple of insect species. But how do these animals deal with the cold? They normally hibernate, mover to warmer regions, or insulate their bodies with layers of fur and fat. Moreover, these animals normally have short legs, ears, and tails, which helps in minimizing heat loss. They also boast larger lungs and a higher number of blood cells. The blood of alpine animals has the capability to work with lower oxygen levels that are typical of high elevations. Here are some of the animals you can find in alpine biome: Elk, Sheep, Mountain goats, Snow leopard, Alpaca, Yak, Chinchilla, Ptarmigan bird, Snowshoe rabbit, Himalayan Tahr, Marmot etc.

4.5 Biome distribution in India

India, with its vast and varied landscape, showcases a rich tapestry of biomes that span from the icy heights of the Himalayas to the sun-soaked shores of its peninsular coastline. The country's unique geographical features, diverse climates, and topographical variations contribute to the formation of distinctive biomes, each characterized by specific flora and fauna. The distribution of biomes in India reflects a harmonious interplay of environmental factors, creating ecosystems that have sustained life for millennia.

i. **Himalayan Biome**

   The majestic Himalayan mountain range, stretching across northern India, harbors a unique biome marked by alpine meadows, coniferous forests, and subalpine shrublands. Iconic species such as the Himalayan blue sheep and the elusive snow leopard find their home in this harsh yet awe-inspiring environment.

ii. **Indo-Gangetic Plain Biome**

   The fertile plains of the Ganges and its tributaries constitute an extensive biome dominated by agriculture. This biome supports a myriad of plant and animal life, including the Bengal tiger, Indian rhinoceros, and countless species of migratory birds that thrive in the wetlands and riverine ecosystems.

iii. **Thar Desert Biome**

   In the northwest, the Thar Desert stands as a testament to the adaptability of life in arid conditions. This biome is home to unique flora like the drought-resistant cacti and fauna such as the Indian gazelle and the spiny-tailed lizard, showcasing remarkable strategies for survival in a water-scarce environment.

iv. Western Ghats Biome

The Western Ghats, a mountain range along the western coast of India, hosts a biodiversity hotspot with dense evergreen forests, moist deciduous forests, and unique grasslands. This biome shelters endemic species like the lion-tailed macaque, the Malabar giant squirrel, and a myriad of amphibians and reptiles found nowhere else on Earth.

v. Eastern Ghats and Deccan Plateau Biome

Stretching across central and eastern India, the Deccan Plateau and the Eastern Ghats support a diverse biome characterized by dry deciduous forests, scrublands, and grasslands. Iconic species such as the Indian elephant and the sloth bear navigate these landscapes, adapting to the seasonal fluctuations in temperature and precipitation.

vi. Coastal Biome

India's extensive coastline gives rise to a coastal biome that includes mangroves, estuaries, and sandy beaches. Mangrove ecosystems, found in regions like the Sundarbans, provide a crucial habitat for diverse marine life, including the Bengal tiger, various species of fish, and migratory birds.

vii. Island Biome

The Andaman and Nicobar Islands in the Bay of Bengal constitute a distinct island biome with unique flora and fauna. These islands are home to endemic species like the Nicobar megapode and the Andaman wild pig, highlighting the evolutionary isolation and ecological uniqueness of island ecosystems.

India's biome distribution is not static; it is influenced by factors such as climate change, human activities, and conservation efforts. Understanding and preserving this mosaic of ecological diversity is crucial for the sustainable management of natural resources and the protection of the country's rich biodiversity. As India continues to grow and develop, the responsible stewardship of its diverse biomes remains a key challenge and an opportunity for promoting a harmonious coexistence between human society and the natural world.

Table 4.1: Major biomes in India, along with brief descriptions

Biome	*Location*	*Key Characteristics*	*Notable Species*
Himalayan Biome	Northern India, Himalayan Mountain region	Alpine meadows, coniferous forests, subalpine shrublands	Snow leopard. Himalayan blue sheep
Indo-Gangetic Plain Biome	Northern and Central India, Ganges plains	Fertile plains, agriculture, wetlands, riverain ecosystems	Bengal tiger, Indian rhinoceros, migratory birds
Thar Desert Biome	Northwestern part of India	Arid conditions, drought-resistant flora, desert fauna	Indian gazelle, spiny-tailed lizard
Western Ghats Biome	Western coast of India	Biodiversity hotspots, evergreen forests, moist deciduous	Lion-tailed macaque, Malabar giant squirrel
Eastern Ghats and Deccan Plateau Biome	Central and Eastern India	Dry deciduous forests, scrublands, grasslands	Indian Elephant, Sloth bear
Coastal Biome	Along the Indian coastline	Mangrove, estuaries, sandy beaches	Bengal tiger, various fish, migratory birds
Island Biome	Andaman and Nicobar Islands	Unique island ecosystems, endemic species	Nicobar megapode, Andaman wild pig

This table 4.1 provides a snapshot of the diverse biomes in India, their locations, key characteristics, and notable species. It is important to note that the descriptions are concise, and each biome encompasses a wide range of ecological nuances and variations.

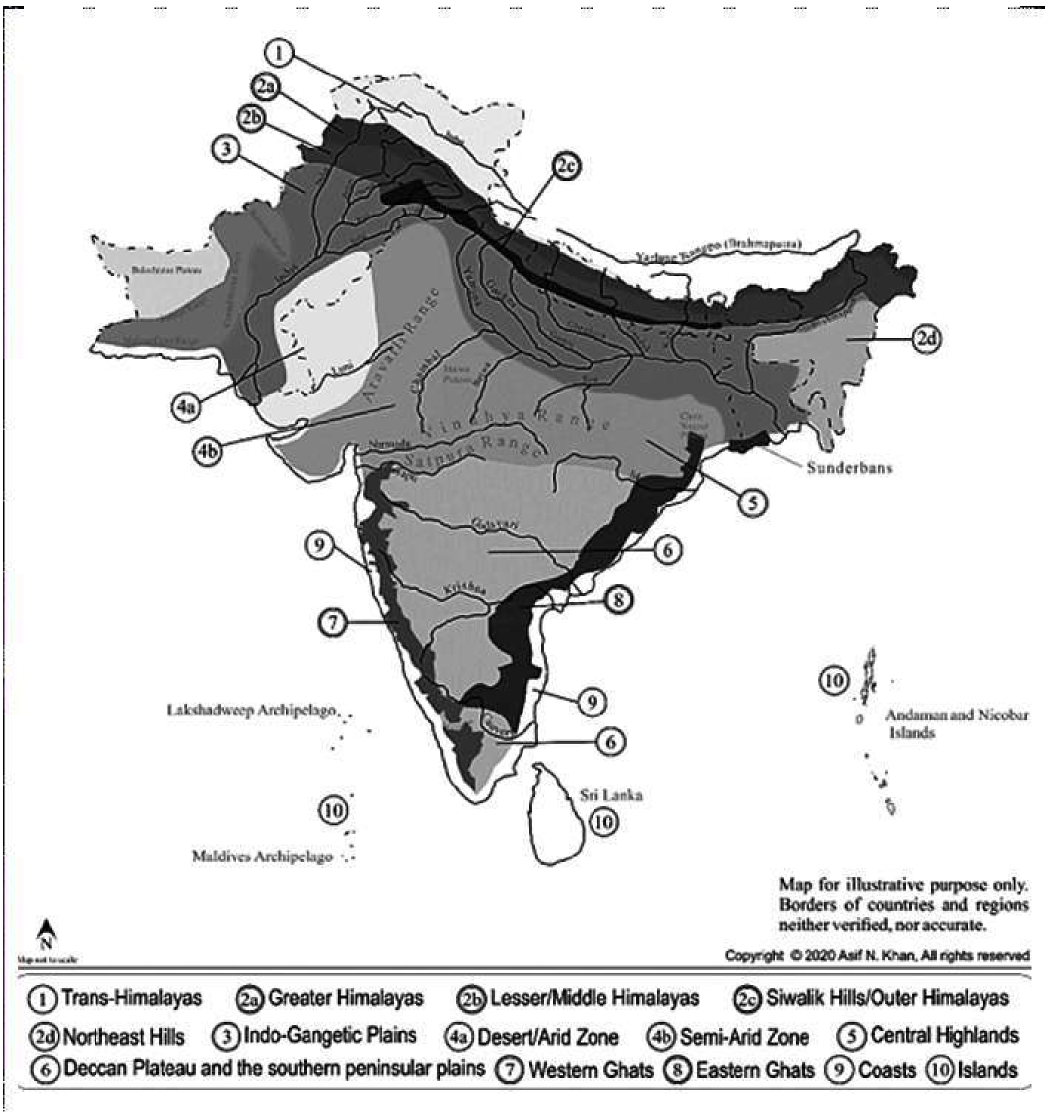

Table 4.2 : Biogeographic regious of Indian Subcontinent

4.6 Summary

- Biomes are geographically extensive ecosystems that occur throughout the world wherever environmental conditions are suitable for their development. The same biome may occur in far-flung places, even on different continents, and in such cases, it will be similar in structure and function but will usually be dominated by different species.

- Plants are main components of terrestrial ecosystems as they are primary producers. Almost all terrestrial life if based on the types of plants found in the area.
- The major types of biomes are; forest, grassland, tundra, desert and aquatic.

4.7 Self-Assessment questions

MCQ types questions

1. Which type of trees is found in a temperate forest?
   a) Deciduous
   b) Evergreen
   c) Ginko
   d) Palm
2. What are the key features of the Tundra?
   a) cold winter, thin acidic soil, evergreen trees
   b) treeless, permafrost, cold dark winters
   c) long cool summers, short dark winters, migrating animals
   d) many evergreen trees, short moist summers, long snowy winters
3. The desert and tundra are alike because they both have
   a) high precipitation
   b) low precipitation
   c) the same organisms
   d) sandy soil
4. The greatest biodiversity on earth is found in the __________ biome.
   a) Taiga
   b) Grassland
   c) Tropical deciduous forest
   d) Tropical rain forest
5. This biome is also known as the "taiga".
   a) tropical rainforest
   b) alpine tundra

c) temperate deciduous forest

d) coniferous forest

Short answer type questions

1. What is a biome? What is main abiotic factor defining biomes?
2. What is the typical vegetation and typical fauna of the tundra?
3. How can the abundance and diversity of living organisms in tropical forests be explained?
4. What are the grasslands of North America and of South America respectively called?
5. Which terrestrial vertebrate group is extremely rare in deserts? What is desert biome of India?

Long answer type questions

1. Write short note on different types of forest biomes.
2. Describe different types of desert biomes with their floral and faunal features.
3. Discuss about alpine biomes and its biotic diversity.

4.8 Suggested Readings

Breckle, S.W. 2002. Walter's Vegetation of the Earth. The Ecological Systems of the Geo-Sphere, 4th ed. Springer-Verlag, Berlin, Germany.

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Unit 5 ☐ Community Ecology

Structure

5.1 Objective

- To learn about community structure and influencing factors.
- Describe the interspecific interaction and competitive exclusion principle.
- Define different symbiotic relationships between species.
- Elucidate species diversity in community ecology.
- To learn about intermediate disturbance hypothesis.
- A brief note on island equilibrium model

5.2 Introduction

Communities are complex systems that can be characterized by their structure (the number and size of populations and their interactions) and dynamics (how the members and their interactions change over time). Understanding community structure and dynamics allows us to minimize impacts on ecosystems and manage ecological communities we benefit from. This chapter will introduce the concept of community, its structure and dynamics. We will examine ecological interactions between populations of different species and interspecies interaction. Lastly, we will discuss about species diversity and population equilibrium in a community.

5.3 Concept of Community

A group of populations of different species living close enough to interact is called a biological community. Ecologists define the boundaries of a particular community to fit their research questions: They might study the community of decomposers and other organisms living on a rotting log, the benthic community in Lake Superior, or the community of trees and shrubs in Banff National Park in Alberta.

Some key relationships in the life of an organism are its interactions with individuals of other species in the community. These interspecific interactions include competition, predation, herbivory, symbiosis (including parasitism, mutualism, and commensalism), and facilitation. In this section, we will define and describe each of these interactions, recognizing that ecologists do not always agree on the precise boundaries of each type of interaction. We will use the symbols + and - to indicate how each interspecific interaction affects the survival and reproduction of the two species engaged in the interaction. For example, predation is a +/- interaction, with a positive effect on the survival and reproduction of the predator population and a negative effect on that of the prey population. Mutualism is a +/+ interaction because the survival and reproduction of both species are increased in the presence of the other. A 0 indicates that a population is not affected by the interaction in any known way. Historically, most ecological research has focused on interactions that have a negative effect on at least one species, such as competition and predation. However, positive interactions are ubiquitous, and their contributions to community structure are the subject of considerable study today.

5.4 Community structure

Different ecological communities can be pretty different in terms of the types and numbers of species they contain. For instance, some Arctic communities include just a few species, while some tropical rainforest communities have huge numbers of species packed into each cubic meter.

One way to describe this difference is to say that the communities have different structures. Community structure is essentially the composition of a community, including the number of species in that community and their relative numbers. It can also be interpreted more broadly, to include all of the patterns of interaction between these different species.

A community's structure can be described by its species richness, which is the number of species present, and species diversity, which is a measure of both species richness and species evenness (relative numbers). Community structure is influenced by many factors, including abiotic factors, species interactions, level of disturbance, and chance events. Some species, such as foundation species and keystone species, play particularly important roles in determining their communities' structure. The exploration of community structure unravels the layers of biodiversity, trophic interactions, spatial patterns, and the profound impacts of biotic relationships. The structure of a community varies depending on the following variables,

- **Species Composition and Diversity:** The foundation of community structure lies in the diversity and composition of species. It's not merely about counting species but understanding the nuanced relationships among them. Species richness, the number of different species, and species evenness, the distribution of abundance among species, collectively define the biodiversity of a community. Diverse communities, with a multitude of interacting species, tend to exhibit greater stability, resilience, and adaptability.
- **Trophic Structure:** The trophic structure of a community orchestrates the flow of energy through different levels. At the base, producers, primarily plants, capture sunlight to synthesize organic matter. Herbivores consume these plants, and carnivores and omnivores feed on herbivores, forming a complex web of interactions. The trophic structure not only dictates who eats whom but also influences nutrient cycling and ecosystem dynamics.
- **Spatial Structure:** How organisms are distributed in space is a critical facet of community structure. Patterns of clustering, dispersion, or uniform spacing reflect adaptations to environmental factors and inter-species relationships. For instance, territorial behaviors, resource partitioning, and responses to abiotic factors contribute to the spatial arrangement of individuals within a community. These spatial dynamics play a pivotal role in shaping community resilience and evolutionary strategies.
- **Biotic Interactions:** Interactions among species, the essence of community structure, include competition, predation, mutualism, parasitism, and commensalism. Competition for limited resources, the perpetual struggle for survival, can lead to niche differentiation, allowing coexistence. Predation shapes population dynamics, influencing prey and predator communities. Mutualistic relationships, where species mutually benefit, and parasitic interactions, where one species exploits another, add layers of complexity to community dynamics.

- **Keystone Species and Ecological Roles:** Certain species, known as keystone species (A keystone species is an organism that helps define an entire ecosystem. Without its keystone species, the ecosystem would be dramatically different or cease to exist altogether.), wield an outsized influence on community structure. Their unique ecological roles have profound impacts on the entire ecosystem. Be it a predator maintaining prey populations or a plant shaping the habitat, the removal of a keystone species can trigger cascading effects, altering the very fabric of the community.
- **Succession and Dynamics:** Communities are not static entities but undergo changes over time through ecological succession. Primary succession occurs in lifeless areas, such as volcanic landscapes, while secondary succession follows disturbances in existing ecosystems, like wildfires or logging. Understanding the patterns of succession provides insights into community resilience and adaptation to changing conditions.
- **Human Impact:** In the Anthropocene era, human activities have become a major force shaping community structures globally. Habitat destruction, pollution, the introduction of invasive species, and climate change are altering the delicate balance of communities. Recognizing and mitigating these impacts is crucial for preserving biodiversity and sustaining the services that ecosystems provide to humanity.

5.5 Factors influencing the structure of communities

The structure of a community is the result of many interacting factors, both abiotic (non-living) and biotic (living organism-related). Here are some important factors that influence community structure:

- The climate patterns of the community's location.
- The geography of the community's location.
- The heterogeneity (patchiness) of the environment.
- The frequency of disturbances, or disruptive events.
- Interactions between organisms.

A community's structure can also be shaped by the chance events that happened during its history. For instance, suppose that a single seed blows into the dirt of a particular area. If it happens to take root, the species may establish itself and, after some period of time, become dominant (excluding similar species). If the seed fails to sprout, another similar species may instead be the lucky one to establish itself and become dominant.

5.6 Community dynamics

Community dynamics are the changes in community structure and composition over time, often following environmental disturbances such as volcanoes, earthquakes, storms, fires, and climate change. Communities with a relatively constant number of species are said to be at equilibrium. The equilibrium is dynamic with species identities and relationships changing over time but maintaining relatively constant numbers. Following a disturbance, the community may or may not return to the equilibrium state. Understanding community dynamics is crucial for comprehending the structure, function, and stability of ecosystems. Here are key aspects of community dynamics:

1. Species Interactions:

- Competition: Species may compete for limited resources such as food, water, and shelter. This competition can lead to the exclusion of one species by another, or it may result in the partitioning of resources to reduce direct competition.
- Predation: Predation involves the consumption of one organism (the prey) by another (the predator). This interaction can regulate the population sizes of both the prey and predator species.
- Mutualism: Mutualistic interactions benefit both species involved. For example, pollination, where plants benefit from the transportation of pollen by animals, and the animals benefit from the nectar or other rewards.
- Commensalism: In commensal relationships, one species benefits while the other is neither significantly harmed nor helped. An example is epiphytic plants growing on trees.

2. Succession:

Succession describes the sequential appearance and disappearance of species in a community over time after a severe disturbance.

- Primary Succession: This occurs in areas where no previous community existed, such as on newly formed islands or after a volcanic eruption.
- Secondary Succession: This occurs in areas where a disturbance has disrupted an existing community, but the soil remains intact. Examples include abandoned agricultural fields or areas affected by fire.

More details about it could be find in chapter 2.

3. Biotic and Abiotic Factors:

- Biotic Factors: Living components of an ecosystem, including all organisms. Interactions between species, such as predation and competition, are considered biotic factors.
- Abiotic Factors: Non-living components like temperature, sunlight, soil composition, and water availability. These factors influence the distribution and abundance of species within a community.

4. Biodiversity:

- Species Diversity: The variety of species within a community. High species diversity is often associated with ecosystem stability and resilience.
- Functional Diversity: The variety of ecological functions performed by different species, such as nutrient cycling, pollination, and decomposition.
- Genetic Diversity: The variety of genes within a population, providing the raw material for adaptation to changing environmental conditions.

5. Keystone Species:

Certain species have a disproportionate impact on the structure and function of a community relative to their abundance. These species are called keystone species. Their removal can have cascading effects on the entire ecosystem.

6. Disturbance and Stability:

- Disturbance: Events such as fire, storms, or human activities that disrupt a community. Some communities are adapted to periodic disturbances, and disturbance can play a role in maintaining diversity.
- Stability: The ability of a community to resist change and return to its original state after a disturbance. High biodiversity often contributes to stability.

7. Trophic Levels:

- Producers: Autotrophic organisms like plants that produce their own food through photosynthesis.
- Consumers: Heterotrophic organisms that obtain energy by consuming other organisms. Consumers are further categorized into herbivores, carnivores, and omnivores.
- Decomposers: Organisms like bacteria and fungi that break down dead organic matter, returning nutrients to the ecosystem.

5.7 Interspecific interactions

Interspecific competition is a -/- interaction that occurs when individuals of different species compete for a resource that limits their growth and survival. Weeds growing in a garden compete with garden plants for soil nutrients and water.

What happens in a community when two species compete for limited resources? In 1934, Russian ecologist G. F. Gause studied this question using laboratory experiments with two closely= related species of ciliated protists, Paramecium aurelia and Paramecium caudatum. He cultured the species under stable conditions, adding a constant amount of food each day. When Gause grew the two species separately, each population grew rapidly and then leveled off at the apparent carrying capacity of the culture. But when Gause grew the two

Table 5 1: Different Interspeciûc Interaction in a community.

Interspecific Interaction	***Description***
Competition (-/-)	Two or more species compete for a resource that is in short supply.
Predation (+/-)	One species, the predator, kills and eats the other, the prey. Predation has led to diverse adaptations, including mimicry.
Herbivory (+/-)	An herbivore eats part of a plant or alga. Plants have various chemical and mechanical defences against herbivory, and herbivores have specialized adaptations for feeding.
Symbiosis	Individuals of two or more species live in close contact with one another. Symbiosis includes parasitism, mutualism, and commensalism.
Parasitism (+/-)	The parasite derives its nourishment from a second organism, its host, which is harmed.
Mutualism (+/+)	Both species benefit from the interaction.
Commensalism (+/0)	One species benefits from the interaction, while the other is unaffected by it.
Amensalism (-/0)	It is a type of biological interaction where one species causes harm to another organism without any cost or benefits to itself.
Facilitation (+/+ or 0/+)	Species have positive effects on the survival and reproduction of other species without the intimate contact of a symbiosis.

species together, P. caudatum became extinct in the culture. Gause inferred that P. aurelia had a competitive edge in obtaining food. He concluded that two species competing for the same limiting resources cannot coexist permanently in the same place. In the absence of disturbance, one species will use the resources more efficiently and reproduce more rapidly than the other. Even a slight reproductive advantage will eventually lead to local elimination of the inferior competitor, an outcome called **competitive exclusion**.

We can use the niche concept to restate the principle of competitive exclusion: Two species cannot coexist permanently in a community if their niches are identical. However, ecologically similar species can coexist in a community if one or more significant differences in their niches arise through time. Evolution by natural selection can result in one of the species using a different set of resources. The differentiation of niches that enables similar species to coexist in a community is called **resource partitioning**.

Closely related species whose populations are sometimes allopatric and sometimes sympatric (geographically overlapping) provide more evidence for the importance of competition in structuring communities. In some cases, the allopatric populations of such species are morphologically similar and use similar resources. By contrast, sympatric populations, which would potentially compete for resources, show differences in body structures and in the resources they use. This tendency for characteristics to diverge more in sympatric than in allopatric populations of two species is called **character displacement**.

5.8 Species diversity in community ecology

The species diversity of a community-the variety of different kinds of organisms that make up the community-has two components. One is species richness, the number of different species in the community. The other is the relative abundance of the different species, the proportion each species represents of all individuals in the community. Imagine two small forest communities, each with 100 individuals distributed among four tree species (A, B, C, and D) as follows:

Community 1: 25A, 25B, 25C, 25D

Community 2: 80A, 5B, 5C, 10D

The species richness is the same for both communities because they both contain four species of trees, but the relative abundance is very different. You would easily notice the four types of trees in community 1, but without looking carefully, you might see only the abundant species A in the second forest. Most observers would intuitively describe community 1 as the more diverse of the two communities. Ecologists use many tools to quantitatively compare the diversity of different communities across time and space. They often calculate indexes of diversity based on species richness and relative abundance. One widely used index is Shannon diversity (H):

$$H = -(PA\ln PA + PB\ln PB + PC\ln PC + \ldots)$$

Where A, B, C . . . are the species in the community, p is the C relative abundance of each species, and ln is the natural logarithm. A higher value of H indicates a more diverse community. Let's use this equation to calculate the Shannon diversity index of the two communities. For community 1, p = 0.25 for each species, so

$H = -4(0.25 \ln 0.25) = 1.39$

For community 2,

$H = -[0.8 \ln 0.8 + 2(0.05 \ln 0.05) + 0.1 \ln 0.1] = 0.71$

These calculations confirm our intuitive description of community 1 as more diverse. Determining the number and relative abundance of species in a community is easier said than done. Many sampling techniques can be used, but since most species in a community are relatively rare, it may be hard to obtain a sample size large enough to be representative. It is also difficult to census the highly mobile or less visible or accessible members of communities, such as microorganisms, nematodes, deep-sea creatures, and nocturnal species. The small size of microorganisms makes them particularly difficult to sample, so ecologists now use molecular tools to help determine microbial diversity. Measuring species diversity is often challenging but is essential for understanding community structure and for conserving diversity.

Higher-diversity communities are often more resistant to **invasive species**, which are organisms that become established outside their native range. **Energetic hypothesis**, suggests that the length of a food chain is limited by the inefficiency of energy transfer along the chain. The energetic hypothesis predicts that food chains should be relatively longer in habitats of higher photosynthetic production, since the starting amount of energy is greater than in habitats with lower photosynthetic production. The **dynamic stability hypothesis,** proposes that long food chains are less stable than short chains. Population fuctuations at lower trophic levels are magnified at higher levels, potentially causing the local extinction of top predators. In a variable environment, top predators must be able to recover from environmental shocks (such as extreme winters) that can reduce the food supply all the way up the food chain. The longer a food chain is, the more slowly top predators can recover from environmental setbacks. This hypothesis predicts that food chains should be shorter in unpredictable environments. Another factor that may limit food chain length is that carnivores in a food chain tend to be larger at successive trophic levels. The size of a carnivore and its feeding mechanism put some upper limit on the size of food it can take into its mouth. And except in a few cases, large carnivores cannot live on very small food items because they cannot procure enough food in a given time to meet their metabolic needs. Among the exceptions are baleen whales, huge suspension feeders with adaptations that enable them to consume enormous quantities of krill and other small organisms.

Dominant species in a community are the species that are the most abundant or that collectively have the highest biomass. As a result, dominant species exert a powerful control over the occurrence and distribution of other species. For example, the dominance of sugar maples in an eastern North American forest community has a major impact on abiotic factors such as shading and soil nutrient availability, which in turn affect which other species live there. In contrast to dominant species, **keystone species** are not usually abundant in a community. They exert strong control on community structure not by numerical might but by their pivotal ecological roles, or niches. A sea star, in maintaining the diversity of an intertidal community is an example of keystone species.

The **intermediate disturbance hypothesis** states that moderate levels of disturbance foster greater species diversity than do low or high levels of disturbance. High levels of

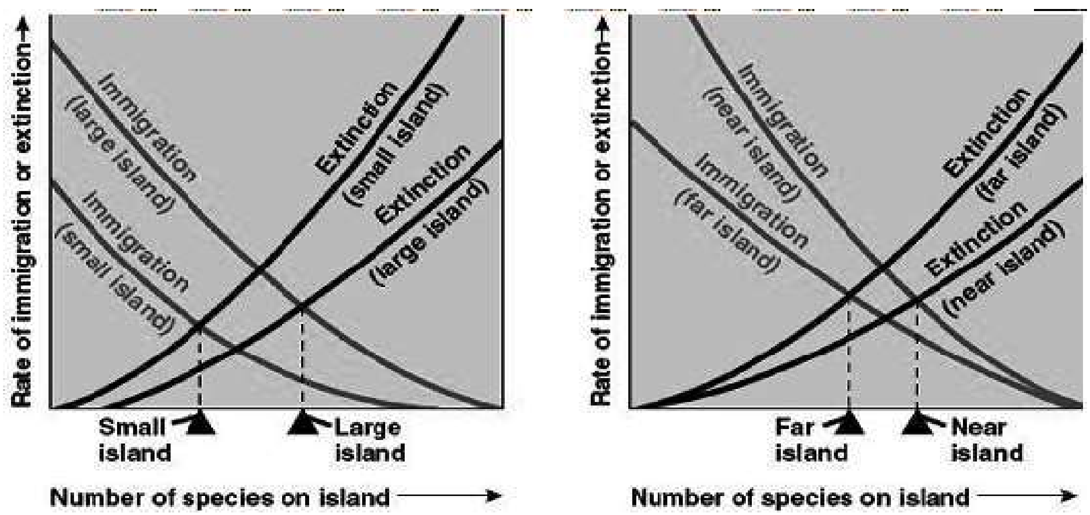


Figure 5 1: Effect of size of island and distance of island from mainland on community size.

disturbance reduce diversity by creating environmental stresses that exceed the tolerances of many species or by disturbing the community so often that slow-growing or slow-colonizing species are excluded. At the other extreme, low levels of disturbance can reduce species diversity by allowing competitively dominant species to exclude less competitive ones. Meanwhile, intermediate levels of disturbance can foster greater species diversity by opening up habitats for occupation by less competitive species. Such intermediate disturbance levels rarely create conditions so severe that they exceed the environmental tolerances or recovery rates of potential community members.

In 1807, naturalist and explorer Alexander von Humboldt described one of the first patterns of species richness to be recognized, the **species-area curve:** All other factors being equal, the larger the geographic area of a community, the more species it has. The likely explanation for this pattern is that larger areas offer a greater diversity of habitats and microhabitats than smaller areas. In conservation biology, developing species-area curves for the key taxa in a community helps ecologists predict how the potential loss of a certain area of habitat is likely to affect the community's diversity.

MacArthur and Wilson's model is called the island equilibrium model because an equilibrium will eventually be reached where the rate of species immigration equals the rate of species extinction. The number of species at this equilibrium point is correlated with the island's size and distance from the mainland. Like any ecological equilibrium, this species equilibrium is dynamic; immigration and extinction continue, and the exact species composition may change over time. MacArthur and Wilson's studies of the diversity of plants and animals on many island chains support the prediction that species richness increases with island size, in keeping with the island equilibrium model. Species counts also fit the prediction that the number of species decreases with increasing remoteness of the island.

5.9 Summary

- A community is a group of organisms in the same environment that interact with one another.
- The main types of interspecific interactions include competition (-/-), predation (+/-), mutualism, (+/+), commensalism (+/0), and parasitism (+/-).
- The principle of competitive exclusion states that two species competing for the same resources cannot coexist.
- The tendency for characteristics to diverge more in sympatric than in allopatric populations of two species is called character displacement.
- The intermediate disturbance hypothesis states that moderate levels of disturbance foster greater species diversity than do low or high levels of disturbance.

5.10 Self-Assessment questions

MCQ type question

1. What type of species interaction is the following: a killer whale kills and eats a seal.

a) Commensalism

b) Predation

c) Mutualism

d) Competition

2. What type of species interaction is the following: two bears fighting over the same mate.

a) Predation

b) Competition

c) Mutualism

d) Parasitism

3. Name the species interaction: a mosquito feeds on human blood & transfers a disease.

a) Predation

b) Competition

c) Mutualism

d) Parasitism

4. ______ is a series of changes that occur in a community over time after disturbances.

a) community succession

b) evolution

c) tertiary succession

d) guild formation

5. According to the competitive exclusion principle, two species cannot continue to occupy the same:

a) Habitat

b) Niche

c) Territory

d) Range

Short answer type question

1. What is competitive exclusion principle? Give an example.

2. What is character displacement? Give an example.
3. What is intermediate disturbance hypothesis?
4. Briefly describe island equilibrium model.
5. What is resource partitioning?

Long answer type question

1. What is a community? What is the main influencing factor of community structure?
2. Describe different types of interspecific interaction with suitable example.
3. Elucidate species diversity in community and dynamic stability hypothesis.

5.11 Suggested Readings

1. Fundamentals of Ecology by Eugene Odum
2. Ecology: Theories & Applications by Peter Stiling
3. Elements of Ecology by Smith & Smith
4. Ecology: Principles and Applications by JL Chapman and MJ Reiss
5. Ecology by Ricklefs & Miller

Unit 6 ☐ Biological Diversity

Structure

6.1 Objectives
6.2 Introduction
6.3 Types of Biodiversity
6.4 Loss of biodiversity
6.5 Threats to biodiversity
6.6 Mega Biodiversity countries
6.7 Biodiversity hotspot in India
6.8 Extinct, rare, endangered, threatened flora and fauna of India
6.9 Strategies for biodiversity conservation
6.10 Conservation of biodiversity
6.11 Convention on Biological Diversity (CBD)
6.12 Bioprospecting
6.13 Bio-piracy in India
6.14 Bio-piracy and the difficulties in protecting traditional knowledge
6.15 Summary
6.16 Self-Assessment questions
6.17 Suggested Readings

6.1 Objective

- To learn about different aspects of biodiversity - components, loss, threats.
- Brief account on biodiversity hotspot of India and megadiverse countries.
- To get informed about Extinct, rare, endangered, threatened flora and fauna of India
- Discussion about conservation strategies in India
- To know about in-situ and ex situ conservation.
- Elucidate bio-piracy in India

6.2 Introduction

The word biodiversity is a modern contraction of the term biological diversity. Diversity refers to the range of variation or variety or differences among some set of attributes; biological diversity thus refers to variety within the living world or among and between living organisms.

"Biodiversity" is a relatively new compound word, but biological diversity (when referring to the number of species) is not. Over the last decade its definition has taken a more reductionist turn. Possibly the simplest definition for biodiversity, lacking in specificity or context, is merely the number of species. Yet many have argued that biodiversity does not equate to the number of species in an area. The term for this measure is species richness (Fiedler and Jain, 1992), which is only one component of biodiversity. Biodiversity is also more than species diversity (simply called diversity by some authors), which has been defined as the number of species in an area and their relative abundance (Pielou, 1977).

6.3 Types of Biodiversity

Various authors have proposed specific and detailed elaborations of this definition. Gaston and Spicer (1998) proposed a three-fold definition of "biodiversity"- ecological diversity, genetic diversity, and organismal diversity-while others conjoined the genetic and organismal components, leaving genetic diversity and ecological diversity as the principal components. These latter two elements can be linked to the two major "practical" value systems of direct use/genetics and indirect use/ecological described by Gaston and Spicer (1998). Other workers have emphasized a hierarchical approach or hierarchies of life systems.

6.3.1 Genetic diversity

Genetic diversity is reliant on the heritable variation within and between populations of organisms. New genetic variation arises in individuals by gene and chromosome mutations, and in organisms with sexual reproduction it can be spread through the population by recombination. It has been estimated that in humans and fruit flies alike, the number of possible combinations of different forms of each gene sequence exceeds the number of atoms in the universe. Other kinds of genetic diversity can be identified at all levels of organization, including the amount of DNA per cell and chromosome structure and number. Selection acts on this pool of genetic variation present within an interbreeding population. Differential survival results in changes of the frequency of genes within this pool, and this is equivalent to population evolution. Genetic variation enables both natural evolutionary change and artificial selective breeding to occur (Thomas, 1992). Only a small fraction

(<1%) of the genetic material of higher organisms is outwardly expressed in the form and function of the organism; the purpose of the remaining DNA and the significance of any variation within it are unclear (Thomas, 1992). Each of the estimated 109 different genes distributed across the world's biota does not make an identical contribution to overall genetic diversity. In particular, those genes that control fundamental biochemical processes are strongly conserved across different taxa and generally show little variation, although such variation that does exist may exert a strong effect on the viability of the organism; the converse is true of other genes. A large amount of molecular variation in the mammalian immune system, for example, is possible on the basis of a small number of inherited genes (Thomas, 1992).

6.3.2 Species diversity

Historically, species are the fundamental descriptive units of the living world and this is why biodiversity is very commonly, and incorrectly, used as a synonym of species diversity, in particular of "species richness," which is the number of species in a site or habitat. Discussion of global biodiversity is typically presented in terms of global numbers of species in different taxonomic groups. An estimated 1.7 million species have been described to date; estimates for the total number of species existing on earth at present vary from 5 million to nearly 100 million. A conservative working estimate suggests there might be around 12.5 million. When considering species numbers alone, life on earth appears to consist mostly of insects and microorganisms. The species level is generally regarded as the most natural one at which to consider whole-organism diversity. While species are also the primary focus of evolutionary mechanisms, and the origination and extinction of species are the principal agents in governing biological diversity, species cannot be recognized and enumerated by systematists with total precision. The concept of what a species is differs considerably among groups of organisms. It is for this reason, among others, that species diversity alone is not a satisfactory basis on which to define biodiversity. Another reason why a straightforward count of the number of species provides only a partial indication of biological diversity concerns the concept of degree or extent of variation that is implicit within the term biodiversity. By definition, organisms that differ widely from each other in some respect contribute more to overall diversity than those that are very similar. The greater the interspecific differences (e.g., by an isolated position within the taxonomic hierarchy), then the greater contribution to any overall measure of global biological diversity. Thus, the two species of Tuatara (genus Sphenodon) in New Zealand, which are the only extant members of the reptile order Rhynchocephalia, are more important in this sense than members of some highly species-rich family of lizards. A site with many different higher taxa present can be said to possess more taxonomic diversity than another site with fewer higher taxa but many more species. Marine habitats frequently have more different phyla but fewer species than terrestrial habitats, that is, higher taxonomic diversity but lower species diversity. By this measure, the Bunaken reef off the north coast of Sulawesi has the highest biodiversity on earth. Current work is attempting to incorporate quanti?cation of the evolutionary uniqueness of species into species-based measures of biodiversity. The ecological importance of a species can have a direct effect on community structure, and thus on overall biological diversity. For example, a species of tropical rain forest tree that supports an endemic invertebrate fauna of a hundred species makes a greater contribution to the maintenance of global biological diversity than does a European alpine plant that may have no other species wholly dependent on it.

6.3.3 Ecosystem diversity

While it is possible to de?ne what is in principle meant by genetic and species diversity, it is difficult to make a quantitative assessment of diversity at the ecosystem, habitat, or community level. There is no unique definition or classification of ecosystems at the global level, and it is difficult in practice to assess ecosystem diversity other than on a local or regional basis, and then only largely in terms of vegetation. Ecosystems are further divorced from genes and species in that they explicitly include abiotic components, being partly determined by soil/parent material and climate. To get around this dif?culty, ecosystem diversity is often evaluated through measures of the diversity of the component species. This may involve assessment of the relative abundance of different species as well as consideration of the types of species. The more that species are equally abundant, then the more diverse that area or habitat. Weight is given to the numbers of species in different size classes, at different trophic levels, or in different taxonomic groups. Thus, a hypothetical ecosystem consisting only of several plant species would be less diverse than one with the same number of species but that included animal herbivores and predators. Because different weightings can be given to these different factors when estimating the diversity of particular areas, there is no one authoritative index for measuring ecosystem diversity. This obviously has important implications for the conservation ranking of different areas. In examining beta diversity (i.e., the change in species composition between areas), the only reliable predictor of community similarity is to compare the species composition of the site immediately adjacent.

6.4 Loss of biodiversity

Species extinction is a natural process that occurs without the intervention of humans since, over geological time, all species have a finite span of existence. Extinctions caused directly or indirectly by humans are occurring at a rate that far exceeds any reasonable estimates of background extinction rates, and to the extent that these extinctions are correlated with habitat perturbation, they must be increasing. Quantifying rates of species extinction is difficult and predicting future rates with precision is impossible. The documentation of de?nite species extinctions is only realistic under a relatively limited set of circumstances, for example, where a described species is readily visible and has a well-de?ned range that can be surveyed repeatedly. Unsurprisingly, most documented extinctions are of species that are easy to record and that inhabit sites that can be relatively easily inventoried. The large number of extinct species on oceanic islands is not solely an artifact of recording, because island species are generally more prone to extinction as a result of human actions. Most global extinction rates are derived from extrapolations of measured and predicted rates of habitat loss, and estimates of species richness in different habitats. These two estimates are interpreted in the light of a principle derived from island biogeography, which states that the size of an area and of its species complement tend to have a predictable relationship. Fewer species are able to persist in a number of small habitat fragments than in the original unfragmented habitat, and this can result in the extinction of species (MacArthur and Wilson, 1967). These estimates involve large degrees of uncertainty, and predictions of current and future extinction rates should be interpreted with considerable caution. The pursuit of increased accuracy in the estimation of global extinction rates is not crucial. It is more important to recognize in general terms the extent to which populations and species that are not monitored are likely to be subject to fragmentation and extinction (Temple, 1986). Loss of biodiversity in the form of domesticated animal breeds and plant varieties is of little signi?cance in terms of overall global diversity, but genetic erosion in these populations is of particular human concern in so far as it has implications for food supply and the sustainability of locally adapted agricultural practices. For domesticated populations, the loss of wild relatives of crop or timber plants is of special concern for the same reason. These genetic resources may not only underlie the productivity of local agricultural systems but may also, when incorporated into breeding programs, provide the foundation of traits (disease resistance, nutritional value, hardiness, etc.) that are of global importance in intensive systems and that will assume even greater importance in the context of future climate change. Erosion of diversity in crop gene pools is difficult to demonstrate quantitatively, but can be indirectly assessed in terms of the increasing proportion of world cropland planted to high-yielding, but genetically uniform, varieties. Genetic modification of organisms, varieties, or cultivars for food production, pharmaceuticals, and other products, which has caused concern in some countries but not others, may also contribute to the loss of biodiversity. Humans exterminate species either directly by hunting, collection, and persecution or indirectly through habitat destruction and modification. Overhunting is perhaps the most obvious direct cause of extinction in animals, but it is undoubtedly far less important than the indirect causes of habitat modi?cation in terms of overall loss of biodiversity. Hunting selectively affects the targeted species, as well as plant and animal species whose populations are subsequently affected either negatively or positively, and so it has important implications for the management of natural resources. Genetic diversity in a hunted population is liable to decrease as a result of the same factors. The genetic diversity represented by populations of crop plants or livestock is also likely to decline as a result of mass production, for the desired economics of scale demand high levels of uniformity. Sustained human activity will affect the relative abundance of species and in extreme cases may lead to extinction. This may result from the habitat being made unsuitable for the species (e.g., clear-felling of forests or severe pollution of rivers) or through the habitat becoming fragmented (discussed earlier). Fragmentation divides previously contiguous populations of species into small sub-populations. If these are suf?ciently small, then chance processes lead to higher probabilities of extinction within a relatively short time. Major changes in natural environments are likely to occur within the next century as a result of changes in global climate and weather patterns. These will cause greatly elevated extinction rates.

6.4.1 Consequences of Biodiversity Loss

The consequences of biodiversity loss are profound and wide-ranging, affecting ecosystems, economies, and human well-being. As the intricate web of life unravels, various cascading effects emerge, exacerbating environmental challenges and jeopardizing the sustainability of our planet. The following are key consequences of biodiversity loss:

i. Ecosystem Instability

Biodiversity loss disrupts the balance within ecosystems, leading to increased vulnerability to disturbances such as diseases, invasive species, and extreme weather events. Species within ecosystems often have specialized roles, and the disappearance of certain species can have cascading effects, destabilizing entire ecosystems. This instability can make ecosystems more susceptible to collapse, reducing their ability to provide essential services.

ii. Impaired Ecosystem Services

Biodiversity is crucial for the provision of ecosystem services, which are essential for human well-being. These services include pollination of crops by bees, water purification by wetlands, and regulation of climate by forests. The decline in biodiversity compromises the capacity of ecosystems to deliver these services, impacting agriculture, water resources, and climate stability. The loss of pollinators, for example, threatens global food security by impairing the reproduction of many crops.

iii. Reduced Resilience to Environmental Change

Biodiverse ecosystems are often more resilient to environmental changes and disturbances. Species within diverse ecosystems can adapt to changing conditions, helping the ecosystem withstand stresses. As biodiversity declines, ecosystems become less resilient, making them more susceptible to the impacts of climate change, pollution, and other stressors.

iv. Economic Impacts

Biodiversity loss can have significant economic consequences, particularly for industries that rely on natural resources. Fisheries, forestry, agriculture, and tourism are all sectors that depend on biodiversity. The collapse of fisheries due to overfishing, for instance, not only affects the livelihoods of those directly involved but also disrupts food supply chains and has economic ripple effects.

v. Loss of Genetic Diversity

Biodiversity includes genetic diversity within species, which is essential for adaptation and evolution. The loss of genetic diversity reduces the capacity of species to respond to changing environmental conditions, making them more susceptible to diseases and less able to cope with new challenges.

vi. Cultural and Aesthetic Impacts

Biodiversity loss also has cultural and aesthetic implications. Many societies have deep cultural connections to their local flora and fauna, which are often intertwined with traditional practices, beliefs, and folklore. The disappearance of iconic or culturally significant species can erode these connections, impacting the identity and well-being of communities.

vii. Human Health Risks

Biodiversity loss can pose risks to human health. The destruction of natural habitats can bring humans into closer contact with wildlife, increasing the likelihood of zoonotic diseases spilling over from animals to humans. Additionally, the loss of biodiversity may limit the availability of certain plants and animals that have provided important sources of food, medicine, and other resources for human societies.

viii. Global Imbalances

Biodiversity loss contributes to global imbalances, affecting different regions and ecosystems unevenly. As certain species decline or go extinct, the interconnectedness of ecosystems means that these losses can have far-reaching consequences across geographic boundaries, leading to imbalances in ecological functions and processes.

6.5 Threats to biodiversity

Scientists have named five main threats to biodiversity. Knowing what they are and how they work can help you identify ways your company's practices might be contributing to declines in biodiversity, as well as areas where you can change.

1. **Land and water use change:** Both our lands and our seas contain many different ecosystems, and these are affected by business actions. For example: when developers drain and fill in marshes or wetlands in order to build housing, they take away the land that captures excess water during storms. The consequences can be drastic. Ecosystem conversion and ecosystem degradation contribute to habitat fragmentation. Habitat loss from exploitation of resources,

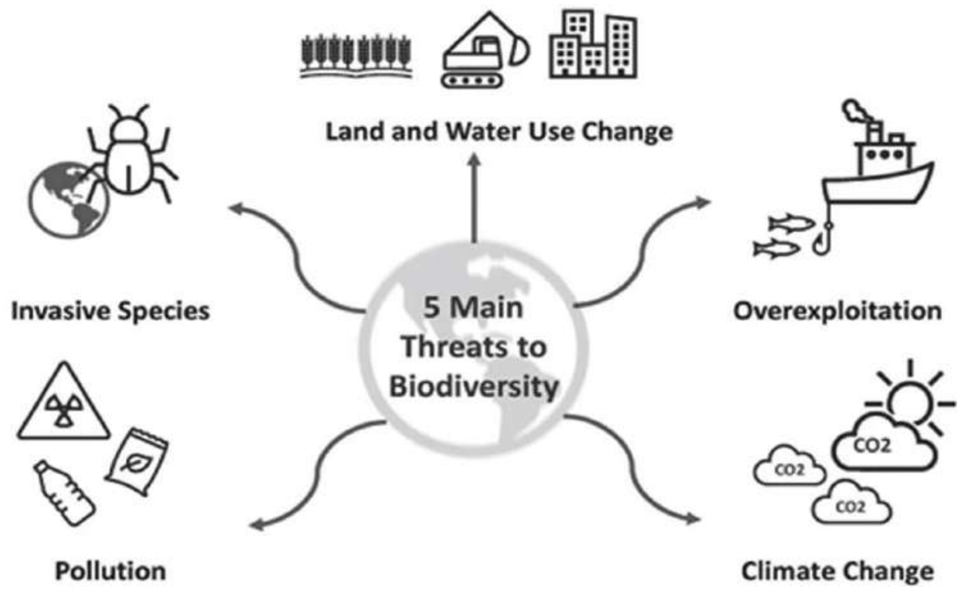


Figure 6.1: Major threats to Biodiversity

agricultural conversion, and urbanization is the largest factor contributing to the loss of biodiversity. The consequent fragmentation of habitat results in small isolated patches of land that cannot maintain populations of species into the future. Scientists report that the effect of habitat fragmentation on biodiversity may not be fully realized for decades after habitat is degraded. Therefore, habitat connectivity must be considered in current management practices to prevent the devastating effects of fragmentation on biodiversity. Maintaining the connectivity of the landscape could offset their impacts on biodiversity. The corridor concept proposes that refuges connected by corridors will have higher immigration rates than isolated patches of natural habitat. This can offset extinction by promoting gene flow and preventing inbreeding. Corridors composed of naturally occurring or restored strips of land that connect large habitat patches may facilitate the movement of species between patches, and decrease the effects of threats to biodiversity. Habitat patches connected by corridors must always be large enough to maintain populations of species, especially for large-bodied vertebrates.

2. **Invasive species:** Global trade brings species from their home ecosystems to other parts of the world, where there are often no predators to eat them and keep their numbers in check. The warming climate allows dangerous species such as disease-carrying mosquitos to thrive in new latitudes. Alien species often throw their new habitats severely out of balance. For instance, the brown rat, which originated in central Asia and has invaded almost every part of the world, has driven hundreds of species extinct. Infestation by alien species, such as the Codling Moth, is also a major threat to ecosystems. The intentional and inadvertent introductions of a wide variety of species to ecosystems in which they do not belong have resulted in ecosystems that differ radically in structure and function from those originally present. Exotic species are typically introduced into ecosystems without their co-evolved predators and parasites, which enables an alien invader to out-compete native species with similar ecological requirements. The interactions between native species are altered or destroyed by these exotic species, and can result in the loss of native biodiversity.

3. **Pollution:** Pollution of air, soil, and water poses a serious problem to many ecosystems. Tiny bits of plastic suspended in ocean water build up inside fish, birds, and other marine species. Industrial toxins kill many species in rivers and lakes. Air pollution makes its way into soil, leaves, and water. It all adds up to fewer species, less diversity, and weakened ecosystems. Atmospheric and hydrologic pollution have far-reaching negative effects on biodiversity. Pollution from burning fossil fuels such as oil, coal and gas can remain in the air as particle pollutants or fall to the ground as acid rain. Acid rain, which is primarily composed of sulfuric and nitric acid, causes acidification of lakes, streams and sensitive forest soils, and contributes to slower forest growth and tree damage at high

elevations. In addition, chemical pollutants such as pesticides and herbicides leach into soils and watersheds. Species' sensitivity to pollution is variable. However, many species are vulnerable to the indirect effects of pollution through the concentration of toxic chemicals in top predators of food chains and disruption of predator-prey interactions.

4. **Climate change:** We're already seeing hotter temperatures, warmer oceans, and more severe weather events. Many species can't adjust to these conditions, and their numbers crash. Carbon dioxide released from burning fossil fuels and biomass, deforestation, and agricultural practices contributes to greenhouse gases, which prevent heat from escaping the earth's surface. With the increase in temperature expected from increasing greenhouse gases, there will be higher levels of air pollution, greater variability in weather patterns, and changes in the distribution of vegetation in the landscape. Some species will not be able to adapt to these changes in the environment and will become extinct. However, it is expected that many plant and animal species will attempt to disperse to higher latitudes and altitudes as the temperature increases. Therefore, any barriers in the landscape, such as highways and urban areas that prevent movement to more hospitable environments, will result in loss of biodiversity.
5. **Overexploitation:** Activities such as logging, farming, and fishing can be done sustainably, but they are often done in ways that overexploit a resource. When too many species, or even just a few important species, are taken out of the ecosystem, the whole network of life in that area can collapse. Think of a rock wall with too many rocks taken out, or a spider web with too many strands cut. Overall, people have been taking far more from nature than it can afford. For example, 70% of fish stocks in the ocean are currently being overfished. A 2016 study suggested that the oceans could be empty of fish by 2050.

6.6 Mega Biodiversity Countries

Megadiverse Countries is a term used to refer to the world's top biodiversity rich countries. This country-focused method raises national awareness for biodiversity conservation in nations with high biological diversity. The mega-diverse countries are those that house the largest indices of biodiversity, including a large number of endemic species. This concept was ?rst proposed in 1988 by Russell Mittermeier and is now used to raise awareness to the protection of natural biodiversity, and particularly in the countries where this is more abundant and threatened.

6.6.1.1 The Megadiversity country concept is based on four premises:

a) The biodiversity of each and every nation is critically important to that nation's survival.

b) Biodiversity is by no means evenly distributed on our planet, and some countries, especially in the tropics, harbour far greater concentrations of biodiversity than others.

c) Some of the most species rich and biodiverse nations also have ecosystems that are under the most severe threat.

d) To achieve maximum impact with limited resources, conservation efforts must concentrate heavily (but not exclusively) on those countries richest in diversity and endemism and most severely threatened.

The identified Megadiverse Countries are: India, Brazil, Madagascar, Colombia, Ecuador, Peru, Venezuela, United States of America, Mexico, Democratic Republic of Congo, South Africa, Malaysia, Indonesia, Philippines, Papua New Guinea, China, Australia.

These countries declared to set up a Group of Like-Minded Megadiverse Countries as a mechanism for consultation and cooperation so that their interests and priorities, related to the preservation and sustainable use of biological diversity, could be promoted. They

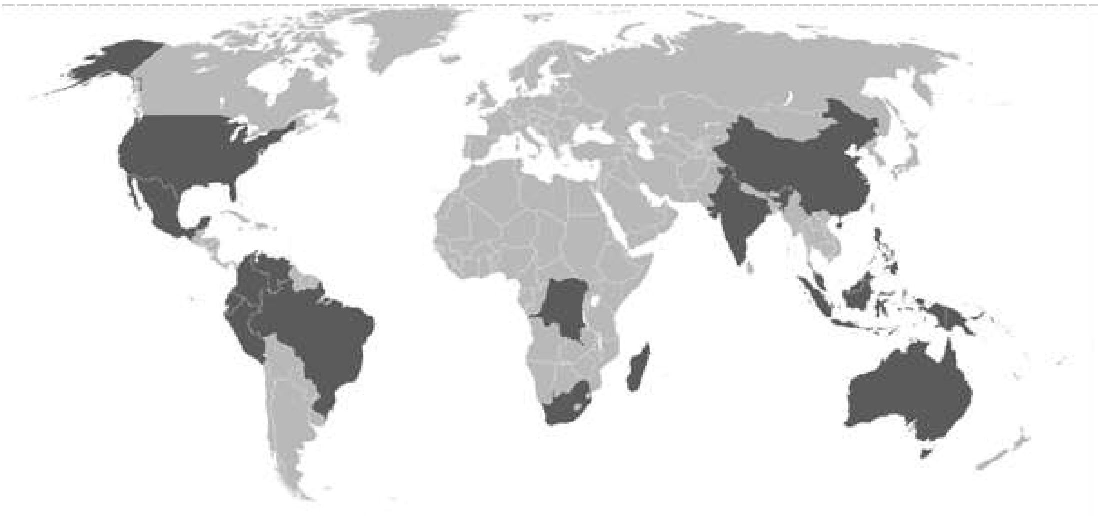


Figure 6.2: Megadiverse Countries shown in world map.

also declared that they would call on those countries that had not become Parties to the Convention on Biological Diversity, the Cartagena Protocol on Biosafety, and the Kyoto

Protocol on climate change to become parties to these agreements.

Why India is a Mega Biodiversity country?

India is recognized as a mega biodiversity country due to its extraordinary ecological and geographical diversity, which supports an incredibly rich variety of plant and animal species. Several factors contribute to India's status as a mega biodiversity hotspot:

i. **Geographical Diversity:** India's diverse topography includes the Himalayan Mountain range in the north, the Thar Desert in the west, the Gangetic plains, the Deccan Plateau, and the coastal regions. This wide range of geographical features creates varied habitats, from alpine meadows to tropical rainforests, providing niches for a multitude of species to thrive.

ii. **Climate Variation:** India experiences a diverse range of climates, from arid and semi-arid to tropical and temperate. This climatic diversity further contributes to the array of ecosystems found in the country, supporting the adaptation and survival of a wide range of plant and animal life.

iii. **Rich Floral Diversity:** India is home to a vast array of plant species, many of which are endemic. The Western Ghats and the Eastern Himalayas, in particular, are recognized as biodiversity hotspots with high levels of endemism. The country's diverse vegetation includes tropical rainforests, deciduous forests, mangroves, grasslands, and alpine meadows.

iv. **Unique Faunal Species:** India hosts a diverse array of animal species, ranging from iconic megafauna such as Bengal tigers and Indian elephants to numerous endemic species found in specific regions. The Western Ghats, for example, are known for their high amphibian diversity, including many endemic species. The country is also rich in bird diversity, with numerous migratory species visiting different regions throughout the year.

v. **Biodiversity Hotspots:** India is part of several global biodiversity hotspots, areas with exceptionally high species richness and endemism. The Western Ghats, the Eastern Himalayas, and the Indo-Burma region are examples of biodiversity hotspots within India. These regions are characterized by unique ecological conditions that have led to the evolution of diverse and often endemic species.

vi. **Cultural and Traditional Practices:** Traditional agricultural and land-use practices in India, shaped by diverse cultures and traditions, have contributed to the maintenance of biodiversity. Agroecosystems, sacred groves, and community-managed landscapes often coexist with natural ecosystems, providing additional habitats for various species.

vii. River Systems: India's extensive river systems, including the Ganges and Brahmaputra, contribute to the country's biodiversity by creating diverse aquatic habitats. These rivers support a variety of fish species and other aquatic life, contributing to the overall richness of India's ecosystems.

viii. Conservation Efforts: India has established an extensive network of protected areas, including national parks and wildlife sanctuaries, to conserve its diverse flora and fauna. Projects like Project Tiger, initiated in the 1970s, focus on the conservation of endangered species, particularly the Bengal tiger. These conservation efforts contribute to the preservation of India's mega biodiversity.

India's mega biodiversity status is a result of the country's varied geography, climates, and ecosystems, which have fostered the evolution and survival of an incredible diversity of plant and animal life. However, the continued conservation of these resources is essential to ensure the long-term sustainability of India's unique biodiversity.

6.7 Biodiversity hotspot in India

The term 'biodiversity hotspot' was coined by Norman Myers (1988). He recognized 10 tropical forests as "hotspots" on the basis of extraordinary level of plant endemism and high level of habitat loss, without any quantitative criteria for the designation of "hotspot" status. Two years later, he added eight more hotspots, and the number of hotspots in the world increased to 18 (Myers 1990).

Subsequently, the Conservation International in association with Myers made the first systematic update of the hotspots, and introduced the following two strict quantitative criteria, for a region to qualify as a hotspot:

i) It must contain at least 1,500 species of vascular plants (> 0.5% of the world's total) as endemics;

ii) It has to have lost ≥ 70% of its original native habitat.

The first systematic update of the hotspots, which involved an extensive global review, introduced seven new hotspots on the basis of the newly defined criteria and authentic new data, thus the number of hotspots has been increased to 25 (Mittermeier al., 1999; Myers al., 2000). The second systematic update revisited the hotspot regions and redefined several hotspots based on the distribution of species, threats, and changes in the threat status of these regions, which resulted in addition of nine more hotspots thus the number of hotspots expanded to 34 (Mittermeier al., 2004). The "Forests of East Australia" harbouring at least 2,144 endemic vascular plant species in an area with just 23% of its original vegetative cover remaining was identified as the 35th biodiversity hotspot (Williams al., 2011; Mittermeier al., 2011). In February 2016, the "North American Coastal Plain" meeting the criteria of hotspot, was recognized as the 36th global biodiversity hotspot.

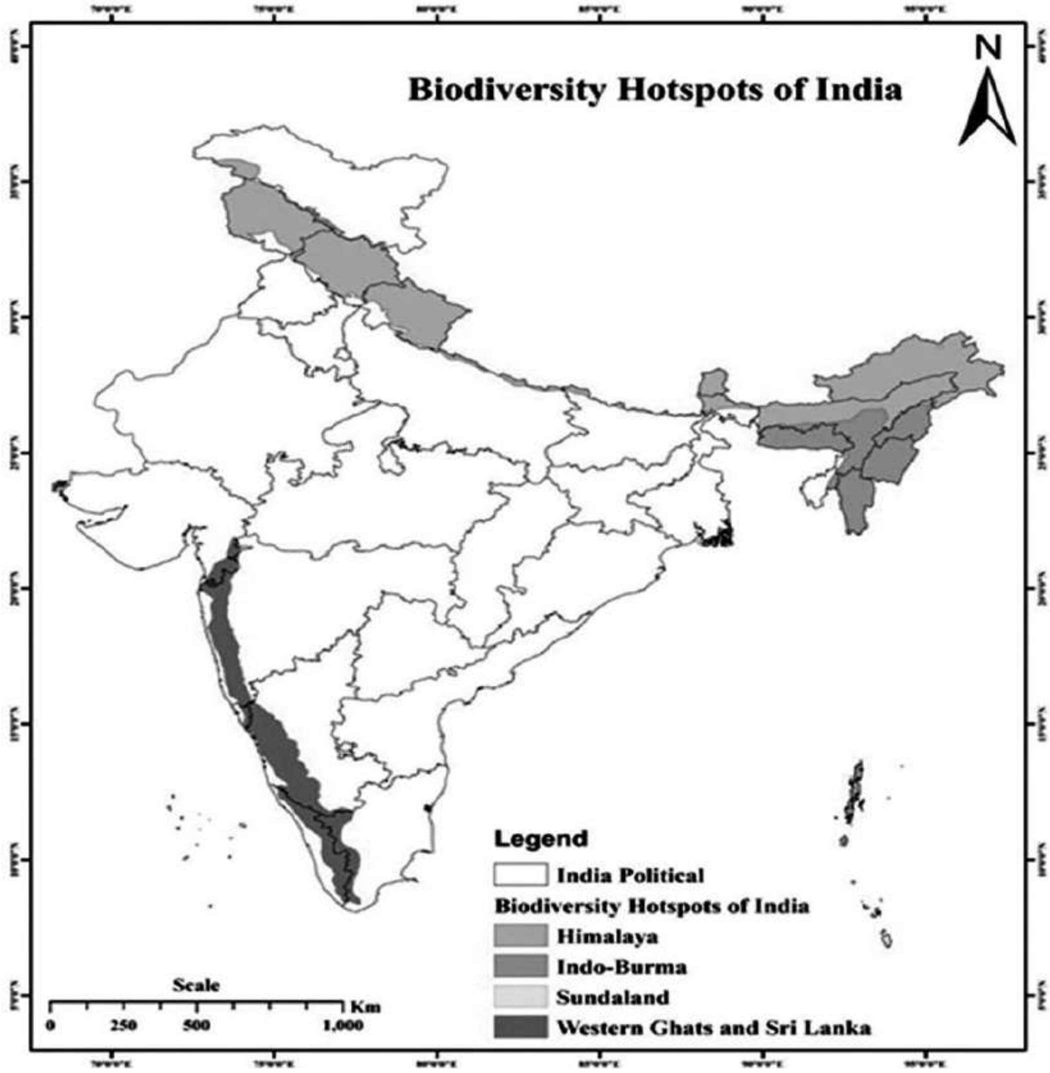


Figure 6.3: Biodiversity hotspots in India

Therefore, according to Conservation International (https://www.conservation.org), at present, there are 36 biodiversity rich areas in the world that have been qualified as hotspots, which represent just 2.5% of earth's land surface, but support over 50% of the world's endemic plant species, and nearly 43% of bird, mammal, reptile and amphibian species as endemics.

India, the seventh largest country in the world by geographical area (constitutes 2.4% of the total geographical area of the world) with varied physiographic divisions, climatic regimes, and ecological habitats exhibits a rich floral diversity, and harbours nearly 8% of the globally known flora, of which 28% of floral elements are endemic to the country (Mao & al., 2020). India is one of the 17 mega diversity countries in the world (Williams, 2001). According to a recent estimation the country harbours a total of 18,800 taxa of angiosperms, 82 taxa of Gymnosperms, 1307 taxa of Pteridophytes, 2786 taxa of Bryophytes, besides 15447 taxa of Fungi, 7434 taxa of Algae, 2917 taxa of Lichens and 1239 species of microbes (Viruses and Bacteria), which represent 8% of total recorded plant species (including algae, fungi, lichens, viruses and bacteria) of the world (Mao & al., 2020). India has four biodiversity hotspots namely Himalaya, Indo-Burma (Northeastern India and Andaman Islands), Sundalands (Nicobar Islands) and Western Ghats (and Sri Lanka) (https://www.conservation.org). The ecosystem profiles of these four hotspot regions are provided in detail below.

1. Himalaya: Includes the entire Indian Himalayan region [Jammu and Kashmir, Himachal Pradesh, Uttarakhand, northern part of West Bengal (Darjeeling), Sikkim, northern part of Assam and Arunachal Pradesh] and that falling in Pakistan, Tibet, Nepal, Bhutan, China and Myanmar. Overall, the Himalayas comprises North-East India, Bhutan, Central and Eastern parts of Nepal. These Himalayan Mountains are the highest in the world and hosts some of the highest peaks of the world including Mount Everest and K2. It also includes some of the major rivers of the world like Indus and Ganga. Himalayas hosts almost 163 endangered species including one-horned rhinoceros, wild Asian water buffalo and as many as 45 mammals, 50 birds, 12 amphibians, 17 reptiles, 3 invertebrates and 36 plant species.

2. Indo-Burma: Myanmar, Thailand, Vietnam, Laos, Cambodia and southern China; also included the entire northeastern India (Mizoram, Manipur, Nagaland, Meghalaya, and Tripura), and Andaman group of Islands, Bangladesh and Malaysia, while originally defined by Mittermeier & al. (2004). This region consists of various countries including North-Eastern India (to the south of the Brahmaputra River), Myanmar, and China's Yunnan provinces, Lao People's Democratic Republic, Vietnam, Cambodia, and Thailand. Almost 13,500 plant species can be spotted in the region, half of which are endemic and cannot be found in any other place in the world. Although this region is quite rich in its biodiversity, the situation has been worsening over the past few decades.

3. Sundaland: Indonesia, Malaysia, Singapore, Brunei and Philippines; also included Nicobar group of Islands while originally defined by Mittermeier & al. (2004). This region lies in South-East Asia and includes Thailand, Singapore, Indonesia, Brunei, and

Malaysia. Nicobar region represents India in this hotspot. UNESCO declared this region as the world biosphere reserve in 2013. These islands have a rich terrestrial as well as marine ecosystem including mangroves, seagrass beds, and coral reefs.

4. Western Ghats and Sri Lanka: Includes the entire Western Ghats [Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat] and Sri Lanka. These hills are found along the western edge of peninsular India. As the region is mountainous and oceanic, it receives a good amount of rainfall. Around 77% of the amphibians and 62% of the reptiles are endemic. Moreover, the region is also home to around 450 species of birds, 140 mammals, 260 reptiles and 175 amphibians.

6.8 Species diversity in community ecology

As per BSI, 18 species of plants - four non-flowering and 14 flowering - have gone extinct. The notable among them are Lastreopsis wattii, a fern in Manipur discovered by

Table 6 1: Some common plants which have become rare and endangered species in the past 30 years due to habitat destruction.

Plant	***Common name***	***Region***	***Status***
Polygala irregularis	Milkwort	Gujarat	Rare
Lotus corniculatus	Bird's foot	Gujarat	Rare
Amentotaxus assamica	Assam catkin yew	Arunachal Pradesh	Threatened
Psilotum nudum	Moa, skeleton, fork fern, and whisk fern	Karnataka	Rare
Diospyros celibica	Ebony tree	Karnataka	Threatened
Actinodaphne lawsonii		Kerala	Threatened
Acacia planifrons	Umbrella tree, kudai vel	Tamil Nadu	Rare
Abutilon indicum	Indian mallow, thuthi, and athibalaa	Tamil Nadu	Rare
Chlorophytum tuberosum	Musli	Tamil Nadu	Rare
Chlorophytum malabaricum	Malabar lily	Tamil Nadu	Threatened
Nymphaea tetragona		Jammu & Kashmir	Endangered
Belosynapsis vivipara	Spider wort	Madhya Pradesh	Endangered
Colchicum luteum		Himachal Pradesh	Threatened
Pterospermum reticulatum	Malayuram, Malavuram	Kerala and Tamil Nadu	Threatened
Ceropegia odorata	Jeemikanda	Gujrat, Rajasthan, Maharastra	Endangered

George Watt in 1882 and three species from the genus Ophiorrhiza (*Ophiorrhiza brunonis, Ophiorrhiza caudate* and *Ophiorrhiza radican*), all discovered from peninsular India. *Corypha taliera Roxb*. a palm species discovered in Myanmar and the Bengal region by William Roxburgh is also extinct.

Among mammals, the Asiatic cheetah (*Acionyx jubatus*), Indian aurochs (*Bos primigenius namadicus*) and the Sumatran rhinoceros (*Dicerorhinus sumatrensisi*) are considered extinct in India. The pink-headed duck (*Rhodonessa caryophyllaceai*) is feared extinct since 1950 and the Himalayan quail (*Ophrysia supercililios*) was last reported in 1876.

The flora of India is one of the richest in the world due to the country's wide range of climate, topology, and environment. There are over 15,000 species of flowering plants in India, which account for 6% of all plant species in the world. Many plant species are being destroyed, however, due to their prevalent removal.

Roughly 1/4 of all plant species in the world are at risk of being endangered or going extinct. The combination of global warming and habitat destruction is the sole reason for the disappearance of many plants. Though there are thousands of interesting and unusual plants, here are some common plants which have become rare and endangered species in the past 30 years due to habitat destruction.

Globally threatened list of the Indian fauna with categories and criteria assigned by IUCN, from the gobal fauna and Flora, and have assessed their conservation status under the various schedules of the Indian Wildlife (Protection) Act 1972, appendices of Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and of Convention of Migratory Species of Wild Animals (CMS) vis-a-vis trends in population status for the 648 species which is approximately 8.91%: of the world's total number of threatened faunal species. The Indian Red List includes 212 Species of Mammals. 143 Birds, 34 Reptiles, 148 Amphibians. 78 Pisces and 33 Invertebrate species of the 648 Threatened Indian Species 183 species are endemic that significantly makes 28.24% of the threatened Indian fauna, which is a very high ratio and the threats to the endemic species is a cause of concern. The data of the threatened Indian species reveals 44 species as Critical, 109 as Endangered. 195 as Vulnerable, 63 as Lower Risk near Threatened, 91 as Near Threatened, 9 as Lower Risk Conservation dependent and 134 as Data Deficient.

6.8.1.1 Critically endangered fauna of India

(a) Birds - Jerdon's Courser (*Rhinoptilus bitorquatus*), Forest Owlet (*Heteroglaux blewitti*), White-bellied Heron (*Ardea insignis*), White-backed Vulture (*Gyps bengalensis*), Slender-billed Vulture (*Gyps tenuirostris*), Long-billed Vulture

(*Gyps indicus*), Himalayan Quail (*Ophrysia superciliosa*), Siberian Crane (*Grus leucogeranus*), Sociable Lapwing (*Vanellus gregarius*), Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*), Bengal Florican (*Houbaropsis bengalensis*)

(b) Mammals - Pygmy hog (*Porcula salvania*), Andaman White-toothed Shrew (*Crocidura andamanensis*), Jenkin's Shrew (*Crocidura jenkinsi*), Nicobar Shrew (*Crocidura nicobarica*), Large Rock-rat (*Cremnomys elvira*), Malabar Civet (*Viverra civettina*), Namdapha Flying Squirrel (*Biswamoyopterus biswasi*)

(c) Reptiles - Gharial (*Gavialis gangeticus*), Leatherback turtles (*Dermochelys coriacea*), Four-toed river terrapin or River terrapin (*Batagur baska*), Hawksbill Turtle (*Eretmochelys imbricata*), Red-crowned Roof Turtle (*Batagur kachuga*)

(d) Amphibia - Gliding Frog (*Rhacophorus pseudomalabaricus*), *Fejervarya murthii, Indirana gundia, Philautus sanctisilvaticus, Raorchestes shillongensis*

(e) Fish - Knifetooth Sawfish (*Anoxypristis cuspidata*), Ganges Shark (*Glyphis gangeticus*), Pondicherry Shark (*Carcharhinus hemiodon*), Largetooth Sawfish (*Pristis microdon*), Deccan Labeo (*Labeo potail*)

The Zoological Survey of India, Kolkata published a booklet titled "Critically Endangered Animal Species of India" in March 2011. The booklet provides details of fauna which are critically endangered and on the verge of extinction. The findings of the status survey of rare and endangered species of fauna have been published by the Zoological Survey of India for the last 15 years as mentioned in Annexure A. The Botanical Survey of India has published four volumes of Red Data Book of Indian Plants, (Eds. Jain & Rao, 1984; Nayar & Sastry 1987 - 1990) and Red List of Threatened Vascular Plant Species in India (Rao et al. 2003), which provide information on 1236 species belonging to different threatened categories like Critically Endangered, Endangered, Vulnerable, etc.

For protection of the interests of flora and fauna, the Government has established a country-wide protected area network (678 Protected Areas (PAs) including 102 National Parks, 515 Wildlife Sanctuaries, 4 Community Reserves, and 57 Conservation Reserves in different biogeographic regions), which primarily covers habitats of threatened flora and fauna. Moreover, 9 of the 18 Biosphere Reserves in India are part of the World Network of Biosphere Reserves of UNESCO. Specific areas are designated by the Govt. of India as Ecologically Sensitive Areas (ESAs), which are protected under the Environment (Protection) Act 1986 (EPA). Several other steps to conserve/protect the wildlife and species of flora and fauna undertaken by the government.

6.9 Strategies for biodiversity conservation

India is a signatory to several major international conventions relating to conservation and management of wildlife. Some of these are Convention on Biological Diversity, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on the Conservation of Migratory Species of Wild Animals etc. Financial and Technical assistance is provided to State/Union Territory Governments for protection and Management of Protected Areas as well as other forests under various Centrally Sponsored Schemes. Indian Government has taken various biodiversity protection steps. Important measures include:

1. The Central Government has enacted the Wild Life (Protection) Act, 1972. The Act, inter alia, provides for the creation of Protected Areas for the protection of wildlife and also provides for punishment for hunting of specified fauna specified in the schedules I to IV thereof.
2. Wetland (Conservation and Management) Rules 2010 have been framed for the protection of wetlands, in the States.
3. The Centrally Sponsored Scheme of National Plan for Conservation of Aquatic Eco-System also provides assistance to the States for the management of wetlands including Ramsar sites in the country.
4. Wildlife Crime Control Bureau has been established for control of illegal trade in wildlife, including endangered species.
5. Wildlife Institute of India, Bombay Natural History society and Salim Ali Centre for Ornithology and Natural History are some of the research organisations undertaking research on conservation of wildlife.
6. The Indian Government has banned the veterinary use of diclofenac drug that has caused the rapid population decline of Gyps vulture across the Indian Subcontinent. Conservation Breeding Programmes to conserve these vulture species have been initiated at Pinjore (Haryana), Buxa (West Bengal) and Rani, Guwahati (Assam) by the Bombay Natural History Society.
7. The Centrally Sponsored Scheme 'Integrated Development of Wildlife Habitats' has been modified by including a new component namely 'Recovery of Endangered Species' and 16 species have been identified for recovery viz. Snow Leopard, Bustard (including Floricans), Dolphin, Hangul, Nilgiri Tahr, Marine Turtles, Dugong, Edible Nest Swiftlet, Asian Wild Buffalo, Nicobar Megapode, Manipur Brow-

antlered Deer, Vultures, Malabar Civet, Indian Rhinoceros, Asiatic Lion, Swamp Deer and Jerdon's Courser.

8. Under the 'Recovery of Endangered Species' component of the Centrally Sponsored Scheme 'Integrated Development of Wildlife Habitats' for the recovery of endangered species viz. Hangul in Jammu and Kashmir, Snow Leopard in Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh, Vulture in Punjab, Haryana and Gujarat, Swiftlet in Andaman and Nicobar Islands, Nilgiri Tahr in Tamil Nadu, Sangai Deer in Manipur, the government has to spend lakhs of rupees.
9. Protected Areas, viz, National Parks, Sanctuaries, Conservation Reserves and Community Reserves all over the country covering the important habitats have been created as per the provisions of the Wild Life (Protection) Act, 1972 to provide better protection to wildlife, including threatened species and their habitat.
10. Financial and technical assistance is extended to the State Governments under various Centrally Sponsored Schemes, viz, 'Integrated Development of Wildlife Habitats', 'Project Tiger' and 'Project Elephant' for providing better protection and conservation to wildlife.
11. The Central Bureau of Investigation (CBI) has been empowered under the Wild Life (Protection) Act, 1972 to apprehend and prosecute wildlife offenders.
12. The State Governments have been requested to strengthen the field formations and intensify patrolling in and around the Protected Areas.

6.9.1 Important Indian Acts and policies related to Environment and Bio Diversity

India has implemented several key acts and policies to address environmental and biodiversity conservation challenges. These legislative and policy measures aim to balance economic development with ecological sustainability. Here are some important acts and policies related to environment and biodiversity in India:

6.9.1.1 Acts

- **Wildlife Protection Act, 1972:** Enacted to protect wildlife and biodiversity, this act provides legal provisions for the conservation of species listed in Schedules I to IV. It establishes wildlife sanctuaries and national parks and regulates hunting and trade in wildlife and their products.
- **Forest (Conservation) Act, 1980:** The primary objective of this act is the conservation of forests and wildlife. It requires the central government's approval for diverting forest land for non-forest purposes like mining, industries, and infrastructure development to ensure sustainable forest management.

- **Environment Protection Act, 1986:** This overarching legislation empowers the central government to take measures to protect and improve the environment. It provides the framework for the formulation and enforcement of environmental standards and regulations.
- **Biological Diversity Act, 2002:** Enacted to meet India's obligations under the Convention on Biological Diversity, this act provides the legal framework for the conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of benefits arising from the utilization of genetic resources.

There are many other acts also present that additionally implicated to conserving the biodiversity of India, those are, the Fisheries Act 1897, Indian Forests Act 1927, Mining and Mineral Development Regulation Act 1957, Prevention of Cruelty to Animals 1960, Water (prevention and Control of pollution) act 1974, Forest Conservation Act 1980, Air (prevention and control of pollution) act 1981, Environment Protection Act 1986, Scheduled Tribes and other traditional forest dwellers (recognition of rights) act 2006.

6.9.1.2 Policies

- **National Forest Policy, 1988:** The policy aims to ensure environmental stability and maintenance of ecological balance, including the conservation of biodiversity. It emphasizes the need for afforestation, regeneration of degraded ecosystems, and the sustainable use of forests.
- **National Biodiversity Action Plan (NBAP), 2008:** This action plan outlines strategies and actions for biodiversity conservation in India. It includes measures for the conservation of ecosystems, sustainable use of biological resources, and the fair and equitable sharing of benefits arising from the use of genetic resources.
- **National Environment Policy, 2006:** The policy outlines India's approach to environmental management, emphasizing the integration of environmental concerns into development policies and programs. It promotes sustainable development and the conservation of natural resources.
- **National Wildlife Action Plan (NWAP), 2002-2016:** This plan provides a comprehensive framework for wildlife conservation in India. It includes strategies for habitat conservation, species recovery, and addressing threats to wildlife.
- **National Mission for Sustainable Agriculture (NMSA):** Part of the National Action Plan on Climate Change, NMSA focuses on promoting sustainable agriculture practices that enhance productivity while conserving biodiversity and natural resources.
- **National Clean Air Program (NCAP):** Launched to tackle air pollution, NCAP aims to enhance air quality monitoring, augmenting the capacity for pollution control,

and creating awareness. It recognizes the importance of clean air for human health and biodiversity.

Additional policies are, the National Conservation Strategy and Policy statement on Environment and Development, National Policy and macro-level action strategy on Biodiversity, National Biodiversity Action Plan (2009), National Agriculture Policy, National Water Policy, National Environment Policy (2006).

6.10 Conservation of biodiversity

Humans have been directly or indirectly dependent on biodiversity for sustenance to a considerable extent. However, increasing population pressure and developmental activities have led to large scale depletion of the natural resources. Conservation is the protection, preservation, management, or restoration of wildlife and natural resources such as forests and water. Through the conservation of biodiversity and the survival of many species and habitats which are threatened due to human activities can be ensured. There is an urgent need, not only to manage and conserve the biotic wealth, but also restore the degraded ecosystems.

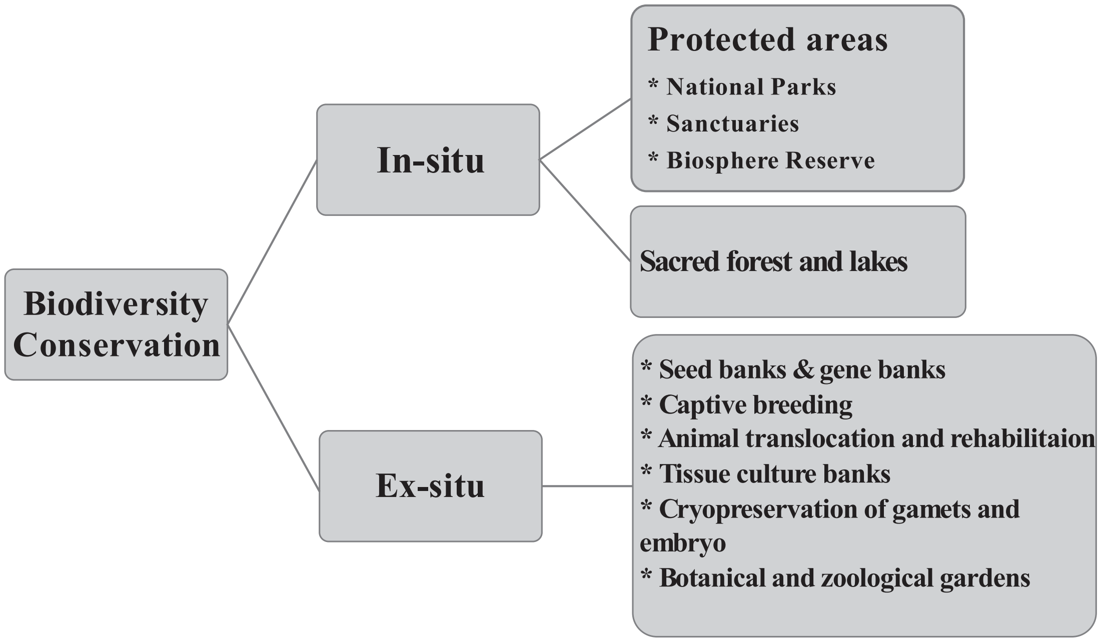


Figure 6.4: Biodiversity conservation

Conservation can broadly be divided into two types:

1. In-situ conservation

2. Ex-situ conservation

6.10.1 In-Situ Conservation Strategies:

In situ conservation means 'on-site conservation'. Here, the plant or animal species are protected in their natural habitat.

This is carried on by two methods: (i) Either by protecting or cleaning up the habitat itself. (ii) By defending the species from predators. Here stress is laid upon protection of total ecosystem. This leads to declaration of 'Protected Areas'. For protecting such areas, legal or other effective strategies are used.

6.10.1.1 Protected Areas in India:

These include:

a) National Parks b) Sanctuaries, and c) Biosphere Reserves.

a) National Parks:

A National Park is a place that is strictly protected with the aim of improving wildlife and biodiversity. In National Parks, it is against the law to engage in any kind of development, forestry, poaching, hunting, or grazing on agricultural land. If a location has sufficient ecological, geomorphologic, and natural significance, the Indian government may designate it as a national park. Indian wildlife is home to over 100 internationally renowned national parks. The International Union for the Conservation of Nature, or IUCN, has designated each of these national parks as belonging to the second category of protected places. Each state has at least one national park that showcases the vibrant local flora and animals.

Status of National Park in India

According to a survey conducted in December 2020, there are 106 National Parks in India that together span an area of 44,378 km^2, or 1.35% of the nation's total land area. In the Protected Area Network Report, 75 more national parks encompassing 16,608 km^2 of land are suggested. After full implementation, the number of parks will increase by 176. Raimona National Park (newest national park in India), Park in Assam was recently added, as India's 106th National Park, on June 5, 2021.

Table 8: Largest National parks of India

S. No.	National Parks in India	Area (km Square)
1	Hemis National Park	4,400.0
2	Desert National Park	3,162.0

3	Gangotri National Park	2390.0
4	Namdapha National Park	1985.2
5	Khangchendzonga National Park	1784.0
6	Guru Ghasidas (Sanjay) National Park	1440.7
7	Gir Forest National Park	1412.0
8	Sundarbans National Park	1330.1
9	Jim Corbett National Park	1318.5
10	Indravati National Park	1258.4

Some National Parks of India:

1. Kaziranga National Park, District Sibsagar (Assam) – Rhinoceros, elephant, wild buffalo, bison, tiger, leopard, sloth, bear, sambhar, swamp deer, barking deer, wild boar, gibbon, python and birds like pelican, stork and ring tailed fishing eagles. This is a famous National Park of famous one-horned rhinoceros of India.
2. Sundarbans (Tiger Reserve) 24 Pargana (West Bengal) – Tiger, wild boar, deer, dolphin, estuarine, crocodile.
3. Hazaribagh National Park, Hazaribagh (Bihar) – Tiger, leopard, hyaena, wild boar, gaur, sambhar, nilgai, chital, sloth, bear, peafowl.
4. Corbett National Park, Nanital (Uttarkhand) – Tiger, elephant, panther, sloth, bear, wild boar, nilgai, sambhar, chital, crocodile, python, king cobra, peafowl, partridge. This is the first National Park of India which is famous for tigers.
5. Gir National Park, District Junagarh (Gujrat) – Asiatic lion, panther, striped hyaena, sambhar, nilgai, chital, 4-horned antelope, chinkara, wild boar, langur, python, crocodile, green pigeon, partridge. This National Park is famous for Asiatic lions.
6. Kanha National Park, Mandla and Balaghat (Madhya Pradesh) – Tiger, panther, chital, chinkara, barking deer, blue bull, deer, langur, wild boar, black buck, nilgai, wild dog, sloth bear, sambhar, crocodile, grey horn bill, egret, peafowl.
7. Tandoba National Park, Chandrapur (Maharashtra) – Tiger, sambhar, sloth bear, bison, chital, chinkara, barking deer, blue bull, four-horned deer, langur, pea-fowl, crocodile.
8. Bandipur National Park, District Mysore (Karnataka) – Elephant, tiger, leopard, sloth bear, wild dog, chital, panther, barking deer, langur, porcupine, gaur, sambhar, malabar squirrel, green pigeon.
9. Desert National Park, Jaisalmer (Rajasthan) – Great Indian Bustard, black buck, chinkara.

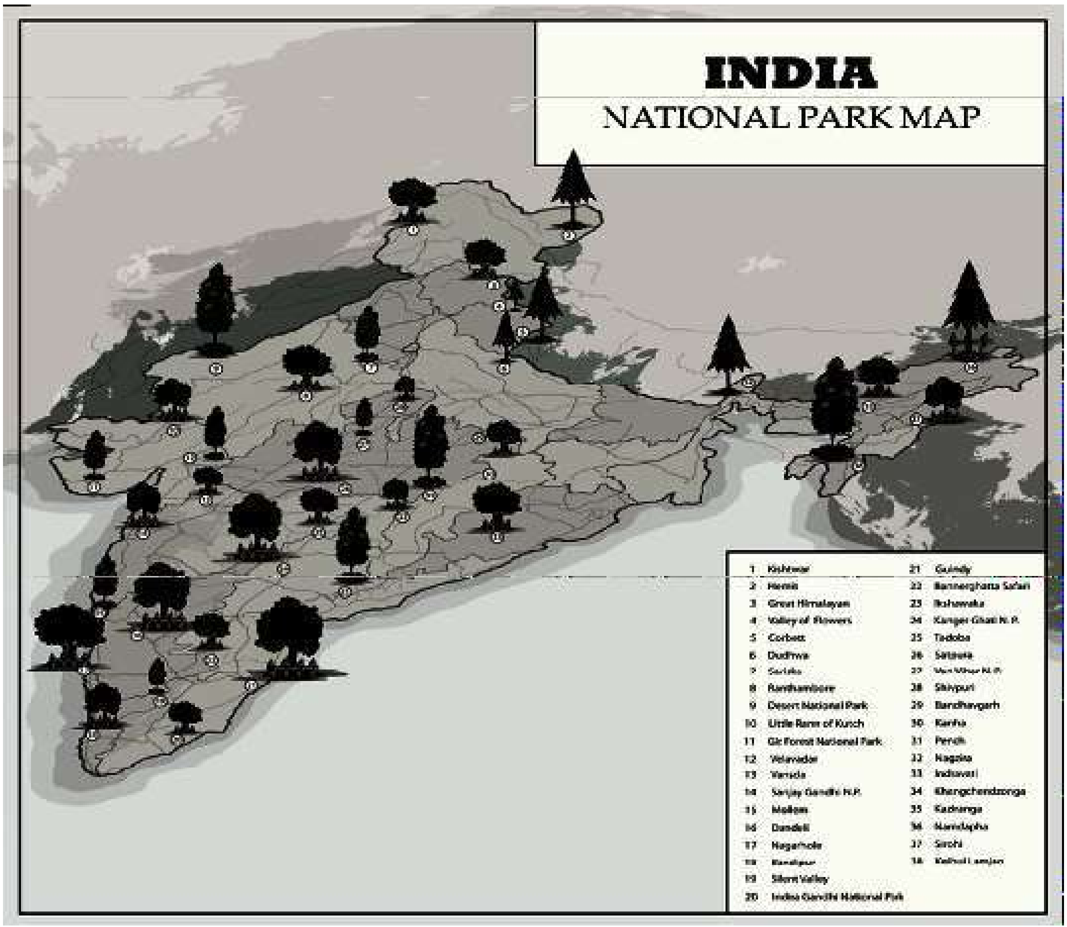


Figure 6.5: Geological representation of some National parks of India

b) Sanctuaries:

A sanctuary is a protected area which is reserved for the conservation of only animals and human activities like harvesting of timber, collection of minor forest products and private ownership rights are allowed so long as they do not interfere with the well- being of animals.

There are 567 existing wildlife sanctuaries in India covering an area of 122,564.86 km^2, which is 3.73% of the geographical area of the country (National Wildlife Database, Jan. 2023). Another 218 sanctuaries are proposed in the Protected Area Network Report covering an area of 16,829 km^2. The first sanctuary or national park established in India is Manas Wildlife Sanctuary which is many in one-a wildlife sanctuary, UNESCO Natural World Heritage site, a Project Tiger reserve, an elephant reserve and a biosphere reserve in Assam, India.

Some important sanctuaries of India are listed below:

1. Annamalai Sanctuary, Coimbatore (Tamil Nadu) - Elephant, tiger, panther, gaur, sambhar, spotted deer, sloth bear, wild dog, barking deer.
2. Jaldapara Sanctuary, Madarihat (West Bengal) - Rhino, elephant, tiger, leopard, gaur, deer, sambhar, different kinds of birds.
3. Keoladeo Ghana Bird Sanctuary, Bharatpur (Rajasthan) - Siberian crane, storks, egrets, herons, spoon bill, etc. Drier parts of this marshy sanctuary have spotted deer, black buck, sambhar, wild boar, blue bull, Indian rock python. This sanctuary is famous for birds.
4. Sultanpur Lake Bird Sanctuary, Gurgaon (Haryana) - Crane, saras, spotbill, duck, drake, green pigeon, wild bear, crocodile, phython.
5. Bir Moti Bagh Wildlife Sanctuary, Patiala (Punjab) - Nilgai, wild boar, hog deer, black buck, blue bull, jackal, pea-fowl, partridge, sparrow, myna, pigeon, dove.
6. Shikari Devi Sanctuary, Mandi (Himachal Pradesh) - Black bear, snow leopard, flying fox, barking deer, musk deer, chakor, partridge.
7. Dachigam Sanctuary, Srinagar (Jammu & Kashmir) - Hangul or Kashmir stag, musk deer, snow leopard, black bear, brown bear.
8. Mudumalai Wildlife Sanctuary, Nilgiri (Tamil Nadu) - Elephant, gaur, sambhar, chital, bar-king deer, mouse deer, four horned antelope, langur, giant squirrel, flying squirrel, wild dog, wild cat, civet, sloth bear, porcupine, phython, rat snake, monitor lizard, flying lizard.
9. Nagarjuna Sagar Sanctuary, Guntur, Kamool and Nalgonda (Andhra Pradesh) - Tiger, panther, wild bear, chital, nilgai, sambhar, blackbuck, foz, jackal, wolf, crocodile.
10. Periyar Sanctuary (Kerela) - Elephants, gaur, leopard, sloth, bear, sambhar, bison, black langur, hornbill, egret. It is famous for animals.
11. Chilka Lake Bird Sanctuary, Balagaon (Orissa) - An oasis of birds like water fowls, ducks, cranes, golden plovers, sand pipers, flamingoes.
12. Manas Wildlife Sanctuary, Kamprup (Assam) - Tiger, panther, rhino, gaur, wild buffalo, sambhar, swamp deer, golden langur, wild dog, wild boar.

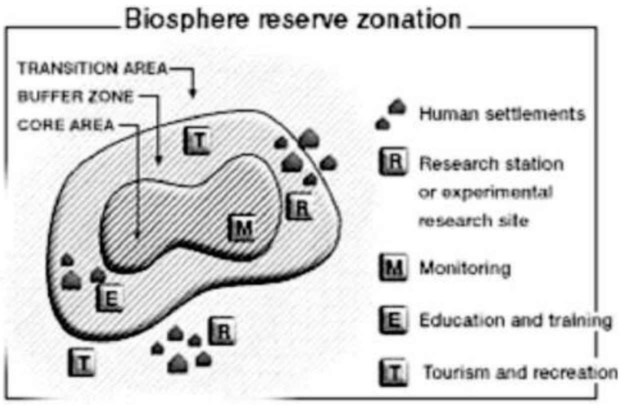
c) Biosphere Reserves:

Under MAB (Man and Biosphere) Programme, UNESCO has established a number of biospheres reserves in the world. The concept of Biosphere Reserves was launched by MAB in 1975 for dealing with the conservation of ecosystems and the genetic resources contained therein. Under MAB programme, UNESCO has studied the impact of human interference and pollution on biotic and abiotic environments and conservation strategies for the present as well as future.

A biosphere reserve is a specified area iii which multiple use of the land is permitted by dividing it into certain zones, each zone being specified for a particular activity.

Zones of a Biosphere Reserve:

A biosphere reserve is basically divided into three zones:



1. Core Zone: It lies at centre where no human activity is allowed. It is legally protected.
2. Buffer Zone: In this zone limited human activities are allowed. It surrounds core area.
3. Manipulative Zone (Transition Zone): In this zone multiple human activities are allowed but ecology is not permitted to be disturbed. It is the outermost part of biosphere reserve.

Biosphere Reserves in India:

In India, there are 18 Biosphere Reserves in India established by the government that protect large areas of natural habitats (Figure 6.6). The first biosphere reserve in the world was established in 1979. Till May 2005, there were 425 Biosphere Reserves located in 95 countries. The number assigned to a biosphere reserve is based on its date of declaration.

The purpose of declaration of biosphere reserve is to conserve bio-diversity in-situ along with its supporting system. Biosphere reserves with human beings as its integral parts are examples of natural biomes. First biosphere reserve established in India, was Nilgiri Biosphere Reserve (1986).

Nanda Devi Biosphere Reserve was established in 1988.

Date of notification of Nilgiri Biosphere reserve is 01.8.1986 with area of 5520 km2 and cover the states of Kerala, Kamataka and Tamil Nadu. Dibru-Saikhowa Biosphere reserve is present in Dibrugarh and Tinsukia districts of Assam. Sunderbans Biosphere reserve with an area of 9630 km^2 covers part of delta of Ganga and Brahmputra river system in West Bengal.

Panchmarhi covers an area of 4926 km^2 and lies in Madhya Pradesh. Kanchanjanga Biosphere reserve with an area of 2619 km is present in Sikkim. Manas Biosphere reserve is in Assam. Nokrek Biosphere reserve is in Meghalaya. Nanda Devi Biosphere reserve with an area of 5860 km^2 is present in Uttaranchal Gulf of Mannar Biosphere reserve is in Tamil Nadu.

Figure 6.6: Biosphere reserves of India map

Significance: The concept of Biosphere Reserves is of immense value for conserving the gene-pool resources of flora and fauna in the country and to serve as bench-marks for future studies.

The concept of Biosphere Reserve has the following objectives:

i. To conserve for present and future human race use, the diversity and integrity of biotic communities of plants and animals within natural ecosystems and to safeguard the genetic diversity of species on which their continuing evolution depends.

ii. To provide areas for ecological and environmental research.

iii. To provide facilities for education and training.

iv. To promote economic development.

d) Sacred Forests and Sacred Lakes:

Some forest patches are being protected by tribals due to religious sanctity are called sacred forests. Such forests have been found to be most undisturbed and they are usually surrounded by most degraded land scapes. Such sacred forests in India are present in states like Karnataka, Maharashtra, Kerela and Meghalaya. In Sikkim, Khecheopalri lake is declared sacred lake by people, thus protecting the aquatic flore and fauna.

6.10.2 Ex-Situ Conservation Strategies:

Such strategies include establishment of botanical gardens, zoos, conservation strands and gene, pollen, seed, seedling, tissue culture and DNA banks. These facilities not only provide housing and care for endangered species, but also have educational and recreational values for the society.

Few noteworthy points of ex-situ conservation are:

a) Seed Gene Bank or Germplasm Bank:

This is the easiest way to store the germ plasm of plants at low temperature. The term seed bank also refers to cryogenic laboratory facility in which the seeds of some species can be kept viable for long period. Germplasm can also be preserved by in vitro culturing where cutting of plants and maintained under controlled conditions.

Example: National Bureau of Plant Genetic Resources (NBPGR) Gene Bank, New Delhi, National Bureau of Animal Genetic Resources (NBAGR) National Gene Bank for Animal Genetic Resources, Karnal.

b) Cryopreservation:

This type of in vitro conservation is done at very low temperature i.e., -196°C in liquid nitrogen. This may be done with very rapid cooking (in storing seeds) or by gradual cooling and simultaneous dehydration (in tissue culture). Cryopreservation is highly successful in crops like potato. Example: National Bureau of Fish Genetic Resources (NBFGR), Lucknow.

c) Tissue culture bank:

Cryopreservation of disease-free meristems is very helpful. Long term culture of excised roots and shoots are maintained. Meristem culture is very popular in plant propagation as it's a virus and disease-free method of multiplication.

d) Captive breeding:

The method involves capture, maintenance, and captive breeding on long term basis of individuals of the endangered species which have lost their habitat permanently or certain highly unfavourable conditions are present in their habitat. Example: Indira Gandhi Zoological Park, Visakhapatnam (for endangered species like the fishing cat).

e) Botanical Gardens:

In more than 1500 botanical gardens and arboreta (botanical gardens where particular shrubs and trees are grum) in world. In such gardens more than 80,000 species are found. Example: Acharya Jagadish Chandra Bose Indian Botanic Garden (AJCBIBG), Kolkata.

Many botanical gardens have the facilities of seed banks, tissue culture and other latest ex-situ technologies.

f) Zoological Gardens:

In world, there are about 800 zoos. Such zoos have about 3000 species of vertebrates. Some zoos have undertaken captive breeding programmes. Example: Nehru Zoological Park, Hyderabad.

6.10.2.1 Limitations of Ex-Situ Conservation:

i) It stops the natural evolution and adaptations processes. In cryogenic preservation of specimens, adaptations processes come to halt altogether.

ii) Ex-situ conservation strategies are highly expensive.

iii) If fails to recreate the habitat as a whole. A species may adapt to changed environmental conditions due to genetic variation of a species, its symbiotic counter parts or other elements.

iv) Seed banks are not effective for few plant species with recalcitrant seeds do not show viability for long time.

6.10.2.2 Advantages of ex-situ preservation:

i) It is useful for declining population of species.

ii) Endangered animals on the verge of extinction are successfully breeded.

iii) Threatened species are breeded in captivity and then released in the natural habitats.

iv) Ex-situ centres offer the possibilities of observing wild animals, which is otherwise not possible.

v) It is extremely useful for conducting research and scientific work on different species.

Table 6.2: Some of the major Differences between In-situ and ex-situ Conservation are as follows

In situ Conservation	*Ex situ Conservation*
It is conservation of endangered species in their natural habitats.	It is conservation of endangered species outside their natural habitats.
The endangered species are protected from predators.	The endangered species are protected from all adverse factors.
The depleting resources are augmented.	They are kept under human supervision and provided all the essentials.
The population recovers in natural environment.	Offspring produced in captive breeding are released in natural habitat for acclimatization.

6.11 Convention on Biological Diversity (CBD)

The CBD, adopted during the Earth Summit in Rio de Janeiro in 1992, serves as the cornerstone of global efforts to safeguard biodiversity. It encompasses three main objectives: the conservation of biological diversity, sustainable use of its components, and the fair and equitable sharing of benefits arising from genetic resources. The CBD emphasizes the interconnectedness of ecosystems and recognizes biodiversity as essential for ecological stability and human well-being.

Key Objectives

The major key objectives of CBD are,

- Conservation of Biological Diversity: The primary objective of the CBD is to promote the conservation of biological diversity. This involves the protection of ecosystems, species, and genetic resources, recognizing their intrinsic value and the critical role they play in sustaining life on Earth.

- Sustainable Use of Biological Resources: The CBD emphasizes the sustainable use of biological resources, acknowledging that human well-being is intricately linked to the health of ecosystems. This objective encourages practices that allow for the utilization of biological diversity in a way that maintains ecosystem resilience and minimizes negative impacts.
- Fair and Equitable Sharing of Benefits: Recognizing the importance of genetic resources for various purposes, including scientific research and commercial applications, the CBD aims to ensure the fair and equitable sharing of benefits arising from the utilization of these resources. This principle is enshrined in the Nagoya Protocol, a supplementary agreement to the CBD.

Key Components of the CBD:

- National Biodiversity Strategies and Action Plans (NBSAPs): The CBD encourages its member countries to develop NBSAPs, which are comprehensive plans outlining strategies for biodiversity conservation and sustainable use at the national level. These plans take into account the unique ecological contexts and challenges faced by each country.
- Access and Benefit-Sharing: The CBD addresses issues related to access to genetic resources and the fair sharing of benefits arising from their utilization. The Nagoya Protocol, adopted in 2010, provides a legal framework for implementing these principles, ensuring that countries providing genetic resources are fairly compensated.
- Ecosystem Approach: The CBD promotes an ecosystem approach to biodiversity conservation. This approach considers entire ecosystems, including their structure, functioning, and the services they provide, recognizing that the conservation of biodiversity is intimately linked to the health and resilience of ecosystems.
- Cartagena Protocol on Biosafety: Established in 2000 as a supplementary agreement to the CBD, the Cartagena Protocol addresses the potential risks posed by modern biotechnology, particularly the transboundary movement of living modified organisms (LMOs). The protocol aims to ensure the safe transfer, handling, and use of LMOs to prevent adverse effects on biological diversity. A key provision of the Cartagena Protocol, Advanced Informed Agreement (AIA) ensures that countries are provided with information about the potential risks associated with the transboundary movement of LMOs, allowing them to make informed decisions and establish measures to manage these risks effectively.

- Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization was adopted in 2010. The Nagoya Protocol complements the CBD by addressing issues related to access to genetic resources and the fair sharing of benefits derived from their utilization. It aims to establish a transparent and equitable system for accessing genetic resources and sharing the benefits with the providers. Fundamental principles of the Nagoya Protocol, Prior Informed Consent (PIC) ensures that countries provide consent before genetic resources are accessed, and Mutually Agreed Terms (MAT) ensures that the terms for access and benefit-sharing are mutually agreed upon between the provider and user countries.
- Aichi Biodiversity Targets: Adopted in 2010 in Nagoya, Japan, the Aichi Biodiversity Targets represent a set of 20 specific, measurable targets organized under five strategic goals. These targets provide a strategic framework for global biodiversity conservation efforts until 2020. The Aichi Targets cover diverse aspects, including the conservation of ecosystems, sustainable use of biodiversity, and the fair and equitable sharing of benefits arising from the utilization of genetic resources. The strategic goals offer a comprehensive roadmap for global biodiversity conservation efforts until 2020.

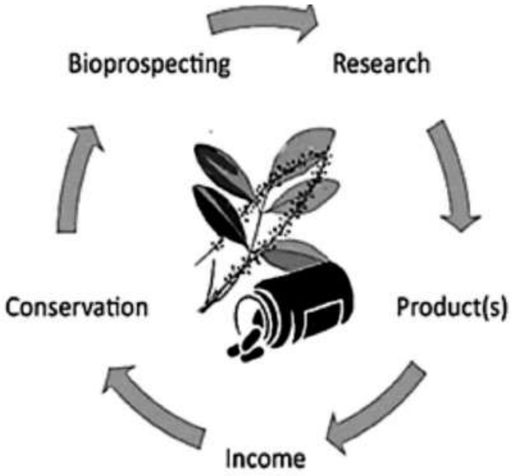


Figure 6.7: Bioprospecting

6.12 Bioprospecting

Bioprospecting, also known as bioprospecting for natural products or biopiracy, is a scientific and systematic exploration of biodiversity to discover, develop, and commercialize novel compounds or materials derived from living organisms. This practice has gained prominence in the fields of pharmaceuticals, agriculture, cosmetics, and various other industries, offering the potential for valuable discoveries with applications ranging from medicine to sustainable agriculture.

6.12.1 Exploring Biodiversity for Medicinal Compounds:

Medicinal Plants and Traditional Knowledge: Bioprospecting often involves the study of traditional knowledge held by indigenous communities regarding the use of plants for medicinal purposes. For example, the Madagascar periwinkle (Catharanthus roseus) is a plant traditionally used in folk medicine. Compounds derived from this plant, vincristine and vinblastine, have become essential in the treatment of leukemia and other cancers.

Microorganisms and Marine Organisms: The exploration of microbes and marine organisms has become a significant aspect of bioprospecting. Streptomycin, one of the first antibiotics, was discovered from a soil bacterium, Streptomyces griseus. Additionally, marine organisms like sponges and soft corals have yielded compounds with anti-cancer properties. For instance, the compound eribulin, derived from a marine sponge, is used to treat metastatic breast cancer.

6.12.2 Bioprospecting Process:

Bioprospecting is a systematic and scientific process that involves the exploration of biodiversity to discover, develop, and commercialize novel compounds or materials derived from living organisms. The aim is to harness the pharmacological potential of nature for various applications, including medicine, agriculture, and industry. The bioprospecting process typically involves several key stages:

i. **Identifying Target Areas:** Bioprospecting often begins with the identification of target areas rich in biodiversity. These areas may include tropical rainforests, coral reefs, deep-sea environments, or even unique terrestrial ecosystems. Researchers may collaborate with local communities and indigenous peoples, leveraging their traditional knowledge about the uses of various plants and organisms.

ii. **Collection of Biological Samples:** The next step involves the collection of biological samples from the identified target areas. This can include plants, microorganisms, marine organisms, and other living entities. Samples are collected with the goal of capturing the diverse genetic and chemical information present in these organisms. In the Amazon rainforest, the plant *Uncaria tomentosa*, commonly known as cat's claw, has been explored for its anti-inflammatory properties.

iii. **Ethnobotanical and Ethnopharmacological Studies:** In cases where traditional knowledge is involved, ethnobotanical and ethnopharmacological studies are conducted. These studies involve interactions with local communities and traditional healers to understand the traditional uses of plants and other organisms for medicinal purposes. This knowledge can guide researchers in the selection of specific species for further investigation.

iv. **Screening for Bioactivity:** Collected samples undergo a screening process to identify bioactive compounds. This involves testing extracts or isolated compounds for specific biological activities, such as antimicrobial, anti-inflammatory, or anticancer properties.

High-throughput screening techniques, involving automation and robotics, have significantly enhanced the efficiency of this stage. Taxol, an anti-cancer drug, was initially isolated from the Pacific yew tree (*Taxus brevifolia*).

v. **Isolation and Characterization:** Bioactive compounds are isolated from the screened samples using various laboratory techniques such as chromatography. Once isolated, these compounds undergo detailed chemical and biological characterization. Researchers aim to identify the structure of the compounds and understand their potential applications.

vi. **Bioassays and Preclinical Studies:** Isolated compounds are subjected to bioassays and preclinical studies to assess their efficacy, safety, and potential mechanisms of action. These studies involve testing the compounds on cells, tissues, or animal models to gather essential data before moving into clinical trials. The compound quinine, obtained from the bark of the cinchona tree, has been historically used to treat malaria.

vii. **Scale-Up and Production:** Compounds showing promising results in preclinical studies move to the scale-up phase. This involves optimizing production processes to ensure efficient and cost-effective extraction or synthesis of the bioactive compounds. It is essential to develop sustainable methods that can be scaled for commercial production.

viii. **Clinical Trials:** Compounds that pass preclinical studies may progress to clinical trials. Clinical trials involve testing the safety and efficacy of the compounds in human subjects. This phase follows a rigorous process with different stages (Phase I, II, and III) before regulatory approval is sought for commercialization.

ix. **Commercialization and Benefit-Sharing:** Upon successful completion of clinical trials and regulatory approval, the bioactive compounds can be commercialized. Access and Benefit-Sharing (ABS) agreements, guided by international frameworks like the Nagoya Protocol, ensure that benefits are shared equitably with the countries and communities that provide genetic resources.

x. **Monitoring and Sustainable Practices:** Ongoing monitoring of the impact of bioprospecting activities on ecosystems and local communities is essential. Sustainable practices, conservation efforts, and ethical considerations are crucial components of responsible bioprospecting, ensuring the long-term viability of both biodiversity and the industries that benefit from it.

6.12.3 Success Stories and Commercial Applications:

Bioprospecting has led to numerous success stories, with the discovery and development of novel bioactive compounds from diverse organisms. These success stories highlight the potential of bioprospecting to contribute to various industries, including pharmaceuticals, agriculture, and cosmetics. Here are some notable examples:

1. Taxol (Paclitaxel):

- **Source:** Pacific Yew Tree (*Taxus brevifolia*)
- **Bioactivity**: Anti-cancer properties
- **Commercial Application:** Taxol, isolated from the bark of the Pacific yew tree, has become a crucial chemotherapy drug for treating various cancers, including ovarian and breast cancer. Its success has paved the way for the development of other taxane drugs.

2. Artemisinin:

- **Source:** Sweet Wormwood (*Artemisia annua*)
- **Bioactivity:** Antimalarial properties
- **Commercial Application:** Artemisinin, extracted from the sweet wormwood plant, has revolutionized malaria treatment. It is a key component of artemisinin-based combination therapies (ACTs), which are now widely used as effective treatments for malaria worldwide.

3. Eribulin:

- **Source:** Marine Sponge (*Halichondria okadai*)
- **Bioactivity:** Anti-cancer properties
- **Commercial Application:** Eribulin, derived from a marine sponge, is used in the treatment of metastatic breast cancer. It inhibits the growth of cancer cells by disrupting microtubule dynamics, representing a significant advancement in cancer therapeutics.

4. Rapamycin:

- **Source:** Soil Bacterium (*Streptomyces hygroscopicus*)
- **Bioactivity:** Immunosuppressive and anti-cancer properties
- **Commercial Application:** Rapamycin, initially isolated from a soil bacterium, has immunosuppressive properties and is used to prevent organ transplant rejection. It also shows promise in the treatment of certain cancers.

5. Quinine:

- **Source:** Cinchona Tree (*Cinchona species*)
- **Bioactivity:** Antimalarial properties
- **Commercial Application:** Quinine, extracted from the bark of the cinchona tree, has historically been used to treat malaria. While synthetic antimalarials are more common today, quinine laid the foundation for malaria treatment.

6. Hoodia gordonii:

- **Source:** Hoodia Plant (*Hoodia gordonii*)
- **Bioactivity:** Appetite suppression

- **Commercial Application:** Hoodia gordonii, a succulent plant native to Southern Africa, gained attention for its traditional use by the San people to suppress appetite during long hunting trips. Although not widely commercialized due to challenges in sustainable harvesting, it sparked interest in appetite-suppressant products.

7. Enzymes from Extremophiles:

- **Source:** Various extremophiles (microorganisms thriving in extreme environments)
- **Bioactivity:** Industrial applications (e.g., heat-stable enzymes)
- **Commercial Application:** Enzymes derived from extremophiles have found applications in various industries, such as the textile and food industries, due to their stability under extreme conditions (high temperatures, acidic or alkaline environments).

8. Spider Silk Proteins:

- **Source:** Genetically modified bacteria and yeast producing spider silk proteins
- **Bioactivity:** High-tensile strength and elasticity
- **Commercial Application:** The genetic engineering of bacteria and yeast to produce spider silk proteins has led to the development of materials with impressive tensile strength and elasticity. Potential applications include lightweight and strong textiles.

9. Aloe Vera:

- **Source:** Aloe Vera Plant (*Aloe barbadensis miller*)
- **Bioactivity:** Skin healing and moisturizing properties
- **Commercial Application:** Aloe vera gel, extracted from the leaves of the Aloe vera plant, is widely used in cosmetics and skincare products for its soothing and moisturizing effects on the skin.

10. Bacterial Compounds for Antibiotics:

- **Source:** Various soil bacteria (e.g., Streptomyces species)
- **Bioactivity:** Antibacterial properties
- **Commercial Application:** Many conventional antibiotics, such as streptomycin, have been discovered from soil bacteria. These compounds have played a pivotal role in treating bacterial infections and saving countless lives.

These success stories underscore the diverse applications of bioprospecting and its potential to contribute to the development of new drugs, agricultural products, and industrial materials. As the field continues to advance, the exploration of biodiversity for valuable compounds remains a promising avenue for scientific discovery and innovation.

6.12.4 Challenges and Future Prospects:

Bioprospecting, while holding significant potential for scientific and commercial advancement, faces various challenges that necessitate careful consideration. Understanding and addressing these challenges is crucial for the responsible and sustainable development of bioprospecting. Here are the key challenges and future prospects:

1. Conservation Concerns:

- **Challenge:** Bioprospecting activities may pose a threat to biodiversity by potentially leading to the overexploitation of natural resources.
- **Future Prospect:** Integration of conservation practices into bioprospecting methodologies, promotion of sustainable harvesting, and the development of responsible management plans are essential. Collaboration with local communities and the integration of traditional ecological knowledge can contribute to sustainable practices.

2. Access and Benefit-Sharing (ABS):

- **Challenge:** Ensuring fair and equitable sharing of benefits with countries and communities providing genetic resources is complex and can lead to ethical and legal disputes.
- **Future Prospect:** Adherence to international agreements like the Nagoya Protocol, establishing clear ABS agreements, and fostering transparent partnerships between researchers and local stakeholders can address these challenges. These agreements should ensure that benefits are shared justly and transparently.

3. Ethical Considerations:

- **Challenge:** Bioprospecting raises ethical concerns related to informed consent, respect for traditional knowledge, and the potential exploitation of local communities.
- **Future Prospect:** Development and adherence to ethical guidelines, meaningful consultations with local communities, and respect for intellectual property rights and traditional knowledge are critical. Establishing ethical standards ensures that bioprospecting activities are conducted with integrity and respect for the rights of all stakeholders.

4. Legal Frameworks and Regulations:

- **Challenge:** The lack of standardized and universally accepted legal frameworks for bioprospecting can result in inconsistent regulations across different countries.
- **Future Prospect:** Strengthening and harmonizing international and national legal frameworks is crucial. Encouraging adherence to existing agreements and promoting the development of clear and comprehensive regulations will create a more stable environment for bioprospecting activities.

5. Technological Advancements:

- **Challenge:** While technological advancements have enhanced bioprospecting capabilities, they also raise concerns about potential overexploitation and unintended consequences of genetic manipulation.

- **Future Prospect:** Responsible use of technology, such as advanced genomics and synthetic biology tools, can aid in more targeted and efficient bioprospecting. However, ethical considerations must guide the use of these technologies to ensure environmental and societal well-being.

6. Benefit to Indigenous Communities:

- **Challenge:** Ensuring that benefits derived from bioprospecting activities directly contribute to the well-being of indigenous communities can be challenging.
- **Future Prospect:** Developing mechanisms for community involvement, capacity-building, and benefit-sharing can enhance the positive impact of bioprospecting on local communities. Establishing partnerships that prioritize community needs and aspirations is essential.

7. Scientific Collaboration:

- **Challenge:** Effective collaboration between scientists, local communities, and industry stakeholders is essential but may face communication and trust barriers.
- **Future Prospect:** Building strong collaborative networks, fostering mutual respect, and promoting knowledge exchange between scientific and local communities can lead to more successful and sustainable bioprospecting initiatives. Open and transparent communication channels are vital.

8. Climate Change Impact:

- **Challenge:** Climate change can alter the distribution of species and affect the availability of certain organisms for bioprospecting.
- **Future Prospect:** Monitoring and adapting to climate change impacts, combined with a focus on sustainable practices, can help mitigate the challenges posed by shifting ecological conditions. Research on climate-resilient organisms and ecosystems may become increasingly important.

9. Intellectual Property Rights (IPR):

- **Challenge:** Issues related to the patenting of biological resources and traditional knowledge can lead to conflicts over intellectual property rights.
- **Future Prospect:** Developing fair and balanced IPR mechanisms that consider the interests of all stakeholders is crucial. Collaborative agreements that acknowledge and respect traditional knowledge while fostering innovation can contribute to a more equitable distribution of benefits.

10. Public Awareness and Education:

- **Challenge:** Lack of public awareness and understanding of the importance of biodiversity and the ethical dimensions of bioprospecting can hinder support for sustainable practices.
- **Future Prospect:** Implementing educational programs and raising public awareness about

biodiversity conservation, the value of traditional knowledge, and the ethical considerations in bioprospecting can foster a more informed and supportive society.

Bioprospecting holds the promise of unlocking nature's pharmaceutical treasure trove, offering innovative solutions for human health and various industries. Ethical considerations, legal frameworks, and conservation efforts are paramount to ensure that the benefits are shared equitably, and that the exploration of biodiversity is conducted responsibly and sustainably. As technology continues to advance, the potential for discovering novel bioactive compounds from diverse ecosystems becomes even more exciting, opening new frontiers in the field of bioprospecting.

6.13 Bio-piracy in India

Since the last two decades multinational corporations are profiting by patenting the indigenous knowledge and resources of Indian hotspots and associated communities. Bio-piracy is hampering the livelihoods of communities and farmers who have invested their time, care, hard work and knowledge in restoring their heritage. An account of various medicinal plants like turmeric, neem, basmati rice, ashwagandha, pudina, kalmegh, aloe-vera, karela, jamun and brinjal have been given, which are victimized by bio-piracy and where India have successfully put forward its perspective in the international courts and came forth as a winner. This is the ripe time where genuine efforts are required from government, Non Government Organization (NGO)'s, scientists and publishers to restrict highly ambitious pharmaceutical and biotechnological firms to escort our national wealth. There is a dire need of modification or amendments in international and national rules in order to safeguard national interests and to negate the privatization of international knowledge and resources. So far, the best solution provided by India has been the construction of databases and traditional knowledge archives -Traditional Knowledge Digital Library (TKDL) to endorse the preservation, promotion, dissemination and exercising suitable use of traditional knowledge as 'Prior art'.

India is a land of traditions and here knowledge is acquired over centuries unknown. India supports about 15% of world's population owing to its unique geographical location and diverse cultures. Our traditional knowledge (TK) is an integral part of our cultural identity and has been playing a vital role in our day to day life from time immemorial as traditional knowledge is the only means of livelihood in rural areas. Besides India, about 80% population of developing countries depend on medicines obtained from traditional plants to meet their health care needs.

Local communities of a particular country imbibe traditional knowledge regarding medicinal values of plants and the same is passed on with incremental improvements over generation. Although, a part of this knowledge is documented but its interpretation is cumbersome because of the involvement of local script used. Due to this unsynchronized documentation of traditional knowledge, patents are often granted to facilitate those persons who traditionally don't owe this knowledge but reap massive profits, there by leading to conflicts in the market interests of the parties involved as the original stakeholders of the traditional knowledge are dissatisfied as no profit flows back to them.

Bio-piracy implies any attempt to acquire proprietary rights over biological resources and its associated indigenous knowledge, or upon product(s) based on them, neglecting the consent and contribution of the bearers of such resources and knowledge. Put differently, bio piracy is defined as a process in which living resources or traditional knowledge and practices are patented, thus applying intellectual property restrictions to their use. These practises will lead to inequality between the developed countries (supported by transnational corporations) and developing countries (dependent solely on their indigenous resources). The issue of bio-piracy is touching threatening horizons because the western countries are toying with the patents of crucial traditional and indigenous products of the progressing nations.

Recently, Ayurveda has captured the interest and excitement of the western part of globe, especially Europe and United States. The ayurvedic knowledge is gaining global attraction as well as adoption due to the awareness regarding the adverse effects of allopathy leading to bio piracy. The Convention on Biological Biodiversity has added up a synergistic effect to the problem by providing a tool of free accession in the hands of multinational companies to the indigenous natural resources and after screening the indispensable resource, gets the exclusive rights for such plants and debaring the natives of their rights of cultural and traditional use.

Similarly, Geographical Indications (GIs) are under serious threats from bio-pirates as domestic regulations of individual nations are inefficient in international markets without suitable rectifications in TRIPS where commodities are moving beyond borders.

Bio pirates carry out their operations under a veil of legality i.e., the international patent system. They make the fields and forests of developing countries their target and apply for exclusive rights in the form of patents- the Intellectual Property Rights (IPR) Protection. An invention should be novel, useful and non-obvious to be patentable but in countries like Japan, United States and Europe, patents are granted for plant varieties which are hardly novel. As stated by the United Nations Human Development Report of 1999 "the current patent system is leading to the silent theft of centuries of knowledge from the developing to developed countries" demands amendments in the current patent law.

With these modern generous policies, the supremacy of rural India is under threat. TRIPS has opened the channels for multinational corporations based on agro-business to involve themselves in bio piracy, geographical indication and genetically modified (GM) seed dominance, thus a set back to our rural and traditional localities. The companies are manipulating the IPR's according to their own advantage, thus making the patents ineffective which in turn put the traditional farmers on a defensive side. A big chunk of farmers have lost their right to grow and possess control over the production cycles leading to indebtness, disempowerment and posing as a danger to their survival.

India has aggressively commenced its struggle against bio-piracy and is successful in revoking a number of patents around the world. The following is an account of ayurvedic drugs against which India has opposed and emerged as a winner.

6.14 Bio-piracy and the difficulties in protecting traditional knowledge

While bio-piracy is inherently an act of appropriation of traditional knowledge by individuals and corporations for commercial gain, there are existing difficulties in protecting such knowledge that allow attempts at appropriation. These include:

1. Collective Resource: Intellectual Property Rights (IPR) provide protection to individual ownership of knowledge but traditional knowledge usually belongs to a community or a tribe who have been practising it for generations.
2. Criteria of novelty in IPR: Most traditional knowledge is not based on scientific methods of assessment and evolves organically with the help of communities as a response to new challenges and needs. The evolution of such knowledge across generations means that the novelty or innovative factor is non-existent. Thus, such knowledge fails to meet the criteria of novelty required for IPR patents.
3. Limited protection under IPR: Traditional knowledge requires protection for an indefinite period simply because it is associated with the living practices of an indigenous population. These practices may also be vulnerable to appropriation (Bijoy: 2007). At present, the Indian Patents Act does not allow for evergreening of patents.
4. Problem of benefit-sharing: When it comes to sharing monetary and other benefits after commercialisation of a traditional practice through a legal procedure, it is sometimes difficult to identify the beneficiary. For instance, in the mid-1990s,

scientists at the Tropical Botanic Garden and Research Institute (TBGRI) developed and patented a drug called "Jeevani". The development of the drug borrowed heavily from the medicinal knowledge of the energising properties of Arogyapacha herb, from the Kani tribe in Kerala. Although TBGRI ended up signing a benefit-sharing agreement with a trust with members from the Kani tribe, not all Kani people agree with the arrangement claiming traditional rights on beneficial properties of the herb (Bijoy 2007).

5. Lack of documentation: Traditional knowledge is usually a product of learning through experience and oral traditions passed over centuries. It may have been generated, transmitted, and strengthened through rituals, songs, oral history, human interactions, ceremonies, languages, experiences, and practices. These traditions are often inaccessible to the patentee or the concerned authority due to the lack of formal documentation.
6. Language Barriers: Even in cases where it is documented, traditional knowledge exists in vernacular languages, which may act as a barrier when it comes to it being universally accessible.

6.14.1 Institutional efforts at preserving traditional knowledge

Over the years there have been several national and international policies/conventions to secure the rights of source countries as well as indigenous populations over traditional knowledge. At the national level, one such intervention is the Traditional Knowledge Digital Library (TKDL) which was created to overcome the problem of documentation and availability of information about traditional knowledge in the public domain (Tarunika and Tamilselvi 2018: 1256). TKDL is a collaborative project between the Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology and the Ministry of Ayurveda, Yoga & Naturopathy, Unani, Siddha and Homoeopathy (AYUSH). It documents traditional knowledge from existing literature in a digitised format, in five international languages, viz. English, French, German, Spanish and Japanese (James 2018). It allows access to this information to patent offices around the world under an access agreement. Although there is no specific legislation for the protection of traditional knowledge in India, the pre-existing legal framework for IPR as well as other acts provide for protection of traditional knowledge through various provisions:

1. The Indian Patents (Amendment) Act 1970: The Act has provisions for mandatory disclosure of source and geographical origin of the biological material used in the invention while applying for patents. Provisions include non-disclosure or wrongful disclosure of known traditional knowledge as grounds for opposition and for revocation of the patents, if granted.

2. The Trade Marks Act 1999: Trademarks can be used to secure protection for the Indian System of Medicine practices since the Trade Marks Act extends to services as well.
3. The Geographical Indications of Goods (Registration and Protection) Act 1999: The Act facilitates protection of collective rights of rural and indigenous communities and their traditional knowledge (Tarunika and Tamilselvi 2018: 1256). By registering an item which is the product of traditional knowledge, as GI, it can be protected indefinitely by renewing the registration when it expires after a period of ten years.
4. Biological Diversity Act 2002 (NBD): The Act establishes a three-tier institutional structure for biodiversity governance in India - National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs) and Biodiversity Management Committees (BMCs). The Act makes applications for IPRs of products/inventions that use traditional knowledge subject to approval by competent authorities. Under the Act, BMCs prepare People's Biodiversity Registers (PBR) in consultation with local communities. PBRs contain comprehensive information on availability and knowledge of local biological resources, their medicinal or any other use or any other traditional knowledge associated with them.
5. Protection of Plant Varieties and Farmers Rights Act 2001 (PPVFR): Among other provisions for recognition of traditional knowledge of farmers, it stipulates benefit-sharing, recognition, and reward (through a Gene Fund) for farmers engaged in the conservation of genetic resources of plants.

At the international level, measures for protection of traditional knowledge range from a mix of binding as well as non-binding agreements. The Convention on Biological Diversity (CBD) was the first move towards international dialogue on the protection of biodiversity and TK protection (Ministry of Environment, Forest and Climate Change 2019). Subsequently, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) 2007 provides indigenous peoples "the right to maintain, control, protect and develop their intellectual property over their cultural heritage, traditional knowledge, and traditional cultural expressions" (United Nations 2007: 23). Under the Declaration, states have to provide "redress through effective mechanisms...developed in conjunction with indigenous peoples, with respect to their cultural, intellectual, religious and spiritual property taken without their free, prior and informed consent or in violation of their laws, traditions and customs.". Additionally, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was adopted by the FAO in 2004. Through an innovative multilateral system of access and benefit sharing, the treaty allows citizens of signatory countries to use the resources provided, as long as they use them for non-commercial purposes and that they do not acquire IP rights over such resources (Food and Agriculture Organization). However, most prominently under the World Trade Organisation (WTO), the Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement as it stands does not extend protection to traditional knowledge. As a result, proponents of protection of traditional knowledge have missed a key opportunity to benefit from the effective implementation and enforcement mechanism of the WTO.

India is prone to Bio-piracy because of its being the earth's richest biodiversity. Bio-piracy provides scarce biological resources to the monopoly control of corporations thus depriving local communities the benefits of its use. It creates market monopolies and excludes the original stakeholders (farmers) from their rightful share to local, national, and global markets. In order to restrict bio-piracy there is a desperate need to make amendments in TRIPS, Biodiversity Bill, Seed Bill and Patent Bill as these are enforced in a hurry to comply with global changes. Ayurvedic courses should be upgraded to accommodate patent awareness among professional, academicians and researchers. GIs should also address the rights of our farmers to use, save, exchange, and improve their seeds for domestic production or protection of our indigenous knowledge. Bio-piracy is a serious tool used by highly desirous pharmaceutical and biotechnological firms which should be restricted and opposed and demands attention and efforts from government, Non-government organizations, scientists and publishers in public and national interests. An attempt has been made in this article to support the developing countries who are victim of bio-piracy by the highly covetous developed countries who are toying with the traditional knowledge of the indigenous residents under the veil of legality-the international Patent System.

6.15 Summary

- A measure of variety at the genetic, species, and ecological levels is called biodiversity.
- The main direct cause of biodiversity loss is land use change.
- The five main threats to biodiversity are habitat loss, pollution, overexploitation, invasive species, and climate change.
- India hosts four biodiversity hotspots: the Himalayas, the Western Ghats, the Indo-Burma region and the Sundaland.
- Megadiverse countries are those which contain the majority of the planet's natural wealth. Only 17 nations are home to between 60 and 80% of life on Earth.

- There are primarily two methods of biodiversity conservation: (a) In-situ Conservation (b)Ex-situ Conservation.
- When traditional knowledge is used without permission by the researchers, or exploit the cultures they are drawing from - it's called biopiracy. Indian government takes a strong stance on protecting its ancient knowledge from being patented by other countries.

6.16 Self-Assessment questions

MCQ type question

1. Spoon-billed Sandpiper is a _______ bird of India.
   a) Endangered
   b) Rare
   c) Vulnerable
   d) Critically Endangered
2. One horned Rhinoceros found on
   a) Sunderban
   b) Bandhabgarh
   c) Kaziranga
   d) Nilgiri
3. Which extinct in India mammal recently brought back to India from Africa
   a) Dodo
   b) Cheetah
   c) Water buffalo
   d) Sumatran rhinoceros
4. Khecheopalri lake is a
   a) Ramsar site
   b) Wasteland
   c) Sacred lake

d) Picnic spot

5. Biodiversity hotspot has been lost _____ of original native habitat

a) ≥ 30%

b) ≥ 70%

c) ≥ 50%

d) ≥ 90%

Short answer type questions

1. What are the different types of biodiversity? What are the reasons behind the loss of biodiversity?
2. Distinguish between In-Situ and Ex-Situ approaches of conservation of biodiversity.
3. Why certain regions have been declared as biodiversity hot spots by environmentalists of the world? Name any two hot spot regions of India.
4. What is megadiverse countries? Name them all.
5. What is Cryopreservation, Germplasm bank and Tissue bank?

Long answer type questions

1. What are the difficulties in protecting biopiracy in India? What are the institutional efforts at preserving traditional knowledge?
2. Give brief account on different In-situ and Ex situ conservation strategies with suitable Indian example.
3. What are the major threats to biodiversity? Give one example of Extinct, rare, endangered, threatened flora and fauna of India.

6.17 Suggested Readings

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