BIODIVERSITY AND SYSTEMATICS

M.Sc. Zoology

Semester-I, Paper-II

Lesson Writers

Prof. G. Simhachalam
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

Prof. K. Veeraiah
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

Prof. K. Sumanth Kumar
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

Prof. P.V. Krishna
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

Dr. N. Gopala Rao
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

Editor

Prof. G. Simhachalam
Dept. Zoology & Aquaculture,
Acharya Nagarjuna University,
Guntur

DIRECTOR, I/c.
Prof. V. Venkateswarlu
M.A., M.P.S., M.S.W., M.Phil., Ph.D.
Professor
Centre for Distance Education
Acharya Nagarjuna University
Nagarjuna Nagar 522 510

Ph: 0863-2346222, 2346208
0863- 2346259 (Study Material)
Website www.anucde.info
E-mail: anucdedirector@gmail.com

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FOREWORD

Since its establishment in 1976, Acharya Nagarjuna University has been forging ahead in the path of progress and dynamism, offering a variety of courses and research contributions. I am extremely happy that by gaining 'A+' grade from the NAAC in the year 2024, Acharya Nagarjuna University is offering educational opportunities at the UG, PG levels apart from research degrees to students from over 221 affiliated colleges spread over the two districts of Guntur and Prakasam.

The University has also started the Centre for Distance Education in 2003-04 with the aim of taking higher education to the door step of all the sectors of the society. The centre will be a great help to those who cannot join in colleges, those who cannot afford the exorbitant fees as regular students, and even to housewives desirous of pursuing higher studies. Acharya Nagarjuna University has started offering B.Sc., B.A., B.B.A., and B.Com courses at the Degree level and M.A., M.Com., M.Sc., M.B.A., and L.L.M., courses at the PG level from the academic year 2003-2004 onwards.

To facilitate easier understanding by students studying through the distance mode, these self-instruction materials have been prepared by eminent and experienced teachers. The lessons have been drafted with great care and expertise in the stipulated time by these teachers. Constructive ideas and scholarly suggestions are welcome from students and teachers involved respectively. Such ideas will be incorporated for the greater efficacy of this distance mode of education. For clarification of doubts and feedback, weekly classes and contact classes will be arranged at the UG and PG levels respectively.

It is my aim that students getting higher education through the Centre for Distance Education should improve their qualification, have better employment opportunities and in turn be part of country's progress. It is my fond desire that in the years to come, the Centre for Distance Education will go from strength to strength in the form of new courses and by catering to larger number of people. My congratulations to all the Directors, Academic Coordinators, Editors and Lesson-writers of the Centre who have helped in these endeavors.

Prof. K. Gangadhara Rao
M.Tech., Ph.D.,
Vice-Chancellor I/c
Acharya Nagarjuna University.

ACHARYA NAGARJUNA UNIVERSITY
M.Sc. ZOOLOGY
SEMESTER-I
PAPER -II

BIODIVERSITY AND SYSTEMATICS
Syllabus
102ZO24 - BIODIVERSITY AND SYSTEMATICS

Course Objectives/Course outcomes :

CO-l: To introduce basic concepts and significance of biodiversity and distribution of world.
CO-2: To analyze Hierarchical components of biodiversity, values and losses.
CO-3: Create awareness about systematic and species identification scientifically.
CO-4: Create knowledge about biodiversity management; in-situ and ex-situ conservation through technical aspects.
CO-5: Applied biotechnology in biodiversity including molecular taxonomy, GIS.

UNIT -I

Biodiversity: Definition and significance; biodiversity at global, national and local levels: magnitude and distribution of biodiversity. Patterns of biodiversity: Latitudinal and Longitudinal gradients; species area relationship Biogeographic realms of the world. Biogeographic zones of India and faunal diversity; Hotspots in the world and in India. Learning outcome: ' Being aware of the significance and faunal diversity, distribution of hotspots in biogeographic realms at international, national, local levels and their patterns in respect of their latitude and altitudinal gradients. Analyze species area relationship.

UNIT - II

Hierarchical components of biodiversity: Species diversity, genetic diversity and ecosystem diversity. Biodiversity values: Direct values and indirect values. Biodiversity in peril: Causes of biodiversity losses and extinction; anthropogenic impact on biodiversity. Learning outcome: o Students have a good understanding of the Hierarchical components of the biodiversity, analyse and evaluate the values of biodiversity and investigate the losses and extinction of biodiversity through anthropogenic activity.

UNIT - III

Systematics: Species concept. Taxonomy and its components Identification: Keys, biodiversity documentation, species identification and identification tools. Nomenclature: International Code of Zoological Nomenclature (ICZN); Types: Holotype, Paratype, Neotype, Lectotype, Syntype, Homonymy and Synonymy. Learning outcome: Upon completion of this unit Student be aware about systematics, concepts, classification and phylogeny. Examine and execute species identification through tools by follow ICZN.

UNIT-IV

Biodiversity management and conservation IUCN classification of wildlife. Biodiversity threats; In-situ conservation and Ex-situ conservation. Gene banks; conservation of genetic resource; cryopreservation. Wildlife protection acts organizations involved in protection of Biodiversity. Learning outcome: Student will learn about status of biodiversity through IUCN classification and implementation of various wildlife protection acts for conservation and management.

UNIT- V

Biodiversity and biotechnology: DNA based wildlife forensics; genetically modified organisms (GMOs) and Bioremediation. Molecular taxonomy: DNA fingerprinting. Satellite Remote Sensing and GIS programs; Environmental Impact Assessment (EIA). Learning outcome: Knowledge applied through biotechnology helps the DNA based wildlife forensics, GMOs, molecular taxonomy and also GIS programmes helps in the observation of movement of wild animals and evaluate environmental problems through EIA'

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CONTENTS

LESSON-1

BIODIVERSITY: DEFINITION AND SIGNIFICANCE

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to

- Understand the concept of Biodiversity and its definition and significance.
- Understand the characteristics of Biodiversity at the National and Global levels.
- Explore the Distribution of biodiversity.
- Know about the magnitude of biodiversity.

STRUCTURE

1.1. INTRODUCTION

Every organism is unique. Differences or variations among them are only within certain limits. These differences or variations are referred to as diversity. Diversity is the essential characteristic of all living organisms at their multiple levels of organisation. The most fundamental differences among the organisms are generally recognised primarily in their levels of biochemical and genetic constituents, morphology, ecological roles (functional attributes), and behavioural traits. Such diversity of living organisms constitutes all levels of natural variations, such as from genetic material (genetic diversity), from species richness to relative abundance (species diversity), as well as from their ecological roles (functional diversity) to ecological processes, including their interactions. The synthetic approach of all these variations is termed biodiversity (combining biological diversity).

The term biodiversity was initially used by Lovejoy (1980) to include the number of species of a region or a taxon only 51, two related concepts, genetic diversity and ecological diversity, were tagged to biological diversity later. Norse, et al. (1986) referred to biological diversity in three levels, genetic diversity (variation within species), species diversity (species number) and ecological diversity.

Diversity within the population of a species is the genetic diversity, between the species is species or taxonomic or organismal diversity and within and between the ecosystems is the ecological or habitat diversity (community/ecosystem diversity). So, biodiversity is understood as the interaction of these three components, and the totality of the variety of species, the genetic variation within these species and the ecological roles they play in a given community, in space and time. Therefore, Di Casti, F. and Younès, T. (1995) defined biodiversity, 'the ensemble and the interactions of the genetic, species and the ecological diversity, in a given place and at a given time' It should be noted that these interactions are of hierarchical nature that forms the central phenomenon of biodiversity. It is a transdisciplinary scientific field- The unique trilogy of biodiversity.

Biodiversity commonly deals with the number, variety and variability of living organisms of an area or an ecosystem. Since biodiversity consists of genetic, species, and ecosystem diversity, each component needs detailed discussion to determine a conservation strategy. (i) Genetic diversity is pivotal to all levels of biological diversity and is a potent factor in evolutionary processes. Conserving genetic diversity means conserving the genetic variety of plants, animals, rare breeds and cultivars. (ii) Conservation of species diversity means conserving the variety of species, preserving the interaction between species and processes in an ecosystem, or the variety of populations of a single species. (iii) Conservation of ecosystem diversity refers to conserving the variety of life occurring in an ecosystem, functional groups (for example, pollinating insects), ecological processes (nutrient cycling), and the life-supporting systems. Population (with their gene pools), species and ecosystems are considered the cornerstones at the intersection of these three scales.

Biological diversity also takes into account higher taxa such as phylum, class (taxonomic diversity), including other units. Organismal diversity, on the other hand, is synonymous with species diversity as species is the building block of both diversity and evolution.

The success of long-term conservation of biological diversity of any area or ecosystem depends on the integrated efforts to protect diversity sustainably. Primary attempts have been made to determine the fundamental biological characteristics, such as genetic variations, species richness, relative abundance and pattern of distribution, besides ecological roles and processes. So, it is mandatory to ascertain the potential utility of biodiversity for human benefit. For the determination of conservation strategies, five divisions, such as genes, population, species, assemblage (associations and communities) and the entire system, are considered.

1.2 DEFINITION

Biodiversity, or **biological diversity**, refers to the variety of life on Earth, including **genes, species, and ecosystems**. It encompasses the richness of different plants, animals, microorganisms, and their interactions within various habitats. Biodiversity is essential for maintaining **ecosystem stability, resilience, and functionality**, as it supports processes like pollination, nutrient cycling, climate regulation, and disease control. Biodiversity plays a crucial role in sustaining life, providing resources for food, medicine, and industry, and maintaining ecological balance. Human activities, such as deforestation, pollution, and climate change, threaten biodiversity, making its conservation vital for the health of the planet and future generations.

Biodiversity includes not only the world's species, each with its unique evolutionary history, but also genetic variability within and among populations of species and the distribution of species across local habitats, ecosystems, landscapes, and whole continents or oceans. Understanding what constitutes and defines biodiversity is essential for managers and policy-makers who must attempt to incorporate its values into their land and water management plans. It is only when we understand all the interacting scientific dimensions of biodiversity outlined in this chapter that we can appreciate the levels of information that must be considered. Biodiversity management options are inevitably constrained by a combination of biological and sociopolitical realities.

The word biodiversity is used in many ways. Economists and ecologists, ranchers and gardeners, mayors and miners all view biodiversity from different perspectives. When people discuss biodiversity, they often use it as a surrogate for "wild places" or "abundance of species" or even "large, furry mammals". Yet from the viewpoint of those engaged in biodiversity-related sciences such as population biology, ecology, systematics, evolution, and genetics biodiversity has a specific meaning: "the variety and variability of biological organisms". The Convention on Biological Diversity similarly defines biodiversity as the "variability among living organisms from all sources". Those definitions are so broad that they can be clearly understood only by considering particular levels of biological organisation genes, species, communities, ecosystems, and even our planet. Each level requires different methods of analysis, different modes of understanding, and, ultimately, different approaches to management. For managers, it is not just a matter of counting species or individuals. Managers must consider the role of biodiversity in the functioning of ecosystems and the effects of management and use of resources on ecosystem processes.

George Evelyn Hutchison (1965), one of the founders of modern ecology, wrote about the "evolutionary play in the ecological theatre". This multilayered drama generates, sustains, shapes, and sometimes even diminishes biodiversity. Charles Darwin's reflections on species diversity underlay one of the most far-reaching theories in the history of ideas: the theory of evolution by natural selection. His travels from England to the strikingly different landscapes of the New World left him awestruck and inspired. Whatever constitutes biodiversity, Darwin recognised that Brazil had a lot of it and certainly more than he left behind in an English midwinter. No modern biologist would disagree. Like Darwin, we often equate biodiversity with the number and novelty of the species present.

1.2.1 Biodiversity is typically categorised into three main levels

- **Genetic Diversity:** Genetic diversity refers to the variety of nucleotides, genes, chromosomes, or the entire genome of the organisms within a species. It includes differences in DNA among individuals of the same species, such as variations in colour, size, disease resistance, and adaptability to the environment. High genetic diversity helps species survive environmental changes, pests, or diseases because some individuals may have traits that help them adapt and survive. For example, different varieties of rice or wheat have different genetic traits suited to different climates.

Genetic diversity plays an important role in the survival and adaptation of a species as even slight variations in genes may produce favourable changes in phenotype for organisms to adapt in a changed environment. A Large degree of genetic diversity among its population has proved to increase its fitness, and thus, an increase in genetic diversity is essential for a species to evolve. Greater diversity is observed in larger populations that are genetically heterogeneous and present greater potential for evolution and adaptation to various environmental conditions. Genetic diversity is, therefore, a key component for the conservation of diverse biological resources. Virtually in nature, two individuals of the same species are not always identical, as they differ in their genotypes. Even if an endangered species is saved from extinction, it tends to lose much of its internal genetic diversity. When such populations get an opportunity to grow, they will not be genetically uniform than their ancestral populations. For example, the genetic diversity of the extant herds of bison is different from those that lived in the early 18th century.

- **Species Diversity:** Species diversity refers to the variety and number of different species in a given time and space. Ecologically, species variety is measured by species richness (the number of different species in an area, taxa or community), species composition (list of species or species assemblage) and relative abundance of species. Relative abundance of species refers to the measure of the relative number of individuals present in different species in a given community or habitat. Species diversity is thus related to the ecological and evolutionary distinctiveness of different species. Species diversity is the most important tool in biodiversity studies and is widely used for conservation. It helps to assess the homogeneity of an environment as well as determine the sensitivity of species and ecosystems. It also provides a picture of the health of the ecosystem.

- **Ecosystem Diversity:** Ecosystem diversity refers to the variety of habitats, natural communities, and ecological processes in the biosphere. It includes different ecosystems like forests, deserts, wetlands, grasslands, rivers, oceans, and coral reefs. Each ecosystem has its own unique set of species and interactions. Ecosystem diversity ensures that life-supporting processes like pollination, water purification, and nutrient cycling continue across the planet. It also takes into account the diversity of ecosystems in the landscape and various biomes of the world. Hence, the diversity of an ecosystem is dependent on the physical characteristics of the environment, the diversity of species present, and the interactions that the species have with each other and with their physical environment. Therefore, the functional complexity of an ecosystem increases with taxonomic diversity of the residing species, along with the vertical and horizontal complexity of the physical environment.

1.3 SIGNIFICANCE OF BIODIVERSITY

Biodiversity is crucial for maintaining ecological balance, ensuring ecosystem stability, and supporting life on Earth. It enhances ecosystem resilience, enabling environments to recover from disturbances like climate change and natural disasters. Biodiversity plays a key role in food security, agriculture, and medicine by providing genetic resources for crop improvement and drug development. It supports economic growth through industries such as forestry, fisheries, and ecotourism. Additionally, biodiversity regulates climate, purifies air and water, and prevents soil erosion, making it vital for environmental sustainability. Culturally and ethically, it enriches human traditions, spiritual beliefs, and indigenous knowledge systems. Preserving biodiversity is essential for sustaining life, protecting natural resources, and ensuring a healthy planet for future generations.

Biodiversity is the foundation of life on Earth and is vital for the survival of all living beings, including humans. It maintains the balance and health of ecosystems by supporting essential natural processes such as air and water purification, soil formation, climate regulation, pollination of plants, and the decomposition of organic matter. These processes ensure the sustainability of life and contribute to the resilience of ecosystems against environmental changes and disasters. Biodiversity also provides a rich source of food, with diverse species of crops, fruits, vegetables, fish, and livestock contributing to human nutrition and agricultural stability. The genetic variety within species enhances disease resistance and adaptability to changing climates, making it crucial for long-term food security.

In addition to its ecological role, biodiversity is a treasure trove for medicine. Many modern drugs, including antibiotics, painkillers, and cancer treatments, originate from natural sources such as plants, fungi, and marine organisms. Economically, biodiversity supports industries like agriculture, forestry, fisheries, biotechnology, and eco-tourism, providing employment and livelihoods to millions of people worldwide. Furthermore, biodiversity holds deep cultural, spiritual, and aesthetic value. It is deeply rooted in the traditions, beliefs, and lifestyles of indigenous and local communities who rely on it for sustenance, identity, and well-being. Biodiversity also plays a major role in combating climate change. Forests, wetlands, and oceans act as carbon sinks, absorbing greenhouse gases and regulating the Earth's temperature. Ecosystems like mangroves, coral reefs, and forests act as natural buffers against extreme weather events such as floods, cyclones, and droughts. Lastly, biodiversity fuels scientific discovery and innovation, serving as a natural laboratory for learning about life, evolution, and environmental interactions. The preservation of biodiversity is, therefore, not just about protecting plants and animals—it's about safeguarding the systems that support all life on Earth, including our own.

➢ **Its significance can be understood through various aspects**

i. **Ecological Stability:** Biodiversity enhances ecosystem resilience, allowing natural systems to recover from disturbances such as climate change, natural disasters, and human activities. It ensures the proper functioning of ecological processes like pollination, nutrient cycling, and water purification. Biodiversity continuously regulates the healthy functioning of an ecosystem which influences the climatic stability of a place. Agriculture remains heavily dependent on stable climate, and human being remains dependent on agricultural products. Biodiversity keeps the world's ecological services running which in turn maintains human civilization.

ii. **Food Security and Agriculture:** A diverse range of plant and animal species contributes to global food production. Most of the food for humans is invariably derived from an organism expecting salt and additives. Agriculture involves the cultivation of crops and the rearing of poultry or cattle to provide food for the world. Both marine and inland freshwater fisheries stand as an important source of protein and are also a leader in world trade.

iii. **Medical and Pharmaceutical Importance:** Many medicines are derived from plants, animals, and microorganisms. Animals have evolved intrinsic chemical defences to protect them from their natural enemies, including several pathogens. Biodiversity provides essential resources for drug discovery, traditional medicine, and modern healthcare advancements. Besides plants, microorganisms like fungi, invertebrates, reptiles, mammals, and amphibians have been attributed medicinal values. Many laboratory animals like mice, rats and rabbits are almost physiologically similar to humans. They are thus widely used as animal models and employed in biomedical research. Therefore, pharmaceutical and biomedical research have developed around diverse biological resources.

iv. **Economic Value:** Industries such as agriculture, forestry, fisheries, and tourism depend on biodiversity. Ecotourism, wildlife conservation, and natural resource harvesting contribute to local and global economies.

v. **Climate Regulation:** Forests, wetlands, and oceans act as carbon sinks, reducing greenhouse gas concentrations and mitigating climate change. Biodiverse ecosystems help in temperature regulation, flood control, and drought prevention. Plants help to maintain and stabilise the microclimatic conditions of a region. They recycle water vapour to maintain rainfall, prevent floods, droughts, erosion, carbon dioxide build-up and other atmospheric turbulences. At a smaller scale, vegetation has a moderating influence on local climate, on which several other organisms are dependent for their existence.

vi. **Cultural and Ethical Importance:** Biodiversity is deeply connected to human culture, traditions, and spiritual beliefs. Many communities, especially indigenous groups, rely on biodiversity for their way of life, rituals, and traditional knowledge. Biological resources have always been an integral part of the culture of any population in any given region of the world. Elements of nature have contributed to the cultural growth of a region that has affected the social, religious and economic evolution of human beings.

vii. **Scientific and Educational Value:** Biodiversity always remains a source of an immense knowledge base. The loss of a species means the loss of information on it. Organisms and their physiological adaptations, morphological peculiarities, and behavioural patterns have always evoked man's quest for knowledge, while nature, with its unknown mysteries, has always evoked man's curiosity. These processes have increased the urge for discoveries. Studying biodiversity helps scientists understand evolution, genetics, and ecological interactions. It provides insights into environmental changes and helps develop conservation strategies to protect endangered species and habitats.

viii. **Sustainability and Future Generations:** Preserving biodiversity ensures that future generations inherit a healthy and functional environment. Conservation efforts protect ecosystems from degradation and prevent species extinction, maintaining nature’s balance.

1.4 BIODIVERSITY AT NATIONAL, GLOBAL AND LOCAL LEVELS

Introduction

Biodiversity, short for biological diversity, refers to the variety of life on Earth, including species diversity, genetic diversity, and ecosystem diversity. It plays a crucial role in maintaining ecological balance, supporting life systems, and providing essential services to humanity. Biodiversity can be studied at different levels, including national and global scales, each having its unique significance and challenges.

1.4.1 Biodiversity at the National Level

Biodiversity at the national level refers to the variety of living organisms, including plants, animals, and microorganisms, found within a country's geographical boundaries. It also includes genetic diversity within species and ecosystem diversity across different regions of the country. National biodiversity is essential for maintaining ecological balance, supporting economic development, and preserving cultural heritage. However, it faces numerous threats due to human activities, climate change, and environmental degradation. Each country has a unique biodiversity profile influenced by its climate, topography, and land use patterns.

Governments implement various policies, laws, and conservation initiatives to protect and sustainably use biodiversity resources.

At the national level, biodiversity is a key natural asset that contributes significantly to a country's environmental sustainability, economic development, and cultural richness. Each country has its own unique set of species and ecosystems shaped by its geography, climate, and history. For instance, countries like India, Brazil, and Australia are considered **megadiverse nations** because they host a large number of endemic species—plants and animals found nowhere else in the world. National biodiversity includes forests, grasslands, rivers, lakes, mountains, deserts, wetlands, coastal zones, and marine ecosystems, all of which provide a wide range of **ecosystem services**. These include water purification, climate regulation, soil fertility, pollination of crops, and protection against natural disasters like floods and droughts. Biodiversity also supports important **sectors of the national economy**, such as agriculture, forestry, fisheries, pharmaceuticals, and tourism. For example, diverse plant species contribute to crop improvement, while forests provide timber, fuel, and non-timber products like medicinal herbs and honey. Ecotourism in biodiversity-rich areas like national parks and wildlife sanctuaries generates income and employment for local communities. Furthermore, biodiversity is deeply intertwined with **national identity and culture**. Many communities, especially indigenous and tribal groups, depend on biodiversity for their traditional knowledge, food, medicine, rituals, and festivals.

To protect and conserve national biodiversity, governments take various steps such as establishing **protected areas** (national parks, wildlife sanctuaries, biosphere reserves), passing environmental laws, conducting biodiversity assessments, and promoting sustainable development. National biodiversity strategies and action plans (NBSAPs), created in line with international agreements like the **Convention on Biological Diversity (CBD)**, guide conservation efforts at the policy level. Public awareness, environmental education, and community participation are also promoted to involve citizens in protecting the natural heritage of their country. Thus, biodiversity at the national level is not just about protecting wildlife—it is about securing the foundation of a healthy, prosperous, and sustainable nation.

Biodiversity at the national level is crucial for environmental sustainability, economic growth, and cultural heritage. However, rapid industrialisation, deforestation, pollution, and climate change pose severe threats to biodiversity. Conservation efforts such as protected areas, environmental laws, sustainable practices, and community involvement are essential for preserving biodiversity for future generations. Governments, organisations, scientists, and citizens must work together to protect and sustainably use biodiversity, ensuring that ecosystems remain resilient and life continues to thrive on Earth.

➢ Components of National Biodiversity

A. Species Diversity

Species diversity refers to the variety of plant, animal, and microbial species found within a country. Some species are native, while others may be introduced or invasive.

- **Native Species:** These are naturally occurring species in a particular country (e.g., Bengal tiger in India, Bald eagle in the USA).

- **Endemic Species:** These are species found only in a specific country or region and nowhere else in the world (e.g., the kangaroo in Australia, the Galápagos tortoise in Ecuador).
- **Threatened and Endangered Species:** Some species are at risk of extinction due to habitat destruction, poaching, and climate change (e.g., the Giant Panda in China, the Asiatic Lion in India).

B. Genetic Diversity

Genetic diversity at the national level refers to the variety of genes within the plant, animal, and microbial species found within a specific country. This includes both wild species and domesticated varieties that are important for agriculture, medicine, and cultural heritage. High genetic diversity within a nation is crucial for ensuring food security, enabling species to adapt to environmental changes, and maintaining healthy ecosystems. It allows crops and livestock to withstand pests, diseases, and climate fluctuations, which is vital for sustainable development. However, genetic diversity at the national level is often threatened by habitat loss, overexploitation, pollution, and the spread of invasive species. To conserve it, countries establish protected areas, maintain seed banks and breeding programs, and implement laws and policies that promote biodiversity conservation. Protecting genetic diversity within a nation strengthens its environmental resilience, supports local livelihoods, and contributes to global biodiversity conservation.

C. Ecosystem Diversity

Ecosystem diversity at the national level refers to the variety of ecosystems, such as forests, grasslands, wetlands, mountains, rivers, coastal zones, and deserts, found within a country's geographic boundaries. Each of these ecosystems supports distinct communities of plants, animals, and microorganisms, contributing to the nation’s overall biodiversity and ecological health. High ecosystem diversity ensures the provision of essential services like clean air and water, soil fertility, climate regulation, and resources for agriculture and industry. It also plays a critical role in cultural and recreational values. However, this diversity is increasingly threatened by deforestation, urbanisation, pollution, climate change, and unsustainable land use practices. To protect ecosystem diversity at the national level, governments implement strategies such as creating protected areas, enforcing environmental regulations, promoting sustainable development, and engaging in habitat restoration. Safeguarding a wide range of ecosystems within a country is key to environmental stability, economic resilience, and the well-being of current and future generations.

1.4.2 Biodiversity at The Global Level

Biodiversity at the global level refers to the vast variety of life forms found on Earth, encompassing the diversity within species (genetic diversity), between species (species diversity), and among ecosystems (ecosystem diversity). It is a fundamental component of Earth's natural systems and supports vital ecological processes that are essential for human survival, such as pollination of crops, purification of air and water, climate regulation, soil fertility, and disease control. Globally, biodiversity is incredibly rich and unevenly distributed, with tropical rainforests, coral reefs, and certain mountainous and island regions serving as hotspots for endemic and threatened species. Despite its importance, biodiversity is under severe threat from human activities. The main drivers of biodiversity loss include habitat destruction due to deforestation, urbanisation, and agriculture; climate change; pollution;

overexploitation of species; and the introduction of invasive species. The consequences of this loss are profound, affecting food security, health, livelihoods, and the resilience of ecosystems to adapt to environmental changes.

To address these issues, the global community has taken several steps, such as the adoption of international agreements like the Convention on Biological Diversity (CBD), which sets global targets for biodiversity conservation, sustainable use, and fair sharing of genetic resources. Organisations like the IUCN, WWF, and UNEP play critical roles in monitoring biodiversity, advocating for conservation policies, and implementing field projects. Moreover, protected areas such as national parks, biosphere reserves, and marine sanctuaries have been established worldwide to safeguard key habitats and species. However, challenges such as limited funding, lack of political will, insufficient local engagement, and the ongoing impact of climate change continue to hinder progress. Ensuring the conservation and sustainable use of biodiversity requires coordinated global action, integration of biodiversity into national and international development plans, and widespread public awareness about the value of preserving the Earth's biological richness for current and future generations.

➢ Components of Global Biodiversity

A. Species Diversity

Species diversity refers to the variety of living organisms on Earth, including animals, plants, fungi, and microorganisms. Scientists estimate that there are approximately **8.7 million species** on Earth, though only about **2 million have been identified and classified**.

- **Megadiverse Countries:** Some countries, like Brazil, Indonesia, and Madagascar, host exceptionally high biodiversity, housing a significant percentage of the world’s species.
- **Endangered and Extinct Species:** Thousands of species are threatened or have already gone extinct due to habitat destruction, poaching, and climate change (e.g., Dodo, Passenger Pigeon, Javan Rhino).

B. Genetic Diversity

Genetic diversity at the global level refers to the variation in genes among all living organisms across the planet. This diversity is crucial for the survival and adaptability of species, enabling them to respond to environmental changes, resist diseases, and evolve over time. High genetic diversity supports stable ecosystems, enhances agricultural productivity through resilient crop and livestock varieties, and contributes to medical research by offering insights into disease resistance. However, global genetic diversity is under threat due to habitat destruction, climate change, pollution, overexploitation, invasive species, and monoculture farming practices. To combat these threats, conservation efforts such as establishing protected areas, maintaining gene banks and seed vaults, implementing breeding programs, and enforcing international agreements like the Convention on Biological Diversity are essential. Preserving genetic diversity is vital for sustaining life on Earth and ensuring a healthy and resilient future for all species.

C. Ecosystem Diversity

Ecosystem diversity at the global level refers to the variety of ecosystems found across the Earth, including forests, deserts, grasslands, wetlands, coral reefs, tundra, and oceans. Each ecosystem supports unique communities of plants, animals, and microorganisms that interact with one another and their physical environment. This diversity is essential for maintaining ecological balance, regulating climate, purifying water, cycling nutrients, and supporting human livelihoods. Globally, ecosystem diversity provides the foundation for biodiversity and helps buffer against environmental changes and natural disasters. However, it is increasingly threatened by human activities such as deforestation, urbanization, pollution, and climate change. To protect global ecosystem diversity, efforts like establishing protected areas, restoring damaged ecosystems, and enforcing international environmental agreements are critical. Preserving a wide range of ecosystems ensures the sustainability of life on Earth and the continued provision of vital ecological services.

1.4.3 Biodiversity at the Local Level

Biodiversity at the local level refers to the variety of living organisms found within a specific area, such as a village, city, forest, lake, or coastal region. It includes the native plants, animals, fungi, and microorganisms that form the unique biological makeup of that place. Local biodiversity is crucial for maintaining ecological balance and directly supports the livelihoods, culture, and well-being of local communities. For example, in a rural area, local biodiversity may provide food, medicine, fuel, building materials, and spiritual or cultural value. Healthy local ecosystems also offer important services such as pollination of crops, soil fertility, pest control, and clean water. However, local biodiversity is increasingly under threat due to land-use changes, pollution, overgrazing, deforestation, use of chemical fertilisers and pesticides, and climate change. In many cases, the introduction of invasive species or the overharvesting of resources also leads to a decline in native biodiversity.

To protect biodiversity at the local level, community-based conservation efforts are essential. These may include protecting sacred groves, managing community forests, practising organic farming, and conserving local breeds and crop varieties. Schools and local institutions can play a role by raising awareness about the importance of native species and encouraging sustainable practices. Government schemes and non-governmental organisations often support such efforts through training, funding, and policy support. Preserving biodiversity at the local level not only contributes to global conservation goals but also helps communities become more self-reliant and resilient to environmental changes.

- **Components of Biodiversity at the Local Level**

A. Genetic Diversity: Genetic diversity refers to the variety of genes found within individuals of the same species in a particular area. At the local level, this can be seen in the different crop varieties or livestock breeds maintained by farmers. For example, a village might grow several types of rice or keep different breeds of cows, each with unique traits like disease resistance, drought tolerance, or high yield. This genetic variation is important for the survival and adaptation of species to local environmental conditions, pests, and diseases, and it supports food security and traditional agricultural practices.

B. Species Diversity: Species diversity is the variety of different species living in a specific area, such as a forest, village, or wetland. It includes all the plants, animals, birds, insects, and microorganisms that share the habitat. For instance, a local pond might support fish, frogs, aquatic plants, and various insects, while nearby fields and forests may be home to birds, mammals, and reptiles. High species diversity at the local level contributes to a balanced ecosystem, where each species plays a role in functions like pollination, seed dispersal, pest control, and nutrient cycling.

C. Ecosystem Diversity: Ecosystem diversity refers to the variety of different ecosystems or natural habitats present within a local area. This can include forests, grasslands, rivers, wetlands, farmlands, and even urban green spaces. Each ecosystem supports different communities of plants and animals and provides essential services such as water purification, climate regulation, and soil fertility. Local ecosystem diversity ensures that nature continues to function well and that communities have access to a range of resources and benefits for their survival and well-being.

Local biodiversity is vital for ecological balance, providing food, medicine, and livelihood resources while supporting traditional knowledge and cultural heritage.

1.5 MAGNITUDE AND DISTRIBUTION OF BIODIVERSITY

1.5.1 Magnitude of Biodiversity

The magnitude of biodiversity refers to the immense variety and abundance of life forms that exist on Earth. Scientists estimate that there are approximately 8.7 million species of plants, animals, fungi, and microorganisms globally, although only about 1.2 to 1.5 million species have been formally described and classified so far. This includes approximately 400,000 species of plants, over 1 million species of insects, and around 70,000 species of vertebrates (mammals, birds, reptiles, amphibians, and fishes). The actual number could be even higher, as many species—especially those in remote ecosystems like deep oceans, tropical rainforests, and underground habitats—remain undiscovered. Biodiversity is not evenly distributed; tropical regions such as the Amazon Basin, the Congo Rainforest, and Southeast Asia are known for having the highest species richness.

In terms of ecosystems, biodiversity spans from forests, grasslands, deserts, and wetlands to freshwater and marine systems, each supporting uniquely adapted life forms. At the genetic level, the magnitude of biodiversity is seen in the vast range of genes that exist within populations of the same species, which helps them adapt to different environments and survive threats like diseases or climate change. This enormous biological wealth is not only a source of wonder and scientific discovery but also a vital resource for food, medicine, agriculture, industry, and ecosystem services. Understanding the magnitude of biodiversity helps emphasise the importance of its conservation at every level—local, national, and global.

There is a fascinating variety of organisms, complex ecological relationships among organisms, genetic diversity within species and a great variety of ecological systems. To develop conservation plans for biodiversity, we must be clear magnitude and distribution of biodiversity. Biodiversity is unevenly distributed across the globe, with **tropical regions** harbouring the highest species richness. For example:

- **Amazon Rainforest** alone contains about **10% of the world's species**.
- **Coral reefs** are among the most biodiverse marine ecosystems, supporting over **25% of marine life**.
- **Boreal forests and polar regions** have lower biodiversity due to extreme climatic conditions.

1.5.2. Distribution Of Biodiversity

Biodiversity is not evenly spread across the planet but varies due to climate, geography, and environmental conditions. Due to the tilt on its axis relative to the sun and the curvature of the Earth, different areas of the planet vary in the amount of sunlight energy received throughout the year. Because of this, the duration of different seasons (warm, cold, wet, and dry) in different areas, as well as other environmental factors (temperature, humidity, etc.) varies. Due to this variation, the distribution of biodiversity varies, establishing different hotspots.

One of the most important outcomes of different affecting factors in different regions on the planet has created particular sets of environmental settings, which results in variation in predominant vegetation. The species living in different regions are distinguished by the adaptations that allow survival under the particular set of environmental conditions of the region and establish biomes. A biome is a biological population of organisms related to particular climatic and geographic conditions (deserts, grasslands, and tropical rainforests). These regions can be broadly classified into terrestrial biomes and aquatic ecosystems, in which the biodiversity distribution varies.

1.5.3 The distribution of biodiversity can be classified into different levels:

1. Latitudinal Gradient: Biodiversity decreases as one moves from the equator towards the poles. Latitudinal gradient in biodiversity refers to the pattern that biodiversity tends to increase as we move from the poles (high latitudes) toward the equator (low latitudes). Tropics are the largest biomes, so they tend to support more species, where each species has large range and population size that allows them to undergo allopatric speciation. Adjoining tropical belt of the two hemispheres provide larger area that supports large population of plants and animals. Species richness is directly proportional to the primary productivity of the plants. So, warmth and abundance of rainfall at lower latitudes lead to increased net primary productivity that supports rich floral diversity. This in turn provides for a diverse population of herbivores for which the number of carnivores increases.

Only few species can physiologically tolerate the cold, harsh climatic conditions at higher latitudes. Moreover, species inhabiting higher latitudes have faced with repeated historical perturbations or environmental calamities in the past, such as periods of glaciations. Thus, an insufficient time period available made it difficult for them to colonize or recolonize in a given region.

In simpler terms, tropical regions near the equator, like the Amazon rainforest or Southeast Asia, have a much higher number of species compared to colder regions like the Arctic or Antarctic. This is because tropical areas have a stable climate, abundant sunlight, and more consistent rainfall, which support a wide variety of habitats and allow species to thrive and evolve over time.

Example: Tropical rainforests like the Amazon and Congo Basin have the greatest biodiversity, while the Arctic tundra has fewer species.

2. Altitudinal Gradient: Altitudinal gradient in the distribution of biodiversity refers to the pattern of changes in species richness and composition as elevation increases or decreases in mountainous regions. Typically, biodiversity tends to be highest at mid-elevations and lower at both high and low extremes, although patterns can vary depending on the region and type of organisms. At lower altitudes, warmer temperatures and greater productivity support a wide variety of species. As altitude increases, temperature drops, oxygen levels decrease, and environmental conditions become harsher, leading to a gradual decline in species richness. However, mid-elevations often provide a balance of favourable conditions, such as moderate climate and habitat diversity, supporting high levels of biodiversity. This gradient also leads to the presence of unique and often endemic species that are specially adapted to specific altitude zones. Understanding altitudinal biodiversity patterns is crucial for conservation planning, especially in the context of climate change, as species may shift their ranges upward in response to rising temperatures. Altitudinal gradients of termite diversity in the Western Himalaya follow similar pattern. Dehra Dun situated at foothills of the Kumaon Himalaya is reported to support 23 species under 9 genera which decreases with increasing height, ultimately reaching to a single species in Caubatia at 2250 m. In the Kashmir Himalayas, the number of species recorded from Udhampur at 634 m is 11 under seven genera which decreases to seven in Sarda and Gangora (1063-1215 m) and then to one species in Achhabal at 1823 m.

Example: Lowland forests have higher species diversity compared to alpine regions.

3. Terrestrial vs. Aquatic Biodiversity: Land ecosystems generally have more described species than oceans, but marine ecosystems remain largely unexplored. Terrestrial and aquatic biodiversity refer to the variety of life forms found in land and water ecosystems, respectively. Terrestrial biodiversity exists in habitats such as forests, grasslands, deserts, and mountains, and includes a wide range of species like mammals, birds, insects, plants, and fungi. It plays a vital role in ecosystem functions such as pollination, oxygen production, soil fertility, and carbon storage. In contrast, aquatic biodiversity is found in freshwater bodies like rivers and lakes, as well as in marine environments such as oceans, coral reefs, and estuaries. This type of biodiversity includes fish, amphibians, aquatic plants, corals, molluscs, and marine mammals, and contributes significantly to climate regulation, oxygen production, water purification, and food supply through fisheries. While terrestrial biodiversity is primarily threatened by deforestation, land degradation, and urbanisation, aquatic biodiversity faces challenges such as water pollution, overfishing, habitat destruction, and ocean acidification. Both forms of biodiversity are essential for ecological balance and human survival, making their conservation a global priority.

Example: Coral reefs and deep-sea hydrothermal vents support unique biodiversity.

4. Biodiversity Hotspots: A biodiversity hotspot is a biogeographic region with a significant reservoir of biodiversity that is under threat from human intervention. A region is designated as a biodiversity hotspot when it contains at least 0.5 per cent or 1500 species of endemic plants and has lost at least 70 per cent of its primary vegetation. There are 34 biodiversity hot spots in the world which support almost 60 per cent of the world's plant and vertebrate species with a high level of endemism. India has two hot spots one at the Western Ghats and the other at the North-east. Biodiversity hot spots are areas that also support high diversity of locally endemic species, which are unrepresented in the other parts of the world.

Mittermeier and Werner (1990) identified several international priority areas for the conservation of biodiversity and endangered ecosystems. Globally, 34 hot spots have been identified, of which the Western Ghats and Sri Lanka, the Andaman and Nicobar Islands and the Eastern Himalayas are within the Indian subcontinent. Biodiversity hot spots have a prominent role in conservation biology.

1.6 SUMMARY

Biodiversity, or biological diversity, refers to the variety of life forms on Earth, encompassing genetic diversity within species, species diversity, and ecosystem diversity. It plays a crucial role in maintaining ecological balance, supporting essential environmental services such as pollination and nutrient cycling, and contributing to economic, cultural, and scientific advancements. Biodiversity is significant at multiple levels: locally, it includes the plants, animals, and ecosystems within a specific area; nationally, it represents the entire range of biodiversity within a country's borders; and globally, it encompasses all life forms and ecosystems across the planet. The magnitude of biodiversity is immense, with an estimated 8.7 million species on Earth, though only about 1.8 million have been identified. However, biodiversity is not evenly distributed; it is richest in tropical regions such as rainforests and coral reefs, and decreases toward the poles. Biodiversity hotspots like the Amazon Basin, Southeast Asia, and the Congo Basin are particularly rich in species and are priorities for conservation due to the high threat levels they face.

1.7 TECHNICAL TERMS

Ecosystem stability, Genetic Diversity, Species Diversity, Ecosystem Diversity, Megadiverse nations, Latitudinal Gradient, Altitudinal Gradient, Biodiversity Hotspots.

1.8 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. Write about the definition and significance of biodiversity.?
2. Illustrate the distribution of biodiversity in detail.?

Short notes

1. Explain about the biodiversity at the Global level.?
2. Describe the components of biodiversity at the national level.?
3. Define about magnitude of biodiversity.?

1.9 SUGGESTED READINGS

1) Agarwal KC. 1998. Biodiversity. India.
2) Kormondy EJ. 1996. Concepts of Ecology. Eastern Economy Edition.
3) Prabodh K. Maiti and PaulamiMaiti. 2011. Biodiversity: Perception, Peril and Preservation.
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Prof. G. Simhachalam

LESSON-2

PATTERNS OF BIODIVERSITY

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to

- Understand the characteristics of Patterns of Biodiversity.
- Explore the Factors Contributing to Latitudinal Gradients.
- Understanding the Patterns along the Altitudinal Gradient.
- Analyse Species Area Relationship.

STRUCTURE

2.1 INTRODUCTION

Organisms are never uniformly distributed on the surface of the Earth; they aggregate in certain parts but remain unrepresentative in other places. Tropics or hyper diverse areas are rich in biodiversity and considered as their cradle land, while temperate, high altitude and higher latitude areas are hypo diverse, representing areas of low species richness. In other words, some areas are hot spots, while others are cold spots or 'War mist spots'. Realisation of these patterns requires a deep understanding of many ecological, evolutionary, geological and biogeochemical processes that have influenced the distribution of plants and animals. Thus, the tropics have the richest diversity due to the combined effects of a higher rate of speciation and a lower rate of extinction. These refer to the predictable distributions and trends in biodiversity across different spatial, temporal, and ecological scales. These patterns reflect how species and ecosystems are distributed across the globe and how they change over time due to ecological, evolutionary, and environmental factors.

In simpler terms, it refers to how biodiversity is organised and distributed in nature, such as why certain areas have more species than others, how biodiversity changes with elevation or latitude, and how human activity impacts these patterns.

2.2 LATITUDINAL GRADIENTS

The Latitudinal gradient in biodiversity refers to the pattern that biodiversity tends to increase as we move from the poles (high latitudes) toward the equator (low latitudes). In simpler terms, tropical regions near the equator, like the Amazon rainforest or Southeast Asia, have a much higher number of species compared to colder regions like the Arctic or Antarctic. This is because tropical areas have a stable climate, abundant sunlight, and more consistent rainfall, which support a wide variety of habitats and allow species to thrive and evolve over time. In contrast, regions closer to the poles have harsher climates, shorter growing seasons, and less stable environments, which support fewer species. This natural pattern is one of the most well-known trends in ecology and shows how geography and climate influence the distribution of life on Earth.

2.2.1 The Global Pattern

- **Tropical Regions (Equator to about 23.5° N/S)**: These areas are typically warm year-round with consistent day length, which promotes a steady and high level of productivity in ecosystems. This results in a large number of species, many of which are highly specialised.
- **Temperate Regions (about 23.5° to 66.5° N/S)**: Biodiversity here is lower compared to the tropics but still rich, though species are generally less specialised and more adaptable to changing conditions (e.g., seasonal temperature changes).
- **Polar Regions (above 66.5° N/S)**: The extreme cold, long winters, and harsh conditions at the poles lead to fewer species, as fewer organisms can survive the extreme cold and limited resources.

2.2.2 Factors Contributing to Latitudinal Gradients in Biodiversity

1. **Climate Stability and Temperature**: The tropics have 7 throughout the year. This consistency means that species can survive and thrive in a relatively predictable environment, allowing more time for species to evolve and diversify. In contrast, areas closer to the poles experience greater seasonal variation in temperature, leading to harsher conditions for survival. This creates greater environmental stress, limiting the number of species that can persist through such temperature extremes.

2. **Solar Energy and Primary Productivity**: Solar energy is the primary driver of life on Earth. The tropics receive more consistent and intense solar radiation, which results in high levels of primary productivity (the rate at which plants and other photosynthetic organisms produce energy). This abundant energy fuels diverse food webs, supporting a wide range of species. As you move toward the poles, the angle of the sun is less direct, and there is much less solar energy throughout the year, leading to lower primary productivity. This results in fewer plants and, consequently, fewer herbivores and predators to support a wide array of species.

3. **Evolutionary History**: The tropics have experienced longer periods of climatic stability, which has allowed ecosystems to evolve and diversify over millions of years. For instance, tropical rainforests have been around for tens of millions of years, allowing ample time for species to evolve and adapt to different niches. In contrast, higher latitudes have undergone significant climatic changes over geological periods, such as ice ages. These changes have

caused repeated shifts in habitats, resulting in a relatively recent development of species in temperate and polar regions.

4. **Ecological Complexity and Niche Diversity**: Tropical ecosystems like rainforests and coral reefs have high ecological complexity. They provide a wide range of habitats, food sources, and environmental niches (the role and space an organism occupies in an ecosystem). This diversity of niches allows for the specialisation of species and facilitates greater diversity.
Tropical forests, for example, contain multiple vertical layers (e.g., canopy, understory, forest floor), which host different species adapted to different conditions. Similarly, coral reefs are made up of numerous microhabitats, from the reef crest to the deeper sea, allowing many species to occupy specialised roles.

5. **Species Interactions and Coevolution**: In the tropics, species often have longer evolutionary histories with each other, leading to complex interdependencies (e.g., pollination by insects, seed dispersal by animals, predator-prey dynamics). Over time, this has driven coevolution, where species adapt in response to each other, promoting diversity. These coevolutionary processes, such as mutualisms (e.g., plants and their pollinators), result in a greater variety of species interacting in ways that support ecosystem functions and contribute to biodiversity.

6. **Higher Speciation Rates**: In tropical regions, speciation rates (the rate at which new species are formed) tend to be higher. The combination of factors like stable climates, high productivity, and ecological complexity provides the ideal conditions for species to diverge and adapt to different niches, leading to the formation of new species over time.
The tropics also tend to have fewer barriers to gene flow, allowing populations to mix and potentially form new species. By contrast, the colder regions may experience more isolation (e.g., by mountains or glaciers), leading to lower rates of speciation.

2.3 ALTITUDINAL GRADIENTS

The global surface is not flat, but moulded into mountains and valleys by regional geological processes. As a general rule of thumb, an increase in elevation of 1000 metres results in a decrease of 6°C temperature. Besides, with increasing elevations along a mountain range, oxygen content of the air decreases, whereas precipitation, wind speeds, and atmospheric moisture content increase, and the air provides minimal protection against the UV radiation of the sun. Near the summit temperature drops below freezing point with rainfall turning into snowfall. Thus, marked changes in species composition are observed as one moves up a mountain.

Endothermic animals often span across the altitudinal zones depending on the seasons and food availability, while ectotherms are not common at higher elevations. Species diversity and abundance decrease as a function of altitude above the montane zone because of the harsher environmental conditions. As plant growth determines the complexity of the food web, higher altitudes supporting fewer vegetation result in low animal diversity. Along the transect of the mountain profile, one would find distinct zones that are characterised by the native vegetation. These zones are referred to as altitudinal vegetation zones or life zones.

For example, A total of 11 species were found in the Teesta Valley at lower altitudes in the Eastern Himalaya, decreasing gradually towards higher elevation at Kalimpong (1209 m), supporting eight species that ultimately stand as a single species at Rangirim (2000 m) situated on a still higher altitude. Similarly, in the Bhutan Himalaya, there are 11 species of termites under 10 genera on record at Samchi, which get reduced to only three species in the Kothoka-Gogona route at an altitude of 2600-3400 m.

2.3.1 Patterns along the Altitudinal Gradient

i. **Lower Elevations (e.g., Foothills or Lowlands)**: At these altitudes, conditions are typically warmer, and oxygen availability is higher. As a result, species diversity is usually at its peak. In tropical regions, rainforests and savannas thrive at lower altitudes with abundant species. In temperate zones, grasslands and deciduous forests dominate. These ecosystems are usually more productive.
ii. **Mid Elevations (e.g., Montane Zone)**: As you move up, biodiversity starts to decrease, but species diversity can still be relatively high depending on the mountain's characteristics and climate. This zone might feature montane forests or alpine meadows in temperate and tropical mountains. Mid-elevations often have a mix of endemic species (species restricted to this zone) and species that are adapted to cooler but still relatively stable conditions.
iii. **High Elevations (e.g., Subalpine/Alpine Zones)**: As you approach the tree line (the point above which trees can no longer grow), species diversity drops significantly. Conditions here are harsh: cold temperatures, low oxygen, and low precipitation. The species that survive here are typically adapted to extreme conditions. For example, plants might be low-growing, with adaptations to conserve water and withstand cold, while animals may have thick fur**.**
iv. **Summit Zone**: At the highest points of mountains, biodiversity is at its lowest. These areas often feature barren landscapes or sparse vegetation and can be covered by glaciers or permanent snow. Only a few species are capable of surviving in these extremely cold, dry, and low-oxygen environments. These include specialised alpine plants, insects, and animals like mountain goats or snow leopards (in some regions).

2.3.2 Features of Altitudinal Gradients

a. **Temperature**: As altitude increases, temperature generally decreases. This cooling effect results in colder conditions at higher elevations, which can be challenging for many species to survive. Tropical regions, for example, experience rapid changes in temperature with altitude. At higher elevations in tropical mountains, you may encounter alpine conditions (cold, low oxygen), even though the surrounding lowlands are warm and support highly diverse ecosystems.
b. **Oxygen Availability**: At higher altitudes, air pressure decreases, leading to lower levels of available oxygen. This is especially significant in mountainous regions above a certain elevation (typically 2,500 meters or more), where the reduced oxygen can limit the survival of many species. Some high-altitude species are specially adapted to cope with these conditions (e.g., animals with larger lungs or more efficient circulatory systems). However, this decreases the total number of species able to survive at these elevations.
c. **Water Availability**: Water availability typically decreases as you go up in elevation, with higher altitudes often being drier. Mountain ranges are also more prone to seasonal variations in precipitation, making ecosystems more vulnerable to droughts or the seasonal availability of water. In high-altitude areas, precipitation may fall as snow in the winter, leading to longer dry seasons or colder conditions for a larger part of the year.

d. Habitat Heterogeneity: Mountainous areas often have complex terrain with a variety of habitats, such as cliffs, valleys, ridges, and forested slopes. This increases habitat heterogeneity, which can allow for a higher diversity of ecological niches and the specialisation of species. However, the further you go up, the less habitat diversity there is due to the increasingly harsh conditions at higher altitudes, limiting the number of species that can survive.

2.4 SPECIES AREA RELATION (SAR)

Species Area Relation represents the ecological pattern of measuring the spatial scale of biodiversity. The relation characterises the spatial distribution of species diversity in community ecology and states that if the area of a region increases, then the number of different inhabitant species also increases. Thus, an increase in species diversity is proportional to the area sampled. The first mathematical description of this hypothesis was proposed by Arrhenius in 1920, which was subsequently modified by Gleason in 1922. The relationship provides an important clue for conservation because the decrease in habitat area reduces the number of species, or in other words, habitat destruction is instrumental for species loss. Larger areas have more habitats that support greater diversity, which increases the rate of speciation. Thus, it can be speculated that habitat destruction or shrinkage can be considered to be the most common cause of species extinction. This hypothesis can be applicable for small and large regions, and for both animals and plants. However, in very small patches of land the hypothesis may not hold good.

It has been observed that larger islands have more species than the smaller ones. Darlington [1966] confirmed this pattern with amphibians and reptilians in the Greater and Lesser Antilles. However, species-area relationships may be reversed at times because the association of increased area with an increasing number of species at a declining rate has also been observed.

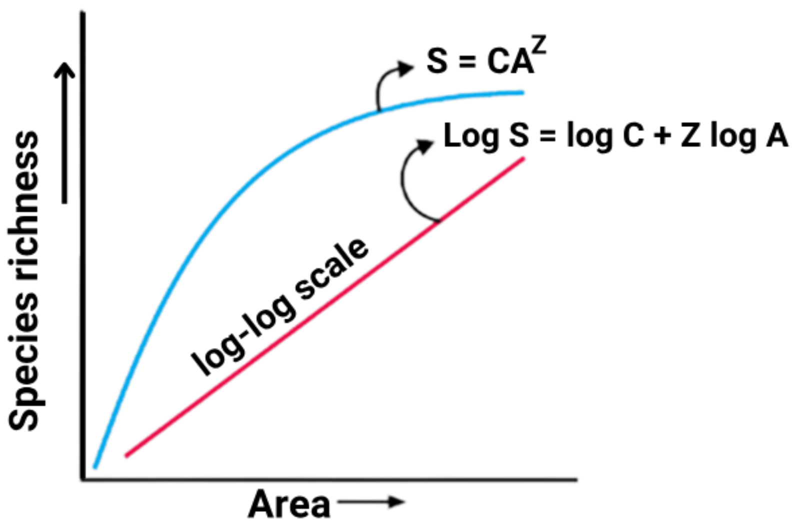


Fig. 2.4 Species Area Relationship

This can be represented by one of the two graphs, depending on the axes used:

i. A concave, upward slope (of species vs. area)
$S = CA^z$
Where **S** is the number of species, **C** is a constant that varies between taxa and from place to place, and **A** is the area of the island(s) concerned.
Many island systems, z-value generally range from about 0.24 to 0.33. The z-value is the exponent in the equation.
Or

ii. A straight, upward sloping line (log (of species) vs. log(area)).
If we use the second form of the graph, we find that the equation describing the line is **$\log(S) = \log(c) + z\log(A)$** where **z** represents the slope.

Larger islands generally support more species of plants and animals than smaller ones. When plotted on a double log scale, the number of species in a given taxon typically increases more or less linearly with island size.

Large values of z result from topographic diversity and spatial replacement of species, or "islands within islands"; lower values arise with reduced replacement of species in space, as on very homogeneous islands, continents, or subsamples of large islands (see subsequent discussion). An area of mainland habitat comparable to and equal in size to an offshore island almost invariably supports more species, especially those at higher trophic levels, than the island does. The number of species in samples of a continental system also increases with the size (area) of the subsample, although not as rapidly as on islands.

Typically, z-values in mainland situations range from about 0.12 to about 0.17. This difference arises because an island is a true "isolate," whereas a similarly sized patch of mainland habitat is only a "sample"; rare species can occur in the mainland sample both due to migration from other areas and because areas immediately adjacent to the subsample also support other members of broad-ranging species.

A mountain lion requiring a 20-km² territory would be unlikely to maintain a viable population on a small island of, say, less than 30 to 40 km², whereas these same cats can survive and replace themselves in a similarly sized subsample of a larger landmass. This is why islands tend to support fewer species at higher trophic levels than mainland areas do.

2.4.1 Equilibrium Theory of Island Biogeography

For many years, islands were considered to be in some sense "impoverished" of species, both because of the obvious problems species have in colonising them and because islands typically support fewer species than a comparable area of mainland habitat. However, the regularity of species-area patterns led Robert MacArthur and E.O. Wilson (1963) to examine the possibility that islands might in fact be supporting as many species as possible.

MacArthur and Wilson reasoned that the rate of immigration of new species to an island should decrease as the number of species on that island increases. The immigration rate must drop to zero as the species density of the island reaches the total number of species in the "species pool" available for colonisation of the island, at which no immigrant can be a new species. (The species pool corresponds to the total number of species in source areas surrounding a particular island system.) Likewise, the rate of extinction of species already present on an island should

increase as the number of species on an island increases; this seems likely because as more species invade an island, average population size must decrease, and both the intensity of interspecific competition and the incidence of competitive exclusion should increase. Moreover, there are more species that are going extinct.
When the rate of immigration equals the rate of extinction, existing species go extinct at the same rate that new ones invade; thus, species density reaches a dynamic equilibrium. Although species density stays constant, the continual turnover of species means that the actual composition of species on an island can change.

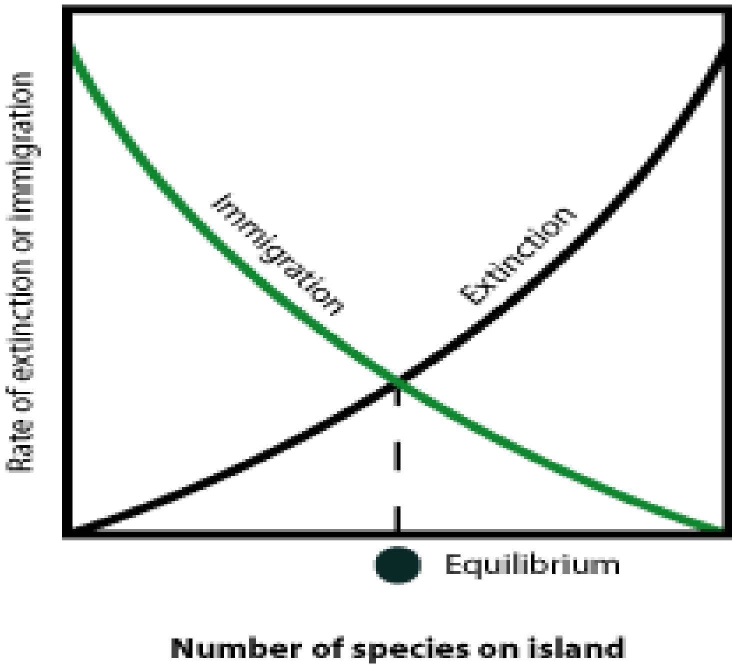
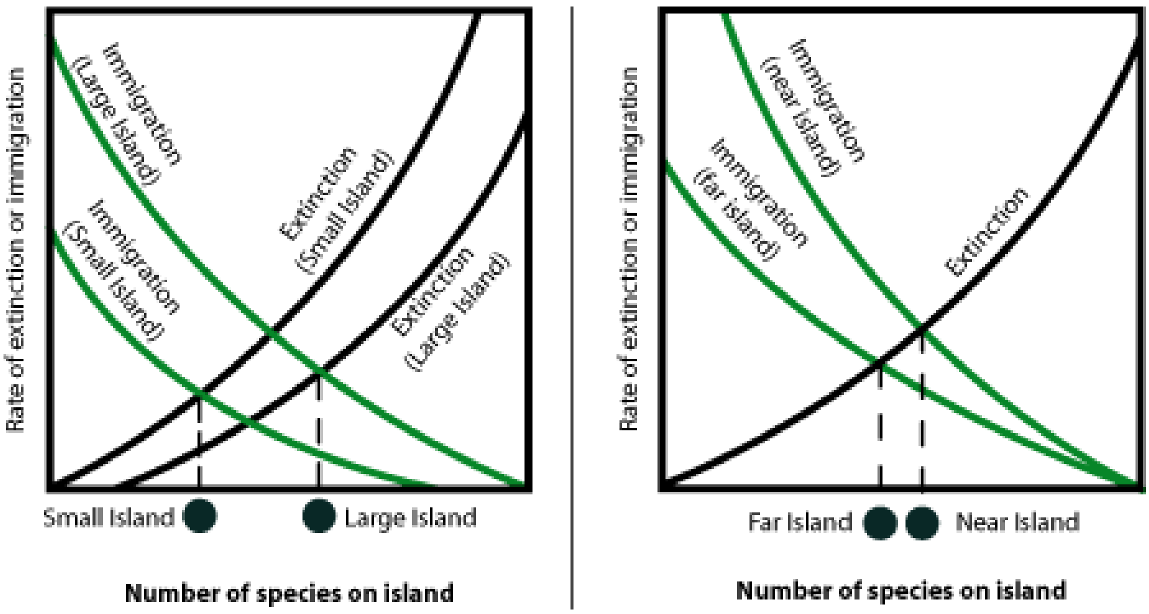


Fig 2.4.1 Equilibrium Theory of Island Biogeography

The figure illustrates the equilibrium theory for island species densities, with the immigration rate of new species falling and the rate of extinction of existing species rising as the total number of species on an island increases.

At equilibrium, the total rate of immigration of species must equal the total extinction rate. However, because species going extinct will undoubtedly often differ from those that successfully invade an island, the composition of an island's biota will be continually changing, even at equilibrium. Immigration and emigration are affected by the distance of an island from a source of colonists (distance effect). Usually, this source is the mainland, but it can also be other islands. Islands that are more isolated are less likely to receive immigrants than islands that are less isolated. The rate of extinction once a species manages to colonise an island is affected by island size (area effect or the species-area curve).

Larger islands contain larger habitat areas and opportunities for more different varieties of habitat. Larger habitat size reduces the probability of extinction due to chance events. Because dispersal falls off more or less exponentially with distance, MacArthur and Wilson reasoned that immigration rates should decrease with increasing distance from source areas. Further, they argued that rates of extinction should be largely unaffected by distance from source areas per se but should instead generally increase with decreasing island size because smaller islands support smaller, more tenuous populations.



Some predictions of equilibrium theory have now been supported by observations; others, especially those involving turnover rates, have proven to be difficult to test. Habitat heterogeneity increases the number of species that will be successful after immigration. Over time, the countervailing forces of extinction and immigration result in an equilibrium level of species richness.

2.5 SUMMARY

Patterns of biodiversity describe how species are distributed across different regions of the Earth. One of the key patterns observed is that biodiversity is **richer in tropical regions** and gradually decreases toward the poles. Factors influencing these patterns include climate, geography, habitat diversity, and evolutionary history. A well-known concept explaining these patterns is the **Species-Area Relationship**, which shows that **larger areas tend to have more species**. This is because bigger habitats offer more niches and resources, reducing extinction risk. The relationship is often expressed mathematically as $\mathbf{S = CA^z}$, where S is the number of species, A is the area, and c and z are constants. This relationship helps ecologists estimate biodiversity in unexplored areas and emphasises the importance of conserving large, continuous habitats to protect species diversity.

2.6 TECHNICAL TERMS

Latitudinal gradient, Global Pattern, Altitudinal Gradient, Rate of immigration, Rate of extinction, Species richness.

2.7 SELF-ASSESSMENT QUESTIONS

Essay questions

1. What are patterns of biodiversity, and how do they vary across the Earth?
2. What is the Species-Area Relationship, and what does it explain about biodiversity?
3. What is the significance of preserving large and continuous habitats in terms of species diversity?

Short Notes

1. How is the Species-Area Relationship mathematically expressed?
2. What factors influence patterns of biodiversity in different regions?

2.8 SUGGESTED READINGS

1) Agarwal KC. 1998. Biodiversity. India.
2) Kormondy EJ. 1996. Concepts of Ecology. Eastern Economy Edition.
3) Prabodh K. Maiti and Paulami Maiti. 2011. Biodiversity: Perception, Peril and Preservation.
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Prof. G. Simhachalam

LESSON-3

BIOGEOGRAPHIC REALMS OF THE WORLD

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to

- Explore the Biogeographic Realms.
- Know about the Biogeographic Zones of India
- Understanding of the Distribution of Fauna
- Explore the Hotspots of India and the world

STRUCTURE

3.1 INTRODUCTION

The Earth's surface is divided into six broad biogeographic regions or realms based on their biotic composition. Spatial variation of biodiversity is obtained by comparing the levels of relative diversity of these regions. The pattern of diversity also varies among different groups of organisms. Initially, P.L. Sclater (1858) attempted to classify natural terrestrial regions of the world to describe the distribution pattern of global birds. Russell Wallace (1876) later defined the different regions of the world according to the distribution of animals, and those regions represent the centre of origin of many species. However, their boundaries may not coincide with those of the continents.

Biodiversity is richest in the tropical zones, supporting two-thirds of all the extant terrestrial species, which proportionately decrease as one moves towards the poles. The tropical realms include the Ethiopian (Afrotropic), Neotropical and Oriental (Indotropics), of which the Neotropical region is most rich in terms of terrestrial biodiversity, followed by Oriental or Indotropics. Indotropics and then the Afrotropics. This information provides baseline data for fixing the priority of conservation of species and their habitat. Direct comparison of the distribution of species composition of the flora and fauna in different parts of the world can be used to identify distinct biogeographic regions (phytogeography-flora and zoogeography-fauna). The criterion of such regional classification is based on high levels of endemism, range of distribution of component species and the presence or absence of any particular taxa. Boundaries between biogeographic regions or provinces are known as biogeographic lines; the most well-known of them is Wallace's Line between Southeast Asia and Australia.

An ecozone or biogeographic realm is the largest scale of biogeographic division of the land surfaces of the earth, which is largely based on the historic and evolutionary distribution patterns of terrestrial plants and animals. Ecozones represent large areas of the earth's surface where plants and animals have developed in relative isolation over long periods of time, and remain separated from one another by geological barriers, including oceans, vast stretches of deserts, or mountain ranges. These barriers prevent the geographic dispersal and migration of plants and animals

➢ According to the **World-Wide Fund for Nature (WWF)**, the Earth is divided into eight biogeographic realms:

1. **Nearctic realm:** The Nearctic realm includes most of North America, including Canada, the United States, parts of Mexico, and Greenland. It features a range of climates from Arctic tundra in the north to temperate forests and deserts in the south. This realm supports species such as bison, grizzly bears, moose, and bald eagles, though much of its biodiversity is threatened by habitat loss and urban expansion.

2. **Neotropical realm:** The Neotropical realm spans South and Central America, southern Mexico, and the Caribbean. Known for its tropical climate and rich biodiversity, it is home to the Amazon rainforest, one of the most diverse ecosystems on Earth. Species like jaguars, sloths, macaws, and countless amphibians thrive here. This realm is a global hotspot for biodiversity but faces severe threats from deforestation and agricultural expansion.

3. **Palearctic realm:** Covering Europe, North Africa, and most of Asia north of the Himalayas, the Palearctic realm is the largest of all realms. It includes a variety of ecosystems such as temperate forests, steppes, deserts, and tundra. Brown bears, wolves, and the endangered Siberian tiger are among its iconic species. Although it spans a massive area, much of the realm has been heavily influenced by human development.

4. **Afrotropical realm:** The Afrotropical realm, also known as the Ethiopian realm, comprises sub-Saharan Africa, Madagascar, and parts of the Arabian Peninsula. This realm is dominated by savannas, tropical forests, and deserts. It supports iconic wildlife such as elephants, lions, gorillas, and the uniquely evolved lemurs of Madagascar. High levels of endemism and rich species diversity make it a conservation priority.

5. **Indo-Malayan realm:** The Indo-Malayan realm, or Oriental realm, includes South Asia, Southeast Asia, and parts of southern China. It features lush tropical rainforests and monsoon forests. Tigers, rhinoceroses, elephants, and orangutans are among its most notable species. The region is densely populated, which puts immense pressure on natural habitats and wildlife.

6. **Australasian realm:** The Australasian realm includes Australia, New Guinea, New Zealand, and surrounding islands. Long-term geographic isolation has led to the evolution of highly unique and endemic species such as kangaroos, koalas, platypuses, and cassowaries. Ecosystems range from rainforests and deserts to coral reefs, including the Great Barrier Reef. This realm is recognised for its exceptional biological distinctiveness.

7. **Oceanian realm:** The Oceanian realm consists of thousands of islands in the central and southern Pacific Ocean, excluding Australia and New Guinea. It includes Micronesia, Polynesia, and Melanesia. These islands host many endemic bird, reptile, and plant species but are extremely vulnerable to climate change, invasive species, and sea-level rise due to their isolation and small size.

8. **Antarctic realm:** The Antarctic realm covers the continent of Antarctica and nearby islands in the Southern Ocean. It is the coldest and most remote of all realms, with minimal terrestrial biodiversity. However, its marine ecosystems are rich, supporting species like penguins, seals, and krill. Though isolated, the Antarctic realm is increasingly affected by climate change and melting ice.

Each of these eight realms represents a distinct chapter in the planet's ecological and evolutionary story, and together they form the foundation of global biodiversity.

Fig. 3.1 Biogeographic realms of the world

3.2 BIOGEOGRAPHIC ZONES OF INDIA AND FAUNAL DIVERSITY

3.2.1 Biogeographic Zones of India

India's biogeographic classification is a division of the country based on biogeographic characteristics. India has a rich heritage of natural diversity. Among the top 17 megadiverse countries in the world, India ranks fourth in Asia and tenth globally. The study of the distribution of species, organisms, and ecosystems in geographical space and over geological time is known as biogeography. India has ten biogeographical zones.

India is a megadiverse country. With only 2.4 per cent of the total land area of the world, the known biological diversity of India contributes 8 per cent to the known global biological diversity. The biogeographic zones are again subdivided into one or more biotic provinces. A community occupying an area where similar climate, physiographic, and soil conditions prevail, leading to the occurrence of similar combinations of organisms, is referred to as a biotic province. These rich, diverse areas are generally based on the distribution pattern of the biota. The biotic province of the Indian subcontinent is as follows. In India (Oriental Biogeographical Region), 26 biotic provinces under 10 biogeographic zones have been recognised based on distinctive biota. Biotic province or biogeographical provinces differs from one another by their composition of flora and fauna.

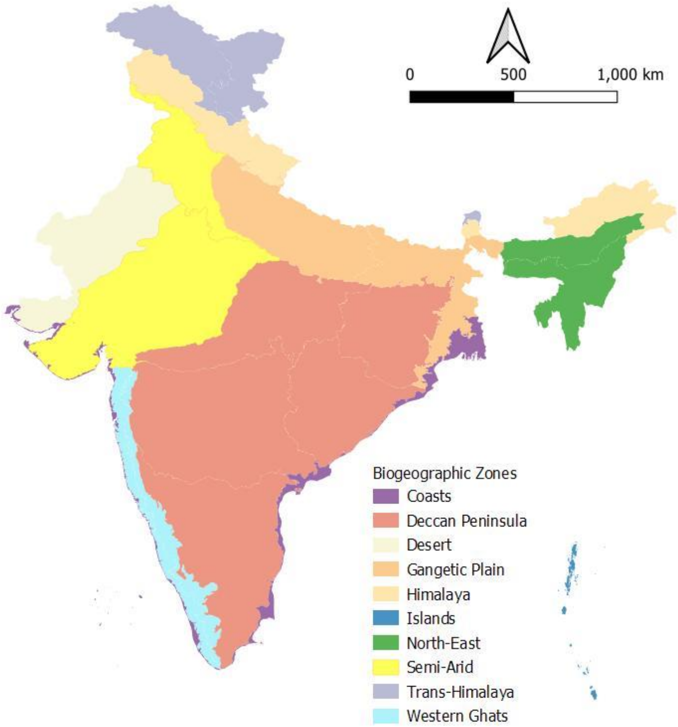

Fig. 3.2.1 Biogeographic zones in India.

1. Trans-Himalayan Zone: This zone lies north of the main Himalayan ranges and includes high-altitude cold deserts like Ladakh and parts of Lahaul-Spiti. It is characterised by dry, harsh conditions, minimal vegetation, and high diurnal temperature variation. Despite these extremes, the zone supports specialised fauna such as the **snow leopard**, **Tibetan wolf**, **wild yak**, **Tibetan wild ass (kiang)**, and **Himalayan ibex**. The flora mainly consists of alpine and steppe grasses, lichens, and mosses. Conservation in this zone is crucial due to its fragile environment and climate sensitivity.

2. Himalayan Zone: Covering the entire Himalayan range in India, from Jammu & Kashmir to Arunachal Pradesh, this zone includes **subtropical to alpine ecosystems**. Its vertical zonation results in diverse vegetation: subtropical pine forests, temperate broadleaf forests, coniferous forests, and alpine meadows. It hosts a variety of species, including the **red panda**, **musk deer**, **Himalayan tahr**, **Himalayan monal**, and **black bear**. This zone is ecologically significant for its role in water regulation, glacial systems, and biodiversity corridors.

3. Desert Zone: Located primarily in western Rajasthan, the Thar Desert is India's only true desert biome. It is characterised by sandy soils, extreme heat, and low rainfall. Despite this, it supports resilient flora such as **cacti**, **acacias**, and **xerophytes**, and rare fauna like the **great Indian bustard**, **desert fox**, **chinkara**, and **monitor lizards**. The Indira Gandhi Canal has altered some parts of the desert, impacting native ecosystems.

4. Semi-Arid Zone: Lying between the desert and more humid regions, this zone spans parts of Gujarat, Madhya Pradesh, Maharashtra, and Deccan Karnataka. It features dry deciduous forests, open scrubland, and seasonal grasslands. Fauna includes the **blackbuck**, **Indian fox**, **caracal**, and **Indian wolf**. This zone is highly impacted by agriculture and grazing, requiring managed conservation strategies to maintain ecological balance.

5. Western Ghats Zone: One of the world's eight "hottest hotspots" of biodiversity, the Western Ghats stretch along the western coast of India. The region receives high rainfall and is covered with dense **tropical evergreen and semi-evergreen forests**. It is home to many endemic species, such as the **lion-tailed macaque**, **Nilgiri tahr**, **Malabar civet**, and a wide variety of frogs, snakes, and butterflies. It also plays a critical role in monsoon regulation and freshwater supply. Protected areas like Silent Valley, Periyar, and Kudremukh are part of this zone.

6. Deccan Plateau Zone: Occupying a major portion of peninsular India, this zone includes parts of Maharashtra, Telangana, Andhra Pradesh, Karnataka, and Tamil Nadu. It features varied topography and dry to moist deciduous forests. Major wildlife includes the **tiger**, **leopard**, **sloth bear**, **four-horned antelope**, and **gaur**. The zone is important for watershed systems and agriculture, and includes reserves like Nagarhole and Bandipur.

7. Gangetic Plains Zone: This fertile and flat alluvial region extends from Punjab in the west to West Bengal in the east. Historically covered in moist deciduous forests, most of the land is now used for agriculture. Remnant natural habitats support species like **barasingha (swamp deer)**, **Indian rhinoceros**, **gharial**, and **Bengal florican**. Major rivers like the Ganges and Yamuna run through this zone, making it vital for both biodiversity and human livelihoods.

8. Coastal Zone: Stretching along the eastern and western coasts of India, this zone includes beaches, estuaries, backwaters, and mangrove forests. The **Sundarbans** in West Bengal, the world's largest mangrove ecosystem, falls under this category and is the habitat of the **Royal Bengal tiger**. Coastal zones support marine biodiversity like **dugongs**, **dolphins**, **sea turtles**, and **migratory birds**. These ecosystems are vital for fisheries, storm protection, and carbon sequestration.

9. North-East Zone: Comprising the states of Assam, Meghalaya, Manipur, Mizoram, Nagaland, Tripura, Arunachal Pradesh, and Sikkim, this zone is part of the Indo-Burma and Eastern Himalayas biodiversity hotspots. It has rich tropical rainforests and subtropical forests, along with high rainfall and river systems. Species include **hoolock gibbons**, **clouded leopards**, **hornbills**, and many orchids and bamboos. Its isolation has led to a high degree of endemism, but it is also highly vulnerable due to deforestation and jhum (shifting) cultivation.

10. Islands Zone: The Andaman & Nicobar Islands in the Bay of Bengal and the Lakshadweep Islands in the Arabian Sea form this zone. These islands host **coral reefs**, **tropical evergreen forests**, and **mangroves**, and support many endemic species such as the **Nicobar pigeon**, **Andaman woodpecker**, and various reptiles and amphibians. The islands also support rich marine life, including **sea cucumbers**, **dugongs**, and **sharks**. Being ecologically sensitive, they are highly susceptible to climate change and sea-level rise.

3.2.2 Faunal Diversity

Faunal Diversity refers to the variety and variability of animal species in a given area or ecosystem. It encompasses not only the species present but also their interactions, distribution, and ecological roles. The term "fauna" typically refers to the animal life of a particular region, period, or environment.

➢ **Importance of Faunal Diversity:**

- **Ecological Balance**: Every species in an ecosystem plays a role, contributing to the stability and functioning of that system.
- **Biodiversity Indicator**: Faunal diversity is a crucial indicator of ecosystem health. High diversity suggests a balanced and resilient ecosystem, while low diversity may indicate disturbance or degradation.
- **Economic and Cultural Value**: Many animal species are directly important to humans through agriculture, hunting, and tourism. Additionally, animals play important cultural roles in many societies.
- **Conservation Significance**: A diverse fauna is essential for maintaining genetic diversity and ensuring the survival of species in the long term.

➢ **Factors Affecting Faunal Diversity:**

- **Habitat**: Different habitats (forests, grasslands, wetlands, oceans, etc.) support different types of animals. Habitat loss or degradation is a major threat to faunal diversity.
- **Climate**: Temperature, precipitation, and seasonal changes influence animal distribution and diversity. For example, tropical regions typically have higher diversity than temperate ones.
- **Food Sources and Predation**: The availability of food and the presence of predators can shape faunal populations. A complex food web often supports greater diversity.
- **Human Activities**: Deforestation, pollution, hunting, and urbanisation are primary factors that negatively impact faunal diversity. Conversely, conservation efforts such as protected areas, wildlife corridors, and breeding programs help maintain or restore diversity.
- **Geographical Isolation**: Islands and mountain ranges often have unique faunal species due to isolation and adaptive evolution.
- **Evolutionary Factors**: Natural selection, speciation, and adaptation to various environmental niches contribute to the development of a diverse fauna.

3.2.3 Types of Faunal Diversity

1. **Terrestrial Fauna**: Terrestrial fauna includes all animals that live primarily on land. These animals have adapted to various land-based habitats such as forests, grasslands, deserts, and mountains. Common examples include elephants, tigers, deer, snakes, and numerous species of insects and birds. Terrestrial fauna plays a vital role in maintaining ecological balance through food webs, pollination, and seed dispersal.

2. **Aquatic Fauna**: Aquatic fauna comprises animals that inhabit freshwater or marine ecosystems. Freshwater fauna includes species found in rivers, lakes, and wetlands, such as fish like mahseer and amphibians like frogs. Marine fauna includes sea creatures such as dolphins, whales, sea turtles, and corals. These organisms are crucial for aquatic food chains and contribute significantly to human livelihoods through fisheries and tourism.

3. **Arboreal Fauna**: Arboreal fauna refers to animals that live in or depend heavily on trees for shelter, food, and movement. These animals are usually well-adapted for climbing and may have strong limbs, gripping tails, or gliding membranes. Examples include monkeys, tree squirrels, tree frogs, and certain birds. Arboreal animals are an essential component of forest ecosystems and help in seed dispersal and insect control.

4. **Aerial Fauna**: Aerial fauna includes animals that spend much of their life in the air. These animals are adapted for flight or gliding and are often involved in crucial ecological functions like pollination, seed dispersal, and pest control. Birds, bats, butterflies, and bees are prime examples of aerial fauna. Many of these species are migratory and rely on multiple ecosystems during their life cycles.

5. **Endemic Fauna**: Endemic fauna consists of species that are native to a specific region and not naturally found anywhere else in the world. These species often evolve in isolated environments, making them highly sensitive to habitat loss and climate change. Examples include the lion-tailed macaque of the Western Ghats and the Nicobar megapode of the Andaman and Nicobar Islands. Conservation of endemic species is vital as they are indicators of a region's unique biodiversity.

6. **Migratory Fauna**: Migratory fauna includes species that travel across regions or countries on a seasonal basis, usually for breeding, feeding, or avoiding harsh climatic conditions. These migrations may be triggered by changes in temperature, food availability, or breeding cycles. Notable examples include the Siberian crane and the olive ridley turtle. Migratory species are often protected under international agreements due to their transboundary movement.

7. **Domesticated Fauna**: Domesticated fauna refers to animal species that have been bred and managed by humans for various purposes such as agriculture, transportation, companionship, and food. Examples include cows, goats, poultry, and dogs. While not typically part of wild biodiversity, domesticated animals have played a key role in the development of human societies and rural economies.

8. **Wild Fauna**: Wild fauna encompasses all animals that live and thrive in their natural, undomesticated state. These species form the foundation of natural ecosystems and include predators, herbivores, scavengers, and decomposers. Examples are leopards, jungle cats, wild boars, and peacocks. Wild fauna are critical for ecological balance, but many are under threat due to habitat destruction, poaching, and human-wildlife conflict.

9. **Vertebrate Fauna**: Vertebrate fauna includes all animals that possess a backbone or spinal column. This group comprises five major classes: mammals, birds, reptiles, amphibians, and fish. These animals are generally more studied and conserved due to their visibility, ecological importance, and charismatic appeal. Tigers, eagles, cobras, and frogs are all examples of vertebrate animals.

10. **Invertebrate Fauna**: Invertebrate fauna includes all animals that lack a backbone. This category makes up the vast majority of animal species on Earth and includes insects, arachnids, molluscs, crustaceans, and worms. Despite their small size, invertebrates are essential for pollination, decomposition, soil formation, and aquatic ecosystems. Examples include ants, butterflies, snails, and jellyfish.

3.2.4 Patterns of Faunal Diversity

Patterns of faunal diversity describe how animal species are distributed across different geographic regions, ecosystems, and environmental conditions. These patterns are influenced by a variety of factors such as climate, altitude, latitude, availability of food and water, habitat types, and evolutionary history.

1. Latitudinal Gradient: One of the most well-established patterns is the latitudinal gradient, where faunal diversity is highest near the equator and decreases toward the poles. Tropical regions such as the Amazon Basin, the Congo rainforest, and the Western Ghats in India host a much richer variety of animal life compared to temperate and polar regions. This is due to favourable climate, stable temperatures, high primary productivity, and greater habitat complexity in tropical areas.

2. Altitudinal Variation: Faunal diversity also changes with altitude. As one ascends a mountain, the temperature decreases and environmental conditions become harsher, leading to a decline in the number of species. Low-altitude regions with warmer climates and denser vegetation typically support a greater variety of animals, while higher altitudes have fewer but often highly specialised and adapted species.

3. Habitat-Specific Distribution: Different types of habitats support different faunal communities. Forests, wetlands, grasslands, deserts, and aquatic ecosystems each host unique sets of animals adapted to their particular environmental conditions. For example, amphibians thrive in moist forest habitats, while reptiles are more abundant in arid and semi-arid regions.

4. Endemism and Regional Uniqueness: Certain regions exhibit high endemism, meaning they harbour species found nowhere else on Earth. These patterns are seen in isolated ecosystems like islands, mountain ranges, or biodiversity hotspots such as the Eastern Himalayas and the Western Ghats. Endemism results from long periods of geographic isolation and evolutionary processes.

5. Species Turnover (Beta Diversity): Faunal diversity also shows variation from one region to another, even within the same broad habitat type. This phenomenon, called beta diversity, reflects species turnover due to differences in microclimate, elevation, soil type, and human influence. Two adjacent forests may host distinctly different animal species depending on these factors.

6. Temporal Patterns: Faunal diversity can also vary over time due to seasonal changes, migration patterns, breeding cycles, and ecological succession. For instance, migratory birds temporarily increase faunal diversity in certain wetlands during winter months, and some insect populations may explode during monsoons and decline afterwards.

3.2.5 Human Impact on Faunal Diversity

i. **Habitat Destruction**: The conversion of forests, wetlands, and other ecosystems into agricultural or urban areas leads to significant loss of biodiversity, caused by deforestation, urbanisation, agriculture, mining, and infrastructure development. This leads to the loss of shelter, food sources, and breeding grounds for many species.

ii. **Climate Change**: Global warming, ocean acidification, and changing weather patterns disrupt ecosystems and affect species distributions driven by human-induced greenhouse gas emissions, altering temperature and weather patterns, affecting migration, reproduction, and survival rates of various faunal species.

iii. **Pollution**: Chemicals, plastics, and other pollutants can degrade habitats and lead to the decline of species. They contaminate water and soil, harming aquatic and terrestrial animals alike.

iv. **Over-exploitation**: Overhunting, overfishing, and illegal wildlife trade. These activities drastically reduce populations of key species, sometimes to the brink of extinction. For example, the illegal poaching of tigers and elephants for skin and ivory has severely impacted their numbers.

v. **Invasive Species**: The introduction of non-native species can disrupt local ecosystems, outcompeting or preying on native fauna. Invasive species, often introduced accidentally or intentionally by humans, also disrupt local ecosystems by outcompeting or preying on native fauna. Examples include the introduction of the Nile perch into Lake Victoria, which led to the extinction of many native fish species.

vi. **Human-wildlife conflict**: This is on the rise due to habitat encroachment, often leading to the killing of animals like leopards, elephants, and bears when they enter human settlements in search of food or water.

3.3 HOTSPOTS OF THE WORLD AND IN INDIA

Introduction

Biodiversity refers to the variety and variability among all groups of living organisms and the ecosystem complexes in which they occur. Areas that exhibit high species richness as well as high species endemism are termed hot spots of biodiversity. A biodiversity hotspot is a biogeographic region that is both a significant reservoir of biodiversity and is threatened with destruction.

The British biologist **Norman Myers** coined the term "biodiversity hotspot" in 1988 as a biogeographic region characterised both by exceptional levels of plant endemism and by serious levels of habitat loss.

Conservation International (CI) adopted hotspots of Myers as its institutional blueprint in 1989. In 1996, the organisation decided to undertake a reassessment of the hotspots concept. Three years later, an extensive global review was undertaken, which introduced quantitative thresholds for the designation of biodiversity hotspots.

According to CI, to qualify as a hotspot, a region must meet two strict criteria:

1. It must contain at least 1,500 species of vascular plants (> 0.5% of the world’s total) as endemics.
2. It has to have lost at least 70% of its original habitat, or it must have 30% or less of its original natural vegetation.

Characteristic features of hotspots

Biodiversity hotspots are regions that are exceptionally rich in species, particularly endemic species, but are also under significant threat from human activities. The concept was first proposed by Norman Myers in 1988 and later refined by Conservation International. These regions are critical for global conservation efforts due to their ecological importance and vulnerability. The main characteristic features of biodiversity hotspots are as follows:

a) **High Species Richness**: Biodiversity hotspots are known for having an exceptionally high number of species of plants, animals, and microorganisms, often more than many other regions on Earth.
b) **High Level of Endemism**: These regions contain a large proportion of species that are found nowhere else in the world. Endemic species often evolve in isolation due to geographic or climatic conditions.
c) **Significant Habitat Loss**: To qualify as a hotspot, a region must have lost at least 70% of its original natural vegetation, primarily due to human activities like deforestation, agriculture, and urbanisation.
d) **Ecological Sensitivity**: The ecosystems in hotspots are often fragile and highly sensitive to environmental changes, making them vulnerable to climate change, pollution, and invasive species.
e) **Centres of Evolution and Speciation**: Many hotspots are considered evolutionary "cradles" where new species have evolved and diversified over millions of years due to unique environmental and geographical factors.
f) **Geographical Distinctiveness**: Hotspots are usually located in specific geographic regions like tropical rainforests, mountain ranges, and islands, which contribute to their isolation and uniqueness.
g) **Global Conservation Priority**: Due to their rich biodiversity and high risk of degradation, these areas are prioritised for conservation by international organisations and governments.

3.3.1 Hotspots in India

India is known for its rich biodiversity and has 23.39% of its geographical area covered by forests and trees. **Among the 36 hot spots** of the world, **4 are found in India**. These areas of the country are exceptionally rich in flowering plants, reptiles, amphibians, butterflies, and some species of mammals.

1. Himalayas: The Himalaya Hotspot is home to a diversity of ecosystems that range from alluvial grasslands and subtropical broadleaf forests to alpine meadows. It comprises of North-East India, Bhutan, Central and Eastern parts of Nepal. It contains large birds and mammals, including vultures, tigers, elephants, rhinos, musk deer, and wild water buffalo.

2. Indo-Burma: It encloses over 2 million square kilometres of tropical Asia. It includes large-antlered muntjac, Annamite muntjac, the grey-shanked douc, Annamite striped rabbit, leaf deer, saola, and freshwater turtle species. There are also 1,300 different bird species, including the threatened White-eared Night-heron, the Grey-crowned Crocias, and the Orange-necked Partridge.

3. Western Ghats and Sri Lanka: The Western Ghats are present along the western edge of peninsular India and cover most of the deciduous forests and rainforests. The region is home to a rich endemic assemblage of plants, reptiles and amphibians. Asian elephants, Indian tigers and lion-tailed macaque are found here.

4. Sundaland: This region is famous for its rich terrestrial and marine ecosystems. The spectacular flora and fauna of the Sundaland Hotspot are succumbing to the explosive growth of industrial forestry in these islands and to the international animal trade that claims tigers, monkeys, and turtle species for food and medicine in other countries. Populations of the orangutan are found only in this hotspot.

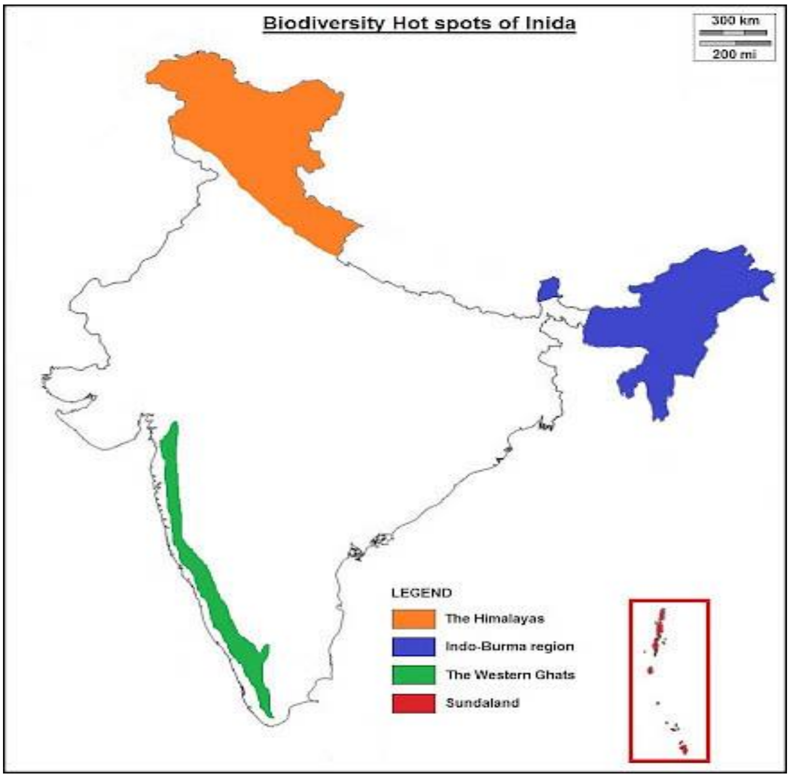

Fig. 3.3.1 Hotspots in India

3.3.2 Hotspots in The World

Biodiversity hotspots are regions that are both rich in endemic species and highly threatened by human activities. Currently, there are 36 recognised biodiversity hotspots around the world, covering just about 2.4% of the Earth's land surface, but supporting more than 50% of the world's endemic plant species and countless animal species. These hotspots are distributed across tropical forests, islands, and mountain ecosystems, which have fostered high levels of species evolution and specialisation. Some of the prominent hotspots include the Amazon Rainforest in South America, known for its immense variety of flora and fauna; the Congo Basin in Africa, rich in primates and rare plants; and the Himalayas, which host unique cold-adapted species. Other important hotspots include Madagascar and the Indian Ocean Islands, famous for their highly endemic wildlife, Mesoamerica in Central America, Indo-Burma in Southeast Asia, and the Sundaland region of Indonesia and Malaysia. The Mediterranean Basin is another major hotspot, being one of the most biologically rich temperate regions in the world. In addition, Australia's Southwest and New Zealand are notable for their ancient, isolated ecosystems. Each of these hotspots faces significant threats from deforestation, climate change, invasive species, and urban expansion. Global conservation efforts focus heavily on these areas to preserve the planet's remaining biological treasures.

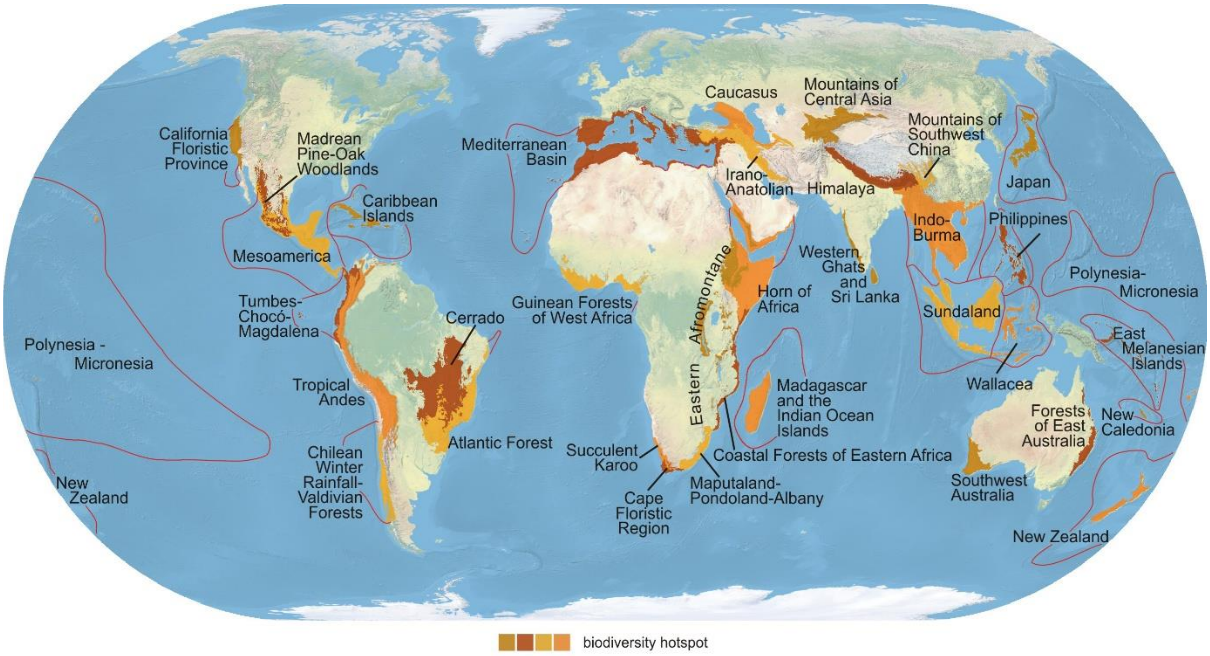

Fig. 3.3.2 Hotspots in the World

3.4 SUMMARY

The world is divided into **biogeographic realms**, which are large regions with distinct animal and plant groups shaped by evolutionary processes, such as the Nearctic, Palearctic, Neotropical, Afrotropical, Indo-Malayan, Australasian, and Antarctic realms. In India, biodiversity is classified into **10 biogeographic zones,** including the Trans-Himalaya, Himalaya, Desert, Semi-arid, Western Ghats, Deccan Peninsula, Gangetic Plain, Northeast, Islands, and Coasts. Each zone hosts unique **faunal diversity**, such as snow leopards in the Himalayas and lion-tailed macaques in the Western Ghats. Globally, biodiversity **hotspots** are regions rich in endemic species but under threat from human activities; examples include the Amazon, Congo Basin, and Southeast Asian forests. India has four major hotspots: the **Himalayas**, **Indo-Burma**, **Western Ghats and Sri Lanka**, and the **Sundaland (Nicobar Islands)**, making it one of the most biologically diverse countries in the world.

3.5 TECHNICAL TERMS

World-Wide Fund for Nature, Megadiverse country, Semi-Arid Zone.

3.6 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. Write a brief note on biogeographic realms of the world.?
2. Explain the biogeographic zones of India.?

Short Notes

1. Define faunal distribution in different patterns.?
2. Write a note on the Hotspots of India.?

3.7 SUGGESTED READINGS

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Prof. G. Simhachalam

LESSON-4
HIERARCHICAL COMPONENTS OF BIODIVERSITY

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to:

- To get an idea about biodiversity and its levels
- To determine the consumptive and intrinsic values of biodiversity
- To determine the ecosystem services (ESs) values
- To get an idea about the monetary benefits of biodiversity

STRUCTURE

4.1 INTRODUCTION

Biodiversity refers to the variety of life on Earth, encompassing a wide range of organisms, ecosystems, and genetic differences. It can be organised into several hierarchical levels, each of which provides a unique perspective on the richness and complexity of life.

The **hierarchical components of diversity** refer to the different levels at which biodiversity is structured and studied, ranging from genetic variation within species to the diversity of entire ecosystems and landscapes. This hierarchical framework helps scientists understand how life is organised, how species interact, and how ecosystems function. Each level contributes uniquely to the stability and resilience of the natural world. At the **lowest level**, **genetic diversity** describes the variety of genes within individuals of a species, ensuring adaptability and survival. **Species diversity**, at the next level, represents the number of different species in a given area, influencing ecosystem health and function. Moving further up, **ecosystem diversity** encompasses the variety of ecosystems, each with unique communities and environmental conditions. This hierarchical structure highlights the **interconnectedness** of biodiversity, where loss at any level—whether genetic, species, or ecosystem—can have cascading effects on ecological balance and sustainability. Understanding and preserving biodiversity at all levels is essential for maintaining ecosystem services, supporting human well-being, and mitigating the impacts of climate change.

4.2 GENETIC DIVERSITY

Genetic diversity refers to any variation in the nucleotides, genes, chromosomes, or the entire genome of organisms (the genome is the entire complement of DNA within the cells or organelles of an organism). Thus, genetic diversity is the sum of the total genetic information contained in the genes of individuals of plants, animals and microorganisms. Diversity of genetic material refers to the variability of genetic material (total set of genes or genome) and amount of variation observed among individuals of the populations of a single species as well as among different species. Genetic variability, on the other hand is the measure of the individual genotypes in a population that tend to vary from one another. Generally genetic diversity occurs as and when organisms undergo gene mutations (sexual reproduction), recombination or change in the allelic frequency due to drift in a population which brings about phenotypic changes. Further, these heritable changes may spread among population and through reproductive isolation or natural selection give rise to diverse group of organisms which is the main driving force of evolution. These organisms although remain closely related to one another may differ in having new characters that give them the status of a new species. Genetic variations may be due to variety and complexity of habitats where the organisms adapt and evolve with the environmental changes and pressure of natural selection. In such manner when the genetic variation within a particular population decreases that species becomes extinct. Genetic diversity plays important role in survival and adaptation of a species as even slight variation in gene may produce favourable changes in phenotype for organisms to adapt in a changed environment. Large degree of genetic diversity among its population have proved to increase its fitness and thus, increase in genetic diversity is essential for a species to evolve. Greater diversity is observed in larger populations which are genetically heterogeneous that present greater potential for evolution and adaptation to various environmental conditions. Genetic diversity is, therefore, a key component for conservation of diverse biological resources.

Virtually in nature, two individuals of the same species are not always identical as they differ in their genotypes. Even if an endangered species is saved from extinction, it tends to lose much of its internal genetic diversity. When such populations get opportunity to grow, they will not be genetically uniform than their ancestral populations. For example, genetic diversity of the extant herds of bison are different from those who lived in of the early 18th century. The phenotype or the appearance of an individual and the variability observed in a population is influenced by its interaction with their surrounding environment. The genotype of organisms is the genetic (hereditary) information conveyed from parents to progeny. In all organisms, the genetic information resides in the chromosome consisting of long chain, double stranded molecules of DNA or deoxyribose nucleic acid except in a few bacteriophages, plants and virus. Each strand consists of a linear arrangement of molecules of the deoxyribose sugar connected via phosphate radicals. This forms the backbone of the strands and to each sugar molecule a base is attached which is either adenine, guanine, thiamine or cytosine. This unit consisting of ribose sugar, phosphate and base is known as nucleotide and each strand is actually a string of polymerized nucleotide or a polynucleotide. The two strands are connected by special links of hydrogen bonding. Binding occurs between the bases and only two combinations of base pairs occur, guanine with cytosine, while adenine with thiamine. In the physical terms, gene is a discrete segment of DNA strands with a particular sequence of bases that encodes for an amino acid sequence producing a functional protein. It compromises of a hereditary section of DNA that occupies a specific place of the chromosome, and controls a particular characteristic of an organism by encoding specific protein. The same gene exists in a number of variants and these variants are known as alleles. Most organisms are diploid, having two sets of chromosomes, and therefore two copies of alleles of each gene. Gene varies greatly in size from less than 100 base pairs to several million base pairs. Within any single organism, the two (or more) alleles for each gene may vary. Each allele codes hall for different proteins. Thus, differences in the sequences of nucleotide in the alleles result in the variant forms of the proteins. This leads to variant anatomical, physiological and behavioural pattern of the organism.

Hence, genetic differences may exist in both among individuals of a species and among populations. Different species can have different numbers of genes. However, a greater number of genes may correspond with greater amount of phenotypic complexity. For example, the predicted size of the human genome is not much larger than the genomes of other organisms. However, some organisms may be haploid, triploid, or tetraploid having one, three, or four sets of chromosomes, respectively. Variation is introduced either through mutation of one of the alleles, or by sexual reproduction (offspring inherit alleles from both parents and these alleles are different). These differences are large if the parents come from different populations or gene pools. Sexual recombination also produces variations. Mutations producing positive traits and sexual recombination may allow the evolution of new characteristics.

4.3 SPECIES DIVERSITY

Species diversity refers to the variety and number of different species in a given time and space. Ecologically, species variety is measured by species richness (the number of different species in an area, taxa or community), species composition (list of species or species assemblage) and relative abundance of species. Relative abundance of species refers to the measure of the relative number of individuals present in different species in a given community or habitat. Species diversity is thus, related to the ecological and evolutionary distinctiveness of different species.

Species diversity is the most important tool in biodiversity studies and is widely used for conservation. It helps to assess the homogeneity of an environment as well as determine the sensitivity of species and ecosystems. It also provides the picture of the health of the ecosystem. Most of the plants and animals exhibit variations caused by the patterns and processes of species formation. Within a population, variation can be continuous (height and weight) or discontinuous (sex, environmentally induced human language) or genetic (blood group). Variation is also observed in time and space between successive generations, seasons and also among allopatric populations. Species generally exist as natural entities possessing certain common characters, that are distinct from their close relatives. Species formation or speciation essentially requires the accumulation of genetic differences between populations, which mostly depends on barriers, and routes of dispersal. Actually, the rate of speciation in the majority of organisms depends on both the geographical distribution in suitable habitats within an area and their intrinsic dispersal capability. Evidently, species diversity depends on habitat diversity and natural selection.

Mutation brings about phenotypic changes which if further acted upon by genetic drift (dispersal) and natural selection, bring about genetic variations among individuals of a species. This often gives rise to new varieties, which become reproductively isolated and lead to formation of new species. This is the main cause of species diversity. Adaptive radiation is another source of large-scale morphological variations or transformations leading to macroevolution. Examples included are bony skeleton of vertebrates, insect-wings and insect pollination of angiosperms. Some ecological theories of species diversity exist in the literature to explain the interacting processes that add or remove species from a habitat. These are:

i. Changes in physical condition that makes the environment unsuitable for existence,
ii. By random fluctuations or change (stochastic) of events that influence the rate of natality and mortality in populations and,
iii. Through exclusion by key biological factors including competition, predation, pathogens, pollinating and dispersal agents. Populations exert their influence through local interactions between individuals that bring about variations.

Species diversity is often expressed as alpha diversity, beta diversity and gamma diversity. These are the three levels of biodiversity recognized by IUCN. Alpha diversity is the diversity or variety of species within a habitat/ecological community or the species richness of a standard sampling site. Usually, alpha diversity is expressed as species richness and species evenness. This is a site-specific diversity expressed in the number of species surveyed where a species list or composition is created that accounts for the total number and names of species recorded at a given site. Usually during sampling, a single site is chosen that is representative of the entire community.

A species list contains total number and names of species recorded for a particular site. This is the first step for measuring biodiversity of an area

- **Species Richness**: The total number of species in a given area. Species richness is the number of different species represented in an ecological community, landscape or region. Species richness is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions. Species richness is sometimes considered synonymous with species diversity
- **Species Evenness**: The relative abundance of each species in a community. High species evenness means that no one species dominates, while low evenness indicates that one or a few species are more abundant than others. Abundance values can be difficult to obtain. Area-based counts, distance methods, and mark–recapture studies are the three general categories of methods for estimating abundance.

Species evenness is combined with species richness (the number of species in the community) in order to determine species diversity, which is an important measure of community structure. Community structure, in turn, provides the quantitative basis needed to create hypotheses and experiments that help to increase understanding of how communities work. To demonstrate the contributions of species richness and species evenness to species diversity, consider the following hypothetical example in which there are two meadow communities, each containing four species of butterflies. Hence, both communities have the same butterfly species richness, however, their species evenness differs.

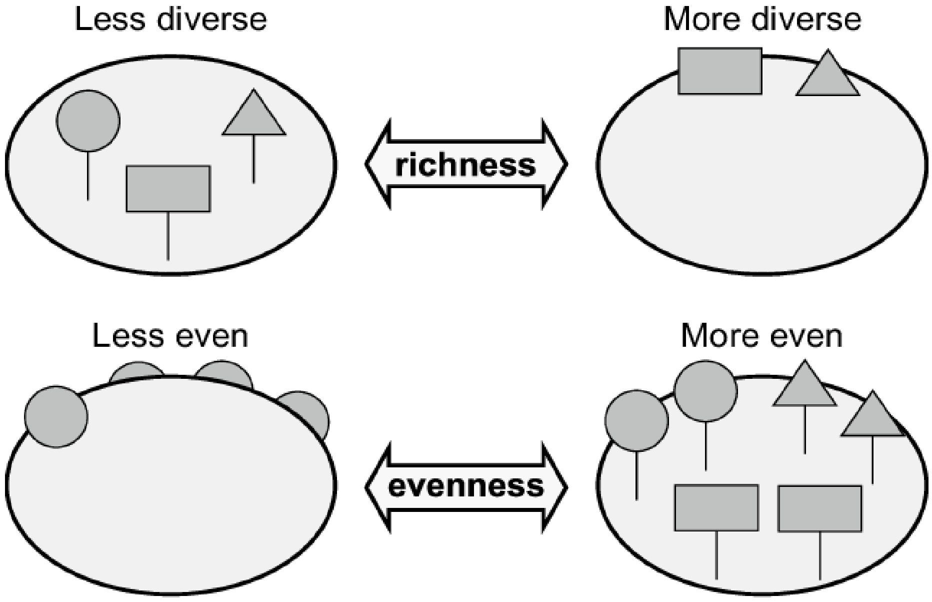

Fig. 4.3 Species Diversity

4.4 ECOSYSTEM DIVERSITY

Ecosystem diversity refers to the variety of ecosystems present in a biosphere. It is the measure of variety of ecological roles played by different groups of species in a community or subsystem (predators, parasites, symbiotic communities) inhabiting in a particular habitat, their ecological roles, and the processes by which the composition of species change across a region. It also takes into account the diversity of ecosystems in landscape and various biomes of the world. Hence, the diversity of an ecosystem is dependent on the physical characteristics of the environment, the diversity of species present, and the interactions that the species have with each other and with their physical environment. Therefore, the functional complexity of an ecosystem increases with taxonomic diversity of the residing species, along with the vertical and horizontal complexity of the physical environment. Since the functional relationship established between a community and habitat constitutes an ecosystem, therefore, an ecosystem consists of three basic components: (i) Physical habitat, (ii) Community structure, and (iii) Ecological functions.

Ecosystem diversity relates to the measure of variety and variability of physical habitats, biotic communities and the functional (ecological) processes within and between ecosystems as well as in the entire biosphere. There is hardly any difference between community and ecosystem, because a biological community cannot survive without any interaction with its physical environment. The variety of species is the building material for biological community in an ecosystem, which interacts with one another and with the abiotic components. The limit of a biological community may be defined either in terms of the dominant vegetations (grassland, woodland) or the dominant fauna (barnacle or coral community). Generally, a limiting line can be drawn around a biological community (such as, a swamp or a lake), but it is impossible to draw a limit around an ecosystem.

However, both are involved in the input and output of energy flow. Ecological diversity is however, the least understood component of biodiversity and the ecosystem is a unique unit for biological conservation. It needs clear understanding of the composition, structure and functioning of an ecosystem from where life can smoothly flourish. The role of plants in cloud formation, water and carbon dioxide balance or soil formation is performed by the functional aggregates of organisms of the ecosystem rather than by a single species. A large number of functionally analogous species also contribute to high stability and continuity of the ecosystem functions during the period of disturbance and environmental stress. As the diverse groups of organisms interact with ecological processes in many ways, the loss of a species from a particular area may have no effect on net primary productivity if competitors take its place in the community.

4.4.1 Habitat or Structural Diversity

It refers to the habitats and landscape patches that comprise the physical components (soil, rocks, and materials) supporting plants and animals in an ecosystem. Habitats form the abiotic structure, while structure is the arrangement of substances in space. Function relates to how these substances change (nutrient cycling, disturbances) over time. A more complex habitat architecture fosters greater species diversity, creating opportunities for more species to coexist. For instance, a complex ecosystem like a three-layered rainforest provides more physical habitats than a simple tidal forest. Habitat cannot exist without a biological community, nor can a community thrive without proper habitat structure. The Thar desert ecosystem in India supports various landforms, including hilly areas, rocky terrain, flat pediments, alluvial plains, river beds, and sand dunes, each hosting diverse plant and animal communities that contribute to the biodiversity of arid ecosystems.

4.4.2 Community Diversity

Community diversity refers to the variety, number, size and relative abundance of the interdependent and interrelated species in a given physical habitat. A biological community consists of co-existing interdependent populations of different species which interact with their abiotic environment as well as among themselves. In other words, community is a local set of functionally, inter-dependent group of species, where the physical factors and ecological processes function as a unit to form an ecosystem. Therefore, community diversity and ecosystem diversity are inseparable. Various species comprising an ecosystem vary with reference to their taxonomic criteria, genetic structure and functional attributes. When different species inhabit together in a certain locality, they may interact in diverse ways among themselves and with the environment, forming a community in which various species have diverse roles to play in determining its structure and function. Community can be thus, structured according to the function of the species. Each species occupies an important ecological niche (niche space), which is characterized by climatic variations like moisture, salinity, light and temperature. Within the physical structure of the habitat when several species share similar niches and also have similar functions, they form a functional group called guild.

4.4.3 Functional Diversity

Functional diversity is the diversity and range of Functional traits possessed by the biota in an ecosystem. It relates to the number, type, and distribution of functions performed by organisms or functional groups within an ecosystem and determines how it functions or operates. Functional diversity is the study of different types of processes that species perform for their survival. These processes include energy flow and recycling of matter. It is thus, the distribution of biological traits of organisms within an ecological community. Indices quantifying the functional aspect of biodiversity are essential in understanding relationships between biodiversity, ecosystem functioning and environmental constraints.

Functional diversity denotes ecological process diversity vital for ecosystem maintenance, influenced by other diversity components. It encompasses the variety and abundance of functionally distinct organism groups and their interactions (competition, predation, parasitism, mutualism) and the ecological processes they facilitate, like nutrient retention and recycling. Functional diversity underscores processes that support biodiversity.

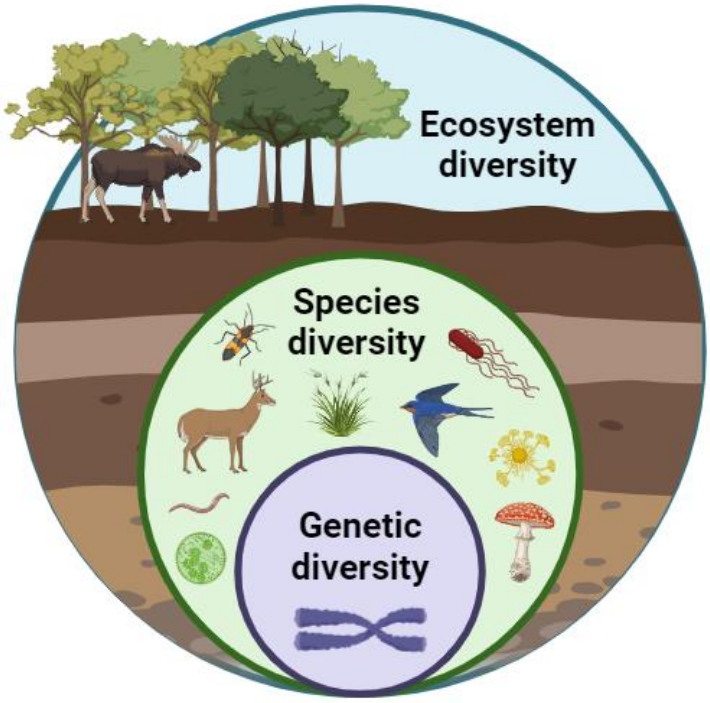

Fig. 4.1 hierarchical components of diversity

4.5 BIODIVERSITY VALUES

Introduction: Biodiversity values refer to the significance and benefits that biological diversity provides to ecosystems, human societies, and the planet as a whole. These values highlight the importance of maintaining a rich variety of life, including different species, genetic variations, and ecosystems, to sustain ecological balance and human well-being. Biodiversity contributes to the stability and productivity of ecosystems by supporting essential processes such as pollination, nutrient cycling, climate regulation, and water purification.

Beyond ecological importance, biodiversity holds economic, cultural, and ethical value. It serves as the foundation for industries such as agriculture, medicine, and tourism while also playing a critical role in human traditions, spiritual beliefs, and recreational activities. The ethical dimension of biodiversity emphasises the responsibility of humans to protect and respect all forms of life, recognising that each species has an inherent right to exist.

The value of biodiversity extends far beyond immediate human use, as it ensures resilience against environmental changes, supports food security, and safeguards ecosystem services that future generations will rely on. Conserving biodiversity is crucial for sustaining life on Earth, maintaining the health of natural systems, and securing the resources that humans depend upon for survival and development.

4.6 TYPES OF BIODIVERSITY VALUES: DIRECT AND INDIRECT VALUES

4.6.1 Direct Values of Biodiversity

Direct value is the benefit derived from the goods provided by biodiversity. Examples of this direct value include food, wood, firewood, medicines, linen, and wool. These commodities can be used by people for their own consumption needs as well as generate income through trade and research. These are the immediate and tangible benefits that humans derive from biodiversity. They include products and resources that can be harvested, consumed, or sold.

➢ **Consumptive Use Value (Non-Market Value)**

These are biological resources used directly for subsistence without going through a commercial market. This is related to natural products that are used directly for food, fodder, timber, fuel wood, etc. Humans use at least 40,000 species of plants and animals on a daily basis. Many people around the world still depend on wild species for most of their needs, like food, shelter and clothing. The tribal people are completely dependent on the forests for their daily needs.

- **Food sources:** Wild plants, fruits, nuts, fish, and bushmeat.
- **Fuel and energy:** Firewood, charcoal, and biofuels.
- **Medicine:** Traditional herbal medicines and plants used in healing.

Example: Many rural communities depend on wild plants and animals for daily survival, such as fishing in rivers or collecting medicinal herbs.

➢ **Productive Use Value (Market Value)**

These are biodiversity products that are commercially harvested and sold in national and international markets. This is assigned to products that are commercially harvested and marketed. Almost all the present date agricultural crops have originated from wild varieties. The biotechnologists continuously use the wild species of plants for developing new, better yielding and disease resistant varieties. Biodiversity represents the original stock from which new varieties are being developed.

- **Agriculture and livestock:** Crops, dairy, and meat products.
- **Timber and forest products:** Wood for construction, furniture, and paper.
- **Pharmaceuticals:** Many modern medicines are derived from plants and microorganisms.

Example: The anticancer drug **Taxol**, extracted from the Pacific yew tree, has high commercial value in the pharmaceutical industry.

4.6.2 Indirect Values of Biodiversity

Indirect value is a benefit that is consistent with services derived from biodiversity and of great value to society as a whole, not individuals or businesses. Examples of indirect value include services such as pollination by bees, maintenance of water and oxygen circulation by plants, decomposition of dead matter by bacteria and fungi, worship of various flora and fauna, sacred forests, and the aesthetic beauty of flora and fauna. Indirect value is a benefit that is consistent with services derived from biodiversity and of great value to society as a whole, not individuals or businesses. Examples of indirect value include services such as pollination by bees, maintenance of water and oxygen circulation by plants, decomposition of dead matter by bacteria and fungi, worship of various flora and fauna, sacred forests, and the aesthetic beauty of flora and fauna.

➢ **Ecological Value (Ecosystem Services)**

Biodiversity maintains essential ecosystem functions that sustain life on Earth. These services also support human needs and activities, such as intensely managed production ecosystems. Recently, the value associated with the self-maintenance of the ecosystem and various important ecosystem services has been recognised. This refers to the services provided by ecosystems, such as preventing soil erosion, preventing flooding, maintaining soil fertility, nutrient cycling, nitrogen fixation, water cycle, serving as a carbon sink, absorbing pollutants, and reducing the threat of global warming.

- **Pollination:** Bees, butterflies, and birds pollinate crops, ensuring food production.
- **Soil fertility:** Microorganisms and earthworms enrich the soil.
- **Water purification:** Wetlands and forests filter pollutants from water sources.
- **Climate regulation:** Forests act as carbon sinks, reducing greenhouse gases.

Example: Mangrove forests protect coastal areas from storms and erosion while supporting marine biodiversity.

➢ **Social and Cultural Value**

Biodiversity is deeply embedded in human traditions, religions, and lifestyles. The social value of biodiversity includes aesthetic, recreational, cultural and spiritual values. To this can be added health benefits resulting from recreational and other activities. While traditional societies, which had a small population and required fewer resources, had preserved their biodiversity as a life-supporting resource, modern man has rapidly depleted it, even to the extent of leading to the irrecoverable loss due to the extinction of several species.
Thus, apart from the local use or sale of products of biodiversity, there is the social aspect in which more and more resources are used by affluent societies. The biodiversity has to a great extent, been preserved by traditional societies that valued it as a resource and appreciated that its depletion would be a great loss to their society.

- **Spiritual and religious significance:** Many species and ecosystems are considered sacred.
- **Traditional knowledge:** Indigenous communities use biodiversity for medicine, rituals, and sustainable living.
- **Recreational and aesthetic benefits:** People find joy in nature through hiking, wildlife watching, and eco-tourism.

Example: The Ganges River in India is considered sacred, and its biodiversity holds deep cultural and religious importance.

➢ **Ethical and Moral Value**

Biodiversity has intrinsic value beyond human needs. Every species has a right to exist, and humans have a moral responsibility to protect them. It is based on the principle of ‘live and let others live'. Ethical values related to biodiversity conservation are based on the importance of protecting all forms of life. All forms of life have the right to exist on Earth. Man is only a small part of the Earth's great family of species.

- **Right to life:** Every organism has a role in the ecosystem and should not be destroyed for short-term human benefits.
- **Future generations:** Conserving biodiversity ensures that future generations can benefit from nature's richness.

Example: Conservation movements worldwide advocate for the protection of endangered species like tigers, elephants, and whales, even if they do not have immediate economic value.

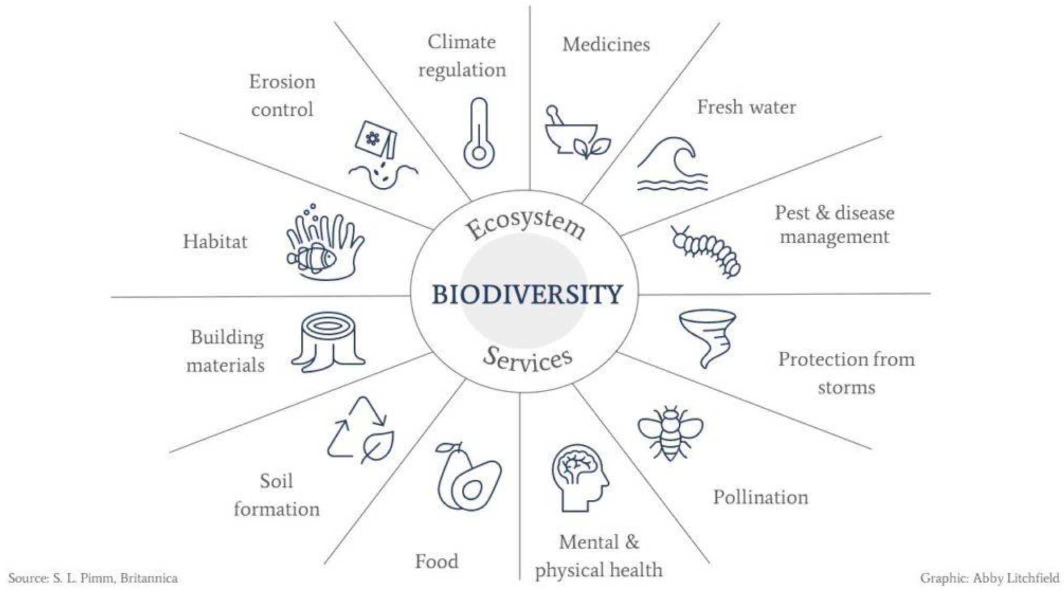

Fig. 4.6 Types of biodiversity values

4.7 SUMMARY

Biodiversity can be understood through its hierarchical components, which are structured at three main levels: genetic diversity, species diversity, and ecosystem diversity. Genetic diversity refers to the variation of genes within a species, ensuring adaptability and survival. Species diversity is the variety and abundance of different species within a particular region or ecosystem. Ecosystem diversity involves the range of different habitats, biological communities, and ecological processes in the biosphere. These three levels are interconnected and together define the richness and complexity of life on Earth.

Biodiversity also holds multiple values that highlight its importance. Ecological values include the role of biodiversity in maintaining ecosystem functions like pollination, climate regulation, and nutrient cycling. Economic values are seen in resources such as food, medicine, and raw materials derived from biodiversity. Aesthetic and recreational values relate to the enjoyment and inspiration humans gain from nature, which also supports tourism. Ethical and moral values stress the responsibility to conserve biodiversity for its own sake and for future generations. Cultural and spiritual values connect biodiversity with religious beliefs, traditions, and indigenous knowledge systems. Educational and scientific values underscore biodiversity's role in research and learning. Together, these hierarchical components and values make biodiversity essential for environmental health, human well-being, and sustainable development.

4.8 TECHNICAL TERMS

Species Richness, Species Evenness**,** Primary productivity, disease-resistant, Genetic variability, phenotypic complexity.

4.9 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. What are the three hierarchical components of biodiversity?
2. What are the different types of biodiversity values?

Short Notes

1. What is the significance of species diversity in an ecosystem?
2. How does biodiversity contribute to ecological stability and ecosystem services?
3. In what ways does biodiversity have economic value?

4.10 SUGGESTED READINGS

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Prof. K. Veeraiah

LESSON-5

BIODIVERSITY IN PERIL

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to:

- To gain the knowledge of how biodiversity is in peril.
- Understanding the causes of biodiversity loss.
- Explore the effects of extinction.
- Understanding the anthropogenic impacts in biodiversity.

STRUCTURE

5.1 INTRODUCTION

Biodiversity, in most simple terms, means the diversity of life. Internationally agreed definition, as per the Convention on Biological Diversity (CBD), is the variability among the living organisms from all sources, including inter alia, terrestrial, and other aquatic ecosystems, as well as the ecological complexes of which they are part. This includes diversity within the species, between the species of the ecosystem. Biodiversity loss is a decrease in biodiversity within a species, an ecosystem, a given geographic area, or Earth as a whole. Biodiversity, or biological diversity, is a term that refers to the number of genes, species, individual organisms within a given species, and biological communities within a defined geographic area, ranging from the smallest ecosystem to the global biosphere. (A biological community is an interacting group of various species in a common location.) Likewise, biodiversity loss describes the decline in the number, genetic variability, and variety of species, and the biological communities in a given area. This loss of variety of life can lead to a breakdown in the functioning of the ecosystem, where decline has occurred.

5.2 CAUSES FOR THE LOSS OF BIODIVERSITY

Direct drivers influence ecosystem processes that bring about species extinction. These include land use change, climate change, invasion of exotic species, overexploitation of natural resources and environmental pollution. Indirect drivers include changes in human population, incomes or lifestyle that operate in a subtle way to alter one or more direct drivers.

However, changes in biodiversity are driven by combinations of several drivers that act chronically and in combination with one another, and that tend to amplify the impact of the other. For example, population growth, clearing of natural areas for settlement, combines with technological advances combine to lead to a shift in global climate.

Currently, changes in the environment with irreplaceable loss of biodiversity are the outcome of human activities. Under constant threat, species may not have enough time and suitable space to migrate, adapt and evolve. Man brings about mega modifications in his surroundings that are detrimental to other living organisms, including their entire environment. The blame for biodiversity loss goes on to man's misdeed that limits the survival of others.

The air is overburdened with pollutants, causing the climate to change drastically. The farmland, pastures and forest covers are decreasing at a rapid pace. Erosion and self-accumulation are rendering soil useless and threatening future food production. Tropical rainforests are being cleared, wetlands are being drained, coastal areas or estuaries are polluted, and coral reefs are being bleached. There has been a pervasive change in the global landscapes that has modified the ecological background on which species evolve. Most species are now suffering from the indirect and subtle changes in the ecological processes. Moreover, dangerous radiation reaching land, lakes, and rivers is rendering them lifeless. As such, rich biodiversity on Earth is being impoverished. The magnitude of biodiversity loss has been accelerated as a consequence of an enhanced rate of extinction compared to the slower rate of speciation. All these are due to an exploding rise in human populations. If this is allowed to continue, the Earth will certainly be lifeless in the near future, as about 90 per cent of all species have become extinct since the origin of life on Earth.

i. **Climate change**: Global warming and the resulting changes in climate patterns have altered habitats, making it challenging for organisms to perform their natural functions or adapt to new conditions. Changes in temperatures or rain patterns, for example, make it different for certain plants to grow or survive, which also affects the species that depend on them. Climate is often defined loosely as the average weather at a particular place, incorporating such features as temperature, precipitation, humidity, and windiness. A more specific definition would state that climate is the mean state and variability of these features over some extended time period. Both definitions acknowledge that the weather is always changing, owing to instabilities in the atmosphere. And as weather varies from day to day, so too does climate vary, from daily day-and-night cycles up to periods of geologic time hundreds of millions of years long. In a very real sense, climate variation is a redundant expression—climate is always varying. No two years are exactly alike, nor are any two decades, any two centuries, or any two millennia.

ii. **Overhunting**: Overhunting of a species to meet high demand for meat or animal byproducts for export, or due to pest control, is one of the main drivers of species extinction. Industrialised hunting does not take into account the effects of species deterioration on the rest of the ecosystem and quickly depletes populations. For example, the sharp commercialisation of otter fur in the 18th and 19th centuries in the United States and Russia nearly drove the species extinct, which catalysed the secondary effects of losing kelp forests and depleting fish populations.

iii. **Overfishing**: Industrialised fishing has led to the depletion of highly-demanded species like tuna, whales and salmon to meet the world's demand. Unsustainable methods of fishing, like bottom trawling, have also destroyed sea-floor habitats, which are important nursery areas for many species. This has the knock-off effect of changing marine ecosystem structures by increasing the populations of predators at the expense of their prey.

iv. **Invasive species**: As ecosystems have evolved to maintain a relative stability of species population, non-native species introduced to new environments can outcompete native species for resources, prey on them, or transmit diseases. When invasive species are at higher levels of the food chain, they can deplete populations of the prey they feed on. Conversely, when invasive species are in the middle or bottom of the food chain, the native species that feed on them may spike in population as they have an abundance of food, which could have repercussions on the rest of the ecosystem. Most introduced species do not survive extended periods in new habitats, because they do not possess the evolutionary adaptations to adjust to the challenges posed by their new surroundings. Some introduced species may become invasive when they possess a built-in competitive advantage over indigenous species in invaded areas. Under these circumstances, new arrivals can establish breeding populations and thrive, especially if the ecosystem lacks natural predators capable of keeping them in check. The ecological disruption that tends to follow such invasions often reduces the ecosystem's biodiversity and causes economic harm to people who depend on the ecosystem's biological resources. Invasive predators may be so adept at capturing prey that prey populations decline over time, and many prey species are eliminated from affected ecosystems. Other invasive species, in contrast, may prevent native species from obtaining food, living space, or other resources. Over time, invading species can effectively replace native ones, often forcing the localised extinction of many native species. Invasive plants and animals may also serve as disease vectors that spread parasites and pathogens that may further disrupt invaded areas.

v. **Pollution**: Air, soil and water pollution can harm species by degrading their habitats, physically harming them, or increasing their vulnerability to diseases or predation. Some pollutants, such as pesticides and heavy metals, can be passed up the food chain, therefore contaminating many levels of the ecosystem. Which is the addition of any substance or any form of energy to the environment at a rate faster than it can be dispersed, diluted, decomposed, recycled, or stored in some harmless form contributes to biodiversity loss by creating health problems in exposed organisms. In some cases, exposure may occur in doses high enough to kill outright or create reproductive problems that threaten the species's survival.

vi. **Diseases**: The spread of infectious diseases, often facilitated by human activities, can devastate wildlife populations. Organisms have developed natural defences against disease-inducing microbes native to their region. However, when human activity contaminates ecosystems with non-native microbes, indigenous species are not equipped to combat them. Mainstream and traditional medicines can be derived from the chemicals in rare plants and animals, and thus, lost species represent lost opportunities to treat and cure. For example, several species of fungi found on the hairs of three-toed sloths (Bradypus variegatus) produce medicines effective against the parasites that cause malaria (Plasmodium falciparum) and Chagas disease (Trypanosoma cruzi), as well as against human breast cancer.

vii. **Ocean acidification**: Increases in carbon dioxide levels are responsible for the acidification of oceans, which makes it difficult for marine organisms, like corals, plankton or shellfish, to maintain their protective coating. The result is a decline in these species populations, as well as those of species that rely on them for food and shelter. Concerning the world's battle against global warming, the presence of a huge oceanic "carbon sink" that pulls excess carbon dioxide from the atmosphere can be a good thing, since temperatures might not rise as fast as they would otherwise. Adding carbon dioxide to seawater, however, kicks off a chemical reaction that lowers seawater's pH, making seawater more acidic. This condition is called ocean acidification, and it has implications for the survival of sea life. Scientists have estimated that the average pH of seawater declined from 8.19 to 8.05 between 1750 and today, corresponding to a 30 per cent increase in acidity.

5.2.1 The effects of Biodiversity loss on the environment:

Biodiversity loss has a cascading effect on ecosystems and the environment, leading to a decline in ecosystem services and reduced resilience to disturbances. The weight of biodiversity loss is most pronounced on species whose populations are decreasing. The loss of genes and individuals threatens the long-term survival of a species, as mates become scarce and risks from inbreeding rise when closely related survivors mate. The wholesale loss of populations also increases the risk that a particular species will become extinct.

Biodiversity is critical for maintaining ecosystem health. Declining biodiversity lowers an ecosystem's productivity (the amount of food energy that is converted into biomass) and lowers the quality of the ecosystem's services (which often include maintaining the soil, purifying water that runs through it, and supplying food and shade, etc.).

Biodiversity loss also threatens the structure and proper functioning of the ecosystem. Although all ecosystems are able to adapt to the stresses associated with reductions in biodiversity to some degree, biodiversity loss reduces an ecosystem's complexity, as roles once played by multiple interacting species or multiple interacting individuals are played by fewer or none. As parts are lost, the ecosystem loses its ability to recover from a disturbance (see ecological resilience). Beyond a critical point of species removal or diminishment, the ecosystem can become destabilised and collapse. That is, it ceases to be what it was (e.g., a tropical forest, a temperate swamp, an Arctic meadow, etc.) and undergoes a rapid restructuring, becoming something else (e.g., cropland, a residential subdivision or other urban ecosystem, barren wasteland, etc.).

Reduced biodiversity also creates a kind of "ecosystem homogenisation" across regions as well as throughout the biosphere. Specialist species (i.e., those adapted to narrow habitats, limited food resources, or other specific environmental conditions) are often the most vulnerable to dramatic population declines and extinction when conditions change. On the other hand, generalist species (those adapted to a wide variety of habitats, food resources, and environmental conditions) and species favoured by human beings (i.e., livestock, pets, crops, and ornamental plants) become the major players in ecosystems vacated by specialist species. As specialist species and unique species (as well as their interactions with other species) are lost across a broad area, each of the ecosystems in the area loses some amount of complexity and distinctiveness, as the structure of their food chains and nutrient-cycling processes becomes increasingly similar.

Some of the sequences include:

- **Loss of ecosystem stability**: Biodiverse ecosystems are more stable and resilient to disruptions such as climate change, disease outbreaks or invasive species. Loss of increases the risk of ecosystem collapse.
- **Decline in ecosystem services**: Healthy, diverse ecosystems provide essential services, such as water and air purification, soil formation, pollination, carbon sequestration and climate regulation. Biodiversity loss can impair these services, leading to a decline in environmental quality.
- **Loss of genetic resources**: Biodiversity is a reservoir of genetic resources that can be used for the development of new crops, medicines and for cultural expression. Altered biogeochemical cycles: Biodiversity loss can affect the cycling of nutrients, such as carbon, nitrogen and phosphorus, in ecosystems. This can lead to changes in ecosystem productivity, water quality, and greenhouse gas emissions. Increased risk of species extinction: The loss of individual species can have cascading effects on other species within the same ecosystem, leading to further declines in biodiversity and increasing the risk of extinction for multiple species. The blue whale is critically endangered.

5.2.2 How Biodiversity loss affects humans

The loss of biodiversity has significant implications for human health, well-being and economic development. Some of the ways in which biodiversity loss affects humans include:

i. **Reduced food security:** Biodiversity is essential for food production, as it provides genetic resources for crop and livestock improvement, pollination services and natural pest control. Declining biodiversity can reduce agricultural productivity and increase the vulnerability of food systems to pests, diseases and climate change. Decline in human health: Biodiversity plays a critical role in the development of new medicines, as many pharmaceuticals and homoeopathic remedies are derived from plants or animals. Losing species could mean losing potential sources of new treatments for diseases. Additionally, the decline in ecosystem services, such as water and air purification, can lead to increased exposure to pollutants and pathogens, negatively affecting human health.

ii. **Economic losses**: Biodiversity supports many industries, including agriculture, forestry, fisheries and tourism. Loss of biodiversity can reduce the productivity and sustainability of these industries, leading to economic losses and reduced employment opportunities.

iii. **Loss of cultural values:** Biodiversity has cultural and spiritual significance for many people, particularly indigenous communities. The loss of species and ecosystems can result in the loss of cultural heritage, traditional knowledge and spiritual connections to nature.

iv. **Increased vulnerability to natural disasters**: Healthy, diverse ecosystems can help protect human communities from natural disasters, such as floods, storms and landslides. Biodiversity loss can reduce the ability of ecosystems to buffer these events, increasing the vulnerability of human settlements to natural disasters.

v. **Reduced resilience to climate change:** Biodiversity is crucial for ecosystem resilience to climate change. Loss of biodiversity can reduce the capacity of ecosystems to adapt to changing climate conditions, potentially exacerbating the impacts of climate change on human societies. Deforestation is one of the main forms of habitat loss and fragmentation, reducing the habitable land for many species. Ocean acidification engenders coral bleaching, killing coral reefs and affecting the species that depend on them for food and shelter. Biodiversity loss decreases the environment’s resilience to withstand the effects of climate change, such as forest fires.

5.3 EXTINCTION

Extinction is an important part of the process of evolution of biodiversity and does not occur at a constant rate. It is the complete disappearance of a species from Earth. Thus, extinction is the final and irreversible event of species loss. Species extinction is the most common way for depletion of biodiversity. When a species becomes extinct none of the individual of that population are left in the biosphere, and the entire gene pool is lost. When a species is lost, a wide variety of other organisms are directly or indirectly affected, and the balance of the ecosystem is also disturbed. As a result, the resource (natural capital) and ecosystem services are degraded. In general, species extinction primarily disrupts the food chain, leaving the ecosystem at greater risk for further loss of biodiversity.

Natural or anthropogenic factors that directly or indirectly induce species loss are referred to as drivers. Drivers include environmental stress or disturbances, extreme climatic conditions, limitation of resources and introduction of non-native species. The main causes of this degradation are natural disasters, human population rise, poverty and the pressures of economic development that exploit raw materials from nature. Economic developments may bring only short-term benefits, from local to global scales, but these are made at the expense of the integrity of ecosystems. Development is defined as the modification of the biosphere and the application of human, financial, living and non-living resources to satisfy man's needs and improve the quality of human life. Environment and development are inevitably related. But the concept of Eco development was conceived at the 1st meeting of the General Council of the New United Nations Environmental Programme, held in Nairobi, 1973.

In contrast, extirpation is the local or regional disappearance of a species from only a part of its range. There have been at least five periods when there was a sudden increase in the rate of extinction to at least double, affecting many different types of plants and animals.

5.3.1 Mass Extinctions

There have been five major extinction events in the history of the earth and the sixth has been predicted in the near future. The previous events were environmental catastrophes, while the next would be largely framed by man.

These catastrophic changes were rapid events where significant part of life became extinct and taxa were exterminated. Life forms of different phyla inhabiting various habitats were affected drastically. The moving of continents, lowering of sea level, unpredictable changes in climatic conditions and large-scale volcanic eruptions initiated these events. As a consequence, a major share of flora and fauna of the earth were wiped away which was followed by very slow recovery. Organisms failing to adapt with the changing conditions perished. After the events the habitats become infested with weeds, pests, opportunists organisms that showed rapid and prolific reproductive rates. Higher rate of invasion of exotic species and loss of unique species made the distribution of species homogeneous and ecological balance was much disturbed.
The five major extinction events are:

1. **Ordovician extinction event** (450-440 million years ago): Historically, this was the first mass extinction event, as evidenced from fossil records. Large glaciation events destroyed about 50-60 per cent of the animal genera and 12 per cent of all the extant families which were mostly the marine invertebrates.

2. **Late devonian extinction event** (380 million years ago): In this era, about 70-72 per cent of the marine invertebrates perished and particularly coral reefs were highly affected. About 14 per cent of all families were threatened.
3. **End of permian extinction event** (248 million years ago): About 95 per cent of marine vertebrates and invertebrates perished following the catastrophe and 70 per cent terrestrial vertebrates were extinct. About, 52 per cent families were affected due to flood basalt, global warming and low oxygen content of the atmosphere.
4. **End of triassic extinction event** (213 million years ago): Almost 44 per cent marine vertebrates and invertebrates were lost in this event. This era witnessed the formation of Manicouagan crater with the flooding of basalt in central Atlantic. This resulted in the loss of about 80 per cent terrestrial quadrupeds along with 50 per cent marine fauna. About 12 per cent families and 65 per cent species living were affected.
5. **Cretaceous tertiary, K.T. extinction event or cretaceous Paleogene event:** This extinction event was dated back about 65 million years ago when 85 per cent of the living species were affected and became extinct. Among them were all major large land animals, several species of dinosaurs, tropical plants (except ferns and seed-bearing plants), marine vertebrates and invertebrates. Even marine sessile organisms were also not spared. Most mammals, birds, turtles, crocodiles, lizards, snakes, and amphibians were affected. It has been assumed that asteroid of about 10 km (6 miles) in diameter had struck the earth at the end of cretaceous that created the Chixculub crater which is about 160 km in diameter. Hot materials ejected from the impact resulted into fire and swiped away about 70 per cent of the inhabiting organisms. This impact was largely felt in the ocean that initiated the tsunami destroying almost 40 per cent of the continental regions. The temperature of the earth rose by 6-14°C severely affecting about 17 per cent of all families, 50 per cent genera and 75 per cent of the species.

5.3.2 Sixth Extinction Crisis

The world has begun, relatively recently, to lose species and habitats at an ever-increasing and alarming rate. This is often referred to as the 6th extinction crisis, after the 5 known extinctions, Waves in geological history. So, what is the Sixth Extinction? When is it coming? And what is its cause? “It’s the next annihilation of vast numbers of species. It is happening now, and we, the human Race, are its cause,” explains Dr. Richard Leakey, the world’s most famous Paleoanthropologist.

The extinction of species is currently occurring as a result of human activities of various kinds. From a study of the history of life on earth through fossil records, we learn that large-scale Loss of species like the one we are currently witnessing has also happened earlier, even before humans appeared on the scene. During the long period (> 3 billion years) since the Origin and diversification of life on Earth, there were five episodes of mass extinction of Species. How is the ‘Sixth Extinction’ presently in progress different from the previous episodes the difference is in the rates; the current species extinction rates are estimated to be 100 to 1,000 times faster than in pre-human times, and our activities are responsible for the faster rates. Ecologists warn that if the present trends continue, nearly half of all the Species on Earth might be wiped out within the next 100 years. Humans endanger the existence of species in three principal ways.

The first is through direct Exploitation, such as hunting. Second is the biological havoc that is occasionally wreaked following the introduction of alien species to new ecosystems, whether deliberately or accidentally. The third, and by far the most important, mode of human-driven extinction is the destruction and fragmentation of habitat, especially the inexorable cutting of tropical Rainforests. The forests, which cover just 7 percent of the world's land surface, are a cauldron of evolutionary and are home to half of the world's specie The continued growth of human populations in all parts of the world daily encroaches on wild habitats, whether through the expansion of agricultural land, the building of towns and cities, or the transport Infrastructure that joins them. As the habitats shrink, so too does the Earth's capacity to sustain its biological heritage.

➢ **How the 6th mass extinction might differ from previous mass extinctions**

The sixth mass extinction, currently believed to be underway, differs from previous mass extinctions in several important ways:

1. Human-Driven: Unlike the past five mass extinctions caused by natural events such as asteroid impacts, volcanic eruptions, or climate shifts, the sixth is primarily caused by human activities, including habitat destruction, pollution, overexploitation, invasive species introduction, and climate change.
2. Rapid Pace: The current rate of species loss is much faster than in previous events. Some studies estimate that extinction rates today are 100 to 1,000 times higher than the natural background rate.
3. Global Impact: Human influence extends to nearly every part of the planet, making this extinction more widespread and comprehensive, affecting all ecosystems—terrestrial, marine, and freshwater.
4. Selective Loss: The sixth extinction tends to affect large-bodied animals (megafauna), island species, and those with limited ranges or specialised habitats more severely, due to human pressures like hunting, urbanisation, and agriculture.
5. Reversible Possibility: Unlike previous extinctions caused by uncontrollable natural forces, the sixth mass extinction could still be mitigated or slowed down through conservation efforts, sustainable practices, and global cooperation.
6. Documented in Real-Time: For the first time, a mass extinction is being scientifically observed and documented as it happens, allowing humans the opportunity to study and potentially change its course.

5.3.3 Ecological factors leading to extinction

1. **Habitat type:** Species in an isolated or fragmented habitat (island) is vulnerable to extinction.
2. **Rarity:** Rare, endemic species with small population size and narrow geographical range or in fragmented habitats, have higher chances of extinction.
3. **Dispersal ability:** Migratory animals and those with higher dispersal ability suffer less. Smaller populations living in fragmented habitats benefit from the arrival of migratory 'rescuers' from other fragments, which reduces their chance of extinction. Good dispersers are at less risk.
4. **Degree of specialisation:** The ecologically specialised fauna depends on specific food resources that are patchily distributed in space and time, or are seasonally available are vulnerable. The rarity of the resource utilised by the species determines its distribution. Among the phytophagous insects, some depend on the flowering season, others on fruiting events and therefore, tend to be rare except during the time of food availability. These habitat specialist species may be at higher risk of extinction due to their lower adaptability.
5. **Niche location:** Adaptable species can survive in habitat fragmentation as they can tolerate the interface between different types of habitats. Forest edge species or

ecophenes benefit from fragmentation as these are capable of adjusting to changes in ecological conditions.

6. **Population variability:** The species with small and fluctuating population sizes are vulnerable to extinction.
7. **Tropic status:** Animals occupying high trophic levels (tertiary feeders) generally have a smaller population size than those below. The top predators are always fewer in number than the herbivores; hence, they are more threatened.
8. **Adult survival rate:** It has been observed that species with naturally low adult survival rates are more likely to become extinct.
9. **Longevity:** The species have a longer life span and are less vulnerable to extinction than those with shorter life spans.
10. **Intrinsic rate of population increases:** A population capable of rapidly expanding is more potentially fit to recover from decline than the others. Moreover, large predators that require a large home range, feed on specific diets, or those sensitive to environmental changes perish first.

However, for the convenience of conservation, it is more important to assess the number of species on earth than to determine the precise figure of extinct species or their rate of extinction. Obviously, rather than focusing so much on extinction rate, it is required to develop the capability to identify the localities of high species diversity and endemism. This is to ensure that these sites are to be under a system of conservation management for maintaining their ecological integrity before they are further perturbed.

5.4 ANTHROPOGENIC IMPACTS ON BIODIVERSITY

Anthropogenic (human-induced) activities have significantly altered biodiversity across the planet, leading to habitat destruction, species extinction, and ecosystem imbalances. These impacts are driven by rapid population growth, industrialisation, deforestation, pollution, and unsustainable resource exploitation. Human actions have disrupted natural ecosystems, causing irreversible damage to biodiversity and threatening ecological stability.

One of the most severe anthropogenic impacts is **habitat destruction**, where forests, wetlands, and grasslands are cleared for agriculture, urbanisation, and infrastructure development. This fragmentation of natural habitats reduces the available space for wildlife, leading to a decline in species populations and increasing human-wildlife conflicts. Similarly, **overexploitation** of natural resources, such as excessive fishing, hunting, and logging, depletes species faster than they can regenerate, pushing many towards extinction.

Pollution is another major factor affecting biodiversity. Chemical pollutants from industries, agricultural runoff, plastic waste, and oil spills contaminate air, water, and soil, harming both terrestrial and aquatic life. For example, plastic pollution in oceans threatens marine species like turtles and seabirds, while pesticides and heavy metals disrupt insect and amphibian populations. **Climate change**, primarily driven by fossil fuel consumption and deforestation, has further intensified biodiversity loss by altering temperature patterns, causing extreme weather events, and shifting ecosystems beyond their natural limits. Many species struggle to adapt to these rapid environmental changes, leading to habitat loss and population declines.

Additionally, the **introduction of invasive species** due to human activities has disrupted native ecosystems. Non-native plants, animals, and pathogens introduced to new environments often outcompete or prey on native species, reducing biodiversity. For instance, the spread of invasive species like the Nile perch in Lake Victoria has led to the decline of native fish populations.

Overall, human activities have placed immense pressure on biodiversity, accelerating the rate of species extinction and ecosystem degradation. Addressing these impacts requires global conservation efforts, sustainable development practices, and policies that promote environmental protection while balancing human needs. Protecting biodiversity is essential not only for ecological balance but also for ensuring the long-term survival of human societies and future generations.

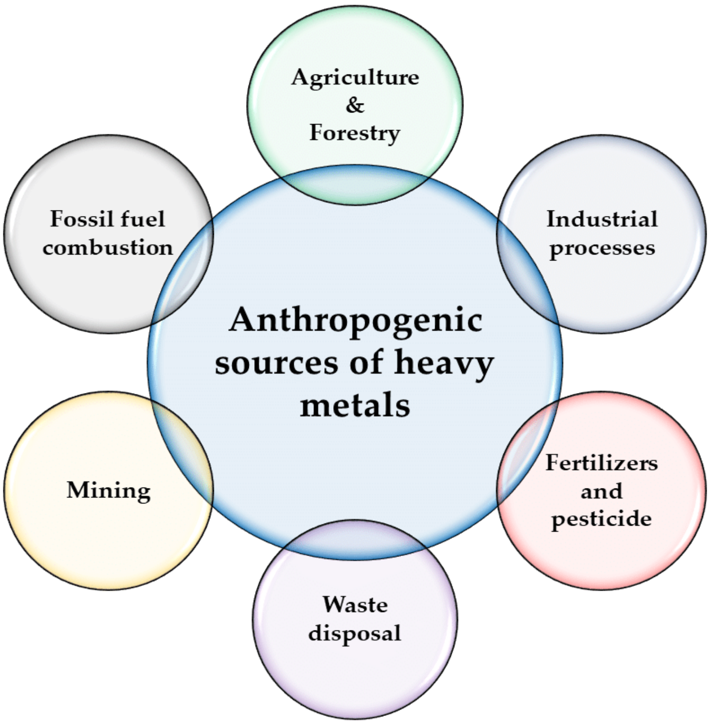

Fig: 3.3 Anthropogenic impacts on biodiversity

5.5 SUMMARY

The Earth is in a continual process of changing naturally, with man enhancing this process manifold. The extinction of species is a natural process that is largely caused by human-related activities. Species' habitats are altered, fragmented and modified which tend to break the existing contiguous landscape into fragmented patches. This impact the inhabitants maximally. Changes in landscape due to agriculture, expansion of urban sectors and construction of communication facilities have destroyed the natural habitats with the subsequent loss of biodiversity. Displacement of native species by exotic invaders and the occurrence of pests and pathogens also deplete populations. The problems of overpopulation, overconsumption, development and industrialisation are intertwined, which tend to enhance the process of species extinction. Species extinction is the cause of biodiversity loss. Conversion of forest to crop fields, capital-intensive, high-technology-driven agricultural practice or aquaculture, use of genetically modified crops results in substantial modifications of soil and degradation of the natural system.

Genetically uniform modern varieties of crops are fast replacing the highly diverse local cultivars and landraces in a traditional agroecosystem. An increase in the level of pollutants by the extensive use of synthetic pesticides and fertilisers in crop fields disrupts the fine balance of the ecosystem. Natural habitats like wetlands, forests and derelict land are also threatened by developmental programmes, but currently, global climate shift is the greatest cause of species extinction. The atmosphere is overburdened with pollutants for that have changed. Tropical rainforests are being cleared. The fertility of farmland and pastures is decreasing at a rapid rate due to excessive use of chemical fertilisers. Air is overloaded with soot, dust, methane, sulphur dioxide, carbon dioxide and secondary pollutants. Ozone has been depleted in the stratosphere, only to increase in concentration in the troposphere, which is extremely harmful. Species extinction interferes with important ecological processes, causing subtle changes in ecological complexes in a biotic community that become vulnerable to environmental threats.

5.6 TECHNICAL TERMS

Mass Extinction, Over-exploitation, Invasive Species, Anthropogenic impacts, Ocean acidification, habitat destruction.

5.7 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. What are the Ecological factors leading to extinction?
2. Briefly describe about Causes of Biodiversity losses.?.
3. Define Anthropogenic Impacts on Biodiversity.?

Short notes

1.How does habitat fragmentation induce biodiversity loss?
2. Explain in detail the various sources of air pollution.?

5.8 SUGGESTED READINGS

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Prof. K. Veeraiah

LESSON-6
SYSTEMATICS

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to:

- Understanding the concept of the systematics of life forms.
- Explore Species Components and their types.
- Understanding Taxonomy and its components.
- To gain knowledge about how life forms were arranged through classification.

STRUCTURE

6.1 INTRODUCTION

Systematics is the study of the diversification of living forms, both past and present, and the relationships among living things through time. Systematics, in other words, is used to understand the evolutionary history of life on Earth. The word systematics is derived from the Latin word of Ancient Greek origin systema, which means systematic arrangement of organisms. The term "systematic" was coined by Carl Linnaeus, the father of taxonomy. The word systematics is derived from the Latin word of Ancient Greek origin systema, which means systematic arrangement of organisms. Carl Linnaeus used *'Systema Naturae'* as the title of his book.

Systematic biology is the field that (a) provides scientific names for organisms, (b) describes them, (c) preserves collections of them, (d) provides classifications for the organisms, keys for their identification, and data on their distributions, (e) investigates their evolutionary histories, and (f) considers their environmental adaptations. This is a field with a long history that in recent years has experienced a notable renaissance, principally with respect to theoretical content. Part of the theoretical material has to do with evolutionary areas (topics e and f above), the rest relates especially to the problem of classification.

Systematics uses taxonomy as a primary tool in understanding, as nothing about an organism's relationships with other living things can be understood without it first being properly studied and described in sufficient detail to identify and classify it correctly. Scientific classifications are aids in recording and reporting information to other scientists and laymen. The **systematist**, a scientist who specialises in systematics, must, therefore, be able to use existing classification systems, or at least know them well enough to skilfully justify not using them.

6.2 SPECIES CONCEPT

A **species concept** is a way of defining and identifying species, which are fundamental units of biological classification. Quantifying species diversity requires developing a definition of a species. We would not expect all members of a species to be identical, so we must consider what magnitude and types of differences between individuals would lead us to consider them members of different species. A species concept is, therefore, a working definition of a species and/or a methodology for determining whether or not two organisms are members of the same species. In this section, we will consider three species concepts that are commonly used by scientists. All species concepts have limitations and work better for some organismal groups than others. Each section below considers the definition of the species concept, its assumptions and limitations, and examples of groups for which that species concept does, and does not, easily apply. Scientists use different species concepts based on various criteria, as there is no single definition that applies universally. Here are some of the most common species concepts:

1. **Biological Species Concept (BSC)** – By far the most well-known species concept is the biological species concept, which was proposed by evolutionary biologist Ernst Mayr. The biological species concept states that a species is a group of actually or potentially interbreeding natural populations that are reproductively isolated from other such groups. Reproductive isolation can occur in several ways (which we will discuss in detail later in the quarter); individuals of different groups may not mate with each other, their mating may not produce offspring, or the offspring produced may not be viable (able to survive) or fertile (able to reproduce).

2. **Morphological Species Concept** – Defines a species based on physical characteristics (morphology). The only evidence that remains of their existence is fossils; there is no behavioural data on reproductive isolation or connectivity with other trilobites, and the fossils are old enough that their DNA has degraded beyond our current analytical capabilities. The morphological species concept is frequently applied in such cases, as it relies entirely on morphology (the physical structures or traits of an organism).

3. **Ecological Species Concept** – Defines a species based on its ecological niche (role in the environment). According to the ecological species concept, the more similar two organisms are then the more likely that their needs will overlap, the more likely they will compete over resources such as food and shelter, and therefore the more likely that they are members of the same species. Not surprisingly, the ecological species concept is thus defined particularly in terms of the ecology of organisms, as with species concepts in general, the ecological species concept is far from perfect. Concerns include that organisms often do not occupy the same ecological niche even over a single lifespan, that it is not necessarily trivial to determine the degree to which competition for resources might be occurring between two organisms as found within natural environments, and the problem of reconciling differences seen between the

perspectives of lumpers and splitters.

4. **Phylogenetic Species Concept (PSC)** – Defines a species as the smallest group of organisms sharing a common ancestor, based on genetic and evolutionary relationships. Useful for: Identifying cryptic species using DNA analysis. Due to the limitations of the biological species concept described above, other species concepts have been developed. The **lineage species concept** defines species as groups of organisms that share a pattern of ancestry and descent and which form a single branch on the tree of life. This concept focuses more on the evolutionary history that has shaped the species as we see it today, and increasingly relies on genetic data to assign individuals to species. The lineage species concept resolves some of the problems of the biological species concept since it can be applied to asexual species and those for which detailed reproductive behavioural data are unavailable. Its reliance on genetic data also makes it difficult to apply to long-extinct species; however, recent advances in genetic analysis have allowed scientists to extract DNA from recently extinct organisms such as Neanderthals and woolly mammoths.

5. **Genetic Species Concept** – Simpson (1961) advocated that genetically identical individuals should be called a Bio species. M. Florkin (1964) gave a definition as follows: Species are groups of individuals with more or less similar combinations of sequences of purine and pyrimidine bases in their DNA and with a system of operators and repressors leading to the biosynthesis of similar amino acid sequences. A genetic species is a group of genetically compatible interbreeding natural populations that are genetically isolated from other such groups. This focus on genetic isolation rather than reproductive isolation distinguishes the Genetic Species Concept from the Biological Species Concept. Recognition of species that are genetically isolated (but not reproductively isolated) results in an enhanced understanding of biodiversity and the nature of speciation, as well as speciation-based issues and the evolution of mammals.

6. **Evolutionary Species Concept** – Proposed by George Gaylord Simpson. Defines a species as a lineage evolving independently from others. Species is a group of organisms that share an evolutionary and ecological history and that are distinct from other groups. The primary difference in the species concepts described above is the forms of evidence used to quantify those differences and to categorise individuals as members of a particular species. The biological species concept relies on behavioural data and emphasises reproductive isolation between groups. The lineage species concept relies on genetic data and emphasises distinct evolutionary trajectories between groups, which result in distinct lineages (branches on a phylogenetic tree). The morphological species concept relies on morphological data and emphasises groups of physical traits that are unique to each species. These lines of evidence are not mutually exclusive, and so multiple species concepts may be used together to define species boundaries. Regardless of the species concept used, not all organisms are easily categorised into distinct groups, and so conversations around species concepts, species boundaries, and the evidence used to define them are a dynamic field of evolutionary biology.

6.2.1 Importance of the Species Concept

Species concepts are essential to biology, influencing our understanding of biodiversity, evolutionary processes, and classification systems. They provide a structured way to categorise and comprehend Earth's diversity. By defining species, scientists classify organisms meaningfully, aiding in identification, naming, and research. This classification underpins taxonomy and allows clear communication about various life forms. In evolutionary biology, species concepts help explore speciation, adaptation, and divergence from common ancestors. In ecology, understanding species boundaries is crucial for studying organism interactions, as these relationships depend on specific traits and behaviours.

The species concept is vital in conservation biology, enabling conservationists to assess biodiversity accurately and develop strategies to protect endangered species and habitats. It ensures resources are allocated toward preserving genetic diversity and ecological balance. In agriculture and medicine, recognising different species is critical—for example, identifying pest species aids in managing crops, while distinguishing pathogenic species is key for disease diagnosis and treatment. Overall, the species concept provides a foundational framework that supports research, policymaking, and applied sciences, enhancing our understanding of and benefit from the natural world.

6.2.2 Speciation or Origin of Species

There were three aspects of evolution, as to how the elementary forces influence the origin of new populations, their diversification (species diversity) and genetic isolation. Speciation is the source of all diversity of sexually reproducing organisms, and the event is responsible for every branch in phylogeny. Speciation refers to the splitting of one existing species into two or more new species by isolation. It can also occur by transformation of one species into a new one in the course of time that has acquired genetic change (gene or chromosomal mutation or recombination). It occurs along two possible paths: gradual change of a complete lineage and branching of a single lineage into two separate lineages. Speciation needs the accumulation of genetic differences between populations, which generally depends on a barrier to dispersal), Reasonably, speciation in many groups of organisms relies on both the geographical distribution of suitable habitat within a region, dispersal ability of individuals as well as the genetic factors that influence the rate of differentiation or variation between isolated patterns of random and non-random variations exhibited within populations suggest that divergence of population has different origin under different conditions leading to origin of new population or species. Only through migration and fragmentation, new demes may arise. In the beginning, gene flow will continue between all segments of the expanding population. However, gradually, genetic exchange from the ancestral stock and the deme would stop, which would lead to the foundation of a new species. A deme is actually a community of potentially interbreeding individuals of a species at a given locality.

From the above discussion, it is clear that the formation of several processes whose importance varies between different taxonomic groups. There are three points associated with the occurrence of speciation: (i) Speciation starts with the existing species; (ii) It is always tagged with genetic change, and (iii) It has a strong ecological context. Thus, speciation may be allopatric, peripatric, parapatric and sympatric.

- **Allopatric speciation:** Populations or species that are mutually exclusive, but usually inhabit adjacent geographical regions (allopatric different countries).

Allopatric speciation occurs when new gene pools arise out of natural selection in those species that are separated from their mother group by a geographical barrier. Firstly, the mother population divides into one or more subpopulations in a new geographical zone after being separated by geographical barriers (oceans, mountains or deserts). After geographical isolation, the subpopulations of the species are acted upon by natural selection or by genetic drift which produces distinctive gene pools. This initiates genetic differentiation among the different groups. When each group has differentiated and adapted to a new genetic identity, gene flow between the resultant groups stops, even if they occur in the same locality. It is then supposed that speciation is complete.

- **Sympatric speciation:** Two or more populations occupying the same geographical area or a population existing in a breeding condition, within the cruising range of individuals of another population.

In sympatric speciation, a population divides into one or more populations that occur in different ecological zones (special habitats or food sources) within the same geographical region. This causes increased genetic differentiation between groups, and the population becomes reproductively isolated. This ultimately leads to the formation of new species.

- **Parapatric speciation:** Allopatric populations whose ranges are in contact and between which gene exchange is geographically possible.

Among plants, speciation occurs by polyploidy, where many species have resulted from chromosomal duplication in the hybrids. In plants, some genotypes of diploid hybrids are fertile, which are reproductively isolated from the parent species and so give rise to new species (recombination speciation)

- **Peripatric speciation:** Achievement of species status by the descendants of a founder population established beyond the periphery of the parental species range.

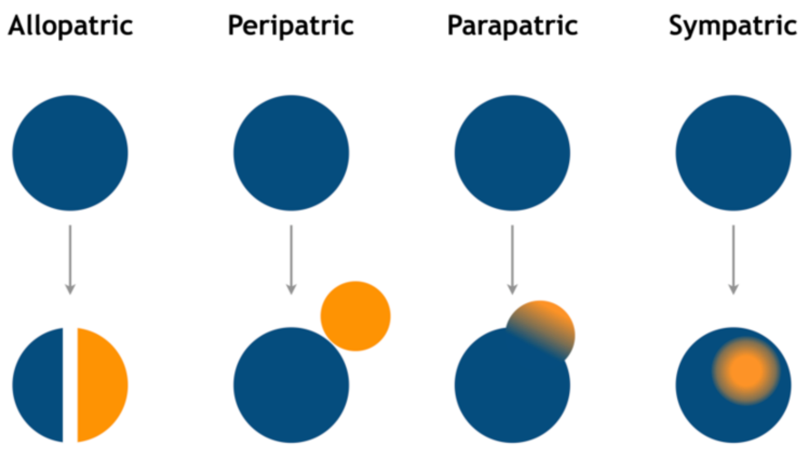

Fig. 6.2.2 Types of Speciation

6.3 TAXONOMY

Taxonomy, in a broad sense the science of classification, but more strictly, the classification of living and extinct organisms—i.e., biological classification. The term is derived from the Greek taxis ("arrangement") and nomos ("law"). Taxonomy is, therefore, the methodology and principles of systematic botany and zoology and sets up arrangements of the kinds of plants and animals in hierarchies of superior and subordinate groups. Among biologists, the Linnaean system of binomial nomenclature, created by Swedish naturalist Carolus Linnaeus in the 1750s, is internationally accepted. It deals with naming, describing and classification of all living organisms, including plants. Classification is based on behavioural, genetic and biochemical variations. Characterisation, identification, and classification are the processes of taxonomy. Organisms are classified into similar categories, namely kingdom, phylum, class, order, family, genus and species.

- **Components of Taxonomy:**

Taxonomy is a systematic approach to organising and naming living organisms based on shared characteristics, evolutionary relationships, and natural similarities. The key components of taxonomy include **classification**, **nomenclature**, **identification**, **phylogeny**, and **characterisation**.

6.4 CLASSIFICATION

The morphological characters of individuals are the most fundamental basis of biological classification. This provides reference information on the existence and taxonomic position (or hierarchy) of each organism. The individuals possessing common features can be grouped together into a large number of different classes, this practice is known as classification. Traditional definition of classification is 'grouping of objects into classes owing to their shared possession of attributes'. Classifications that attempt to reflect a similarity and/or relationship are based on numerous (greatest possible number of) characters.

Classification is an essential tool in our daily life also. For example, we need to know the harmful or beneficial animals, plants and microorganisms around us. Every community uses indigenous classification system, referred as Folk classification. Cultural diversity (culture related to man's food, medicine, folklore, myths, totem, taboo and custom with reference to plants and animals) also influences such classification. In the past, great philosophers and naturalists, amazed by the immense diversity of the living world, devoted themselves to classify the organisms according to their morphological features, ways of life, habits and habitats, adaptation and other characteristics. For the first time the most pioneering contribution was made by Aristotle (384-322 BC) who is known as the father of biological classification. His classificatory scheme was not only based on morphology, but also included the attributes of embryology, habits, ecology and other features of the animals. He classified animals in different groups, such as birds, fish, wingless insects, insects with wings and so on. Even insects were classified into orders like Coleoptera and Diptera, which are still valid today. Such classification is based on observation of similarities and differences among organisms without reference to their origin. This classification is known as **artificial classification,** which is based on shared characters and is used only for limited purposes. However, Aristotle's system of animal classification was followed for the next 200 years. In the early 1600s, the European naturalists created many schemes of classification. There was a steady progress of plant classification during the time of Cisalpine (1519-1603) and Carolus Linnaeus (1707-1778) including the contribution of Magnol, Tournefort, Rivinus, Bauhin, Ray and others. Ultimately, all such classification schemes were suppressed by the excellent contribution of a Swedish Botanist Carolus Linnaeus who is called the father of taxonomy. He created careful keys, telegraphic languages and synonyms. In the *Systema Naturae* (1778), 10th edition, he introduced a system of binomial nomenclature for a species having two names (genus and species) which replaced the then existing system. His concept reflects the existence of earlier fixed and unchanged criteria (essence). Within the animal kingdom, he recognized six taxonomic category ranks arranged in a nested hierarchical system, i.e. phylum, class, order, family, genus and species. Each level of hierarchy indicates a degree of similarity. His hierarchical classification is supplemented by numerous interrelated categories, such as suborder, superfamily, tribe, subgenus, etc. Each of this level is known as the taxonomic category, while a particular group of organisms assigned to a categorical rank is a taxon. This hierarchy of nested categories is called the Linnaean hierarchy.

For example, dog-like animals fall under the genus Canis are classified with other canid like genera (*Vulpes*), to form family Canidae. Further, the members of this family and those of other carnivorous families, such as, the Felidae and Mustelidae are grouped together under the order Carnivora and so up to even larger and higher ranks. The process goes until all living organisms are grouped into five kingdoms, of which the Animalia is only one among four others, such as Plantae, Fungi, Protista, and Monera (prokaryote). The rank in this hierarchy shows the degree of similarity and decency of common origin.

A system of classification proposed in the pre-Linnaean period was used to serve as an identification to key only. Today it serves for both practical and theoretical purposes. Arbitrary ranking of Linnaean hierarchy consisting of a nested set of taxa of different was initially criticised as unscientific classification. However, Darwin provided the scientific interpretation of categorical ranking. He (1859) stated that the natural system is genealogical in its arrangement, as a pedigree, but the degree of modification, which the different groups have undergone, has to be expressed by ranking them under different anas, so-called genera, subfamilies, families, sections, orders and classes. However, some authors envisaged that the origin of higher categories was just the opposite. The higher categorical rank of taxa evolves through evolution from a lower rank, but a lower rank does not evolve through subdivision of higher categories.

Even though Darwin stated emphatically in the Origin of Species (1859:420) that a natural classification must be based on genealogy, the concept was not accepted by most systematists for nearly 100 years. However, some authors constructed a classification based on only the similarities of a few diagnostic characters.

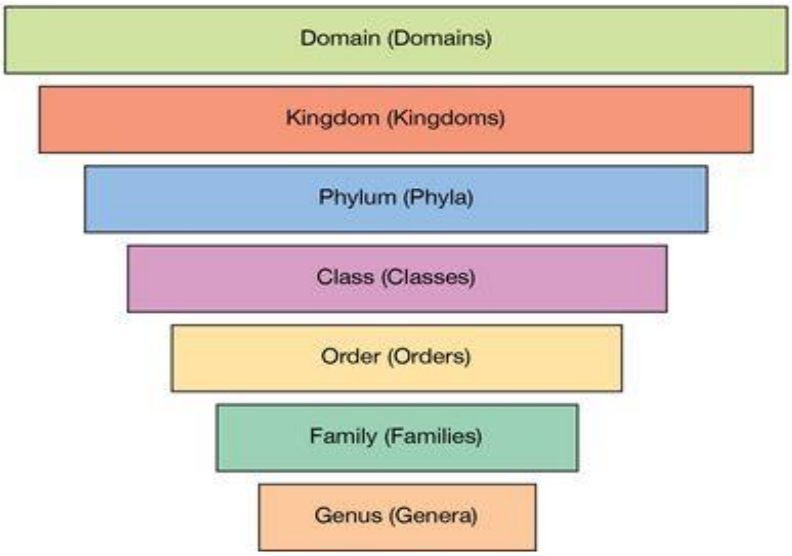

Fig. 6.4 Classification of taxonomy

6.4.1 The Linnaean system

Carolus Linnaeus, who is usually regarded as the founder of modern taxonomy and whose books are considered the beginning of modern botanical and zoological nomenclature, drew up rules for assigning names to plants and animals and was the first to use binomial nomenclature consistently (1758). Although he introduced the standard hierarchy of class, order, genus, and species, his main success in his own day was providing workable keys, making it possible to identify plants and animals from his books. For plants, he made use of the hitherto neglected smaller parts of the flower.

Linnaeus attempted a natural classification but did not get far. His concept of a natural classification was Aristotelian; i.e., it was based on Aristotle's idea of the essential features of living things and on his logic. He was less accurate than Aristotle in his classification of animals, breaking them up into mammals, birds, reptiles, fish, insects, and worms. The first four, as he defined them, are obvious groups and generally recognised; the last two incorporate about seven of Aristotle's groups.

The standard Aristotelian definition of a form was by genus and differentia. The genus defined the general kind of thing being described, and the differentia gave its special character. A genus, for example, might be "Bird" and the species "Feeding in water," or the genus might be "Animal" and the species "Bird." The two together made up the definition, which could be used as a name. Unfortunately, when many species of a genus became known, the differentia became longer and longer. In some of his books, Linnaeus printed in the margin a catch name, the name of the genus and one word from the differentia or some former name. In this way, he created the binomial, or binary, nomenclature. Thus, modern humans are *Homo sapiens*, Neanderthals are *Homo neanderthalensis*, the gorilla is *Gorilla gorilla*, and so on.

6.4.2 Taxonomic Classification Hierarchy

Basically, no special theory lies behind modern taxonomic methods. In effect, taxonomic methods depend on:

1. Obtaining a suitable specimen (collecting, preserving and, when necessary, making special preparations).
2. Comparing the specimen with the known range of variation of living things.
3. Correctly identifying the specimen if it has been described, or preparing a description showing similarities to and differences from known forms, or, if the specimen is new, naming it according to internationally recognised codes of nomenclature.
4. Determining the best position for the specimen in existing classifications and determining what revision the classification may require as a consequence of the new discovery.
5. Using available evidence to suggest the course of the specimen's evolution. Prerequisite to these activities is a recognised system of ranks in classifying, recognised rules for nomenclature, and a procedure for verification, irrespective of the group being examined. A group of related organisms to which a taxonomic name is given is called a taxon (plural: taxa).

Here's the typical hierarchy used in modern taxonomy, from the most general (broadest) to the most specific (narrowest):

1. **Domain**: The highest, broadest classification. There are three domains:
- **Archaea**: Single-celled organisms without a nucleus (prokaryotes), often living in extreme environments.
- **Bacteria**: Single-celled organisms without a nucleus (prokaryotes), common and widespread in nature.
- **Eukarya**: Organisms with complex cells that have a nucleus (eukaryotes), including plants, animals, fungi, and protists.

2. **Kingdom**: Each domain is divided into several kingdoms. The five traditionally recognised kingdoms (though some systems use more) are:
- **Animalia**: Multicellular organisms that are heterotrophic (cannot produce their own food), such as humans, animals, etc.
- **Plantae**: Multicellular organisms that are autotrophic (produce their own food via photosynthesis), such as plants.
- **Fungi**: Organisms like mushrooms and yeast that absorb nutrients from their environment.
- **Protista**: Mostly single-celled organisms that are eukaryotic (e.g., algae, protozoans).
- **Monera** (in some systems): A now outdated kingdom for prokaryotic organisms (split into Bacteria and Archaea in modern classifications).

3. **Phylum (plural: Phyla)**: A division within a kingdom based on major structural and functional features. In animals, a phylum might include organisms with similar body plans or features. For example:
- **Chordata**: Animals with a notochord (e.g., vertebrates).
- **Arthropoda**: Insects, arachnids, and crustaceans with an exoskeleton and segmented body.

4. **Class**: A further division within a phylum. For example:
- **Mammalia** (within Chordata): Warm-blooded vertebrates with hair or fur and the ability to nurse their young.
- **Insecta** (within Arthropoda): Insects like bees, ants, and butterflies.

5. **Order**: A division within a class. For example:
- **Carnivora** (within Mammalia): Carnivorous mammals like lions, wolves, and tigers.
- **Lepidoptera** (within Insecta): Butterflies and moths.

6. **Family**: A division within an order that groups together organisms with even more specific characteristics. For example:
- **Felidae** (within Carnivora): The cat family, including lions, tigers, and domestic cats.
- **Nymphalidae** (within Lepidoptera): A family of butterflies, such as the brush-footed butterflies.

7. **Genus**: A group of closely related species that share many similarities. It is the first part of the scientific name in binomial nomenclature (e.g., *Panthera* for lions, tigers, and leopards).
- **Panthera** (within Felidae): The genus that includes large cats like lions and tigers.
- **Danaus** (within Nymphalidae): A genus that includes the famous monarch butterfly (*Danaus plexippus*).

8. **Species**: The most specific level of classification. A species is a group of organisms that can interbreed and produce fertile offspring. It is the second part of the scientific name in binomial nomenclature (e.g., *leo* for lions).

- **Panthera leo**: The lion.
- **Danaus plexippus**: The monarch butterfly.

Example: Classification of a Lion (*Panthera leo*)

- **Domain**: Eukarya (organisms with eukaryotic cells)
- **Kingdom**: Animalia (multicellular, heterotrophic organisms)
- **Phylum**: Chordata (organisms with a notochord)
- **Class**: Mammalia (warm-blooded, hair/fur, and mammary glands)
- **Order**: Carnivora (meat-eating animals)
- **Family**: Felidae (cats)
- **Genus**: Panthera (large cats)
- **Species**: Panthera leo (lion)

6.5 PHYLOGENY

Phylogeny in taxonomy refers to the study of the evolutionary history and relationships among different species or groups of organisms. It is concerned with understanding how different organisms are related to each other through common ancestry and the evolutionary processes that have shaped their development over time. Phylogeny helps explain the **evolutionary paths** that have led to the diversity of life on Earth.

In the context of taxonomy, **phylogeny** plays a key role in determining the **evolutionary relationships** between organisms, which ultimately informs how organisms are classified. The aim is to group organisms based on their evolutionary lineage, rather than just on observable traits, although traits (especially genetic ones) are also used in the analysis. Fundamental to phylogeny is the proposition, universally accepted in the scientific community, that plants or animals of different species descended from common ancestors. The evidence for such relationships, however, is nearly always incomplete, for the vast majority of species that have ever lived are extinct, and relatively few of their remains have been preserved in the fossil record. Most phylogenies, therefore, are hypotheses and are based on indirect evidence. Different phylogenies often emerge using the same evidence. Nevertheless, there is universal agreement that the tree of life is the result of organic descent from earlier ancestors and that true phylogenies are discoverable, at least in principle.

This taxonomy type of classifying organisms is based on phylogeny. Early taxonomic systems had no theoretical basis; organisms were grouped according to apparent similarity. Since the publication in 1859 of Charles Darwin's on the Origin of Species by means of Natural Selection, however, taxonomy has been based on the accepted propositions of evolutionary descent and relationship.

The data and conclusions of phylogeny show clearly that the tree of life is the product of a historical process of evolution and that degrees of resemblance within and between groups correspond to degrees of relationship by descent from common ancestors. A fully developed phylogeny is essential for devising a taxonomy that reflects the natural relationships within the world of living things.

6.5.1 Evidence for specific phylogenies

Biologists who postulate phylogenies derive their most useful evidence from the fields of palaeontology, comparative anatomy, comparative embryology, and molecular genetics. Studies of the molecular structure of genes and of the geographic distribution of flora and fauna are also useful. The fossil record is often used to determine the phylogeny of groups containing hard body parts; it is also used to date divergence times of species in phylogenies that have been constructed based on molecular evidence. Most of the data used in making phylogenetic judgments have come from comparative anatomy and from embryology, although those are rapidly being surpassed by systems constructed using molecular data. In comparing features common to different species, anatomists try to distinguish between homologies, or similarities inherited from a common ancestor, and analogies, or similarities that arise in response to similar habits and living conditions.

6.5.2 Key Concepts in Phylogeny

1. **Common Ancestry**: The basis of phylogenetic classification is the concept that species within a group share a common ancestor. Organisms that are more closely related share more recent common ancestors.
2. **Phylogenetic Tree (Cladogram)**: Phylogeny is often depicted visually in the form of a phylogenetic tree (also called a **cladogram**). This tree represents the evolutionary relationships between species, with branching points (nodes) indicating the most recent common ancestor of the organisms connected by those branches.
3. **Monophyly**: A group of organisms is considered **monophyletic** if it consists of a single common ancestor and all its descendants. For example, the class **Mammalia** (all mammals) is a monophyletic group, meaning it includes all animals descended from their most recent common mammalian ancestor.
4. **Synapomorphies**: These are shared derived characteristics that are used to define phylogenetic relationships. A synapomorphy is a trait that evolved in a common ancestor and was passed down to all of its descendants. For instance, the presence of hair in mammals is a synapomorphy that distinguishes them from other vertebrates.
5. **Clade**: A clade is a group of organisms that includes a common ancestor and all of its descendants. Clades can be represented as branches on a phylogenetic tree.
6. **Outgroup**: An outgroup is a species or group of species that is closely related to, but not part of, the group being studied (the ingroup). The outgroup is used to help determine the ancestral vs. derived characteristics of the ingroup.

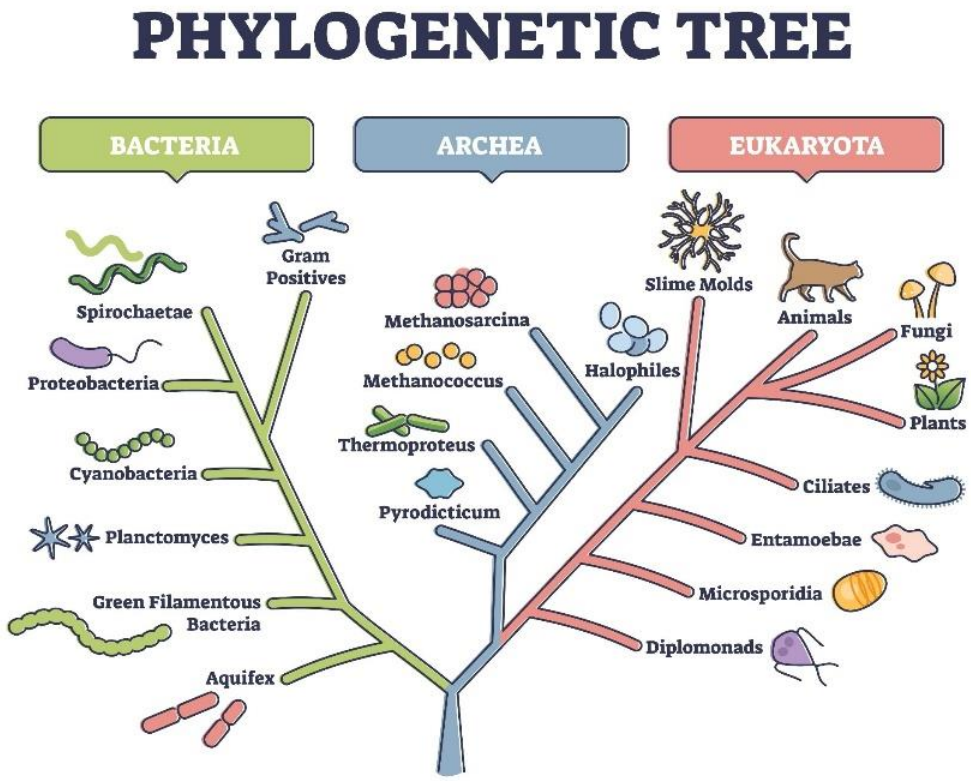

Fig. 6.5.2 Phylogenetic Tree

6.5.3 Phylogenetic Methods

i. **Morphological Phylogeny**: In earlier times, phylogenetic relationships were determined largely based on morphological (physical) characteristics, such as skeletal structure, shape, or form. These characteristics were used to group species into evolutionary lineages.
ii. **Molecular Phylogeny**: With advancements in genetic science, modern phylogeny often relies on molecular data, such as DNA, RNA, or protein sequences. Comparing these molecular markers between organisms helps reveal evolutionary relationships that might not be apparent from morphology alone. **Molecular phylogeny** is now a primary tool for reconstructing evolutionary trees.
iii. **Cladistics**: This is a method of phylogenetic analysis that focuses on identifying **clades** based on shared derived characteristics (synapomorphies). Cladistics is used to build cladograms, which represent evolutionary relationships.

6.6 CLADISTIC CLASSIFICATION

Cladistic classification (or simply cladistics) is a method of classifying organisms based on their evolutionary relationships through the analysis of shared derived characteristics, known as synapomorphies. This approach groups organisms into clades, which are evolutionary branches that include a common ancestor and all of its descendants. The primary goal of cladistics is to reflect the true evolutionary history of life on Earth, without relying solely on the traditional characteristics (morphological traits) that may be superficial or misleading.

i.6.1 Key Principles of Cladistics

i. **Clade**: A **clade** is a group of organisms that includes a common ancestor and all of its descendants. Clades are identified based on shared evolutionary traits that arose in their common ancestor. For example, the clade **Mammalia** includes all mammals (e.g., humans, whales, elephants) and their common ancestor.

ii. **Synapomorphies**: These are **shared derived characteristics** that are used to define and identify clades. A **derived characteristic** is a trait that evolved in a specific lineage after it diverged from its ancestor. These traits are passed down to all descendants of that lineage. In cladistics, organisms that share these traits are grouped together.

iii. **Example:** The presence of **feathers** is a synapomorphy for the clade **Aves** (birds), as it evolved in their most recent common ancestor and is found in all modern birds.

iv. **Outgroup**: An **outgroup** is a species or group of species that is closely related to, but not part of, the group being studied (called the **ingroup**). The outgroup is used to determine the **ancestral (primitive)** and **derived (novel)** traits. It serves as a reference to infer which traits are shared and which are unique to the ingroup.

v. **Example:** If you're studying the evolutionary relationships among primates, you might use an outgroup like **lemurs** (which are primates but more distantly related) to help determine the evolutionary traits of the more closely related species, like humans, chimpanzees, and gorillas.

vi. **Monophyly**: A clade must be **monophyletic**, meaning it includes a single common ancestor and all of its descendants. This is the goal of cladistics — to group organisms based on their shared evolutionary history.

vii. **Example**: The clade **Mammalia** is monophyletic because it includes all mammals and their most recent common ancestor. A **paraphyletic** group, on the other hand, would leave out some descendants of that ancestor.

viii. **Parsimony**: In cladistics, the **principle of parsimony** is used to select the simplest explanation for evolutionary relationships. The idea is that the tree that requires the fewest evolutionary changes (the least number of steps) is most likely to be correct. Cladists use this principle to help create the most likely phylogenetic tree.

6.6.2 Steps in Cladistic Classification

i. **Identify the Group to Study (Ingroup)**:

- Choose the group of organisms that you want to classify. This group is referred to as the **ingroup**.
- Example: If you're studying the evolutionary relationships of **amphibians**, they are your ingroup.

ii. **Select an Outgroup**:

- Choose an **outgroup** that is closely related to the ingroup but not part of it. The outgroup provides a comparison point to identify ancestral traits.
- Example: If you're studying amphibians, you might choose **fish** as an outgroup, since amphibians evolved from fish-like ancestors.

iii. **Determine Character Traits**:

- Identify **characters** (traits or features) to compare. These can be **morphological** (physical features) or **molecular** (genetic sequences).
- Example: Traits like skin type (smooth, dry, or wet), presence of lungs, and number of limbs can be used to compare species.

iv. Determine Which Traits Are Derived:

- Classify each trait as either **ancestral** (primitive) or **derived** (novel).
- An **ancestral trait** is a feature that was present in the common ancestor of the ingroup and outgroup.
- A **derived trait** is a feature that evolved in the most recent common ancestor of the ingroup and was passed down to its descendants.
- Example: Lungs are a derived trait in amphibians, as they evolved after the fish-amphibian split.

v. Build a Character Matrix:

- Create a matrix that lists all the species (or taxa) you're studying and the presence or absence of each trait.
- This allows you to compare the distribution of traits among the ingroup and outgroup.

vi. Construct the Cladogram:

- Using the character matrix, construct a **cladogram** (phylogenetic tree) that reflects the evolutionary relationships of the ingroup.
- The cladogram is built by grouping organisms based on shared derived traits (synapomorphies), with each branching point representing a **common ancestor**.
- The tree should minimise evolutionary changes (parsimony) and reflect the shared common ancestors.

vii. Refine the Cladogram:

- Evaluate the cladogram for consistency and simplicity. If necessary, adjust the tree to reflect the most parsimonious evolutionary path.
- If new traits or species are discovered, the cladogram can be updated to reflect the most accurate evolutionary history.

6.6.3 Cladistic Classification Example: Reptiles vs. Birds

Let's consider the example of birds and reptiles to illustrate cladistics

- **Ingroup**: The ingroup could be **birds** (Aves) and reptiles (Reptilia).
- **Outgroup**: An outgroup might be **amphibians** because they are more distantly related to reptiles and birds.

Traits for Comparison

- **Scales** (ancestral trait in reptiles and amphibians)
- **Feathers** (derived trait in birds)
- **Lungs** (ancestral trait in reptiles, amphibians, and birds)
- **Eggs with hard shells** (ancestral trait in reptiles and birds)

- **Shared Derived Traits**:

- Both **birds** and **crocodiles** (a type of reptile) share **feathers** as a derived trait, indicating that birds and crocodiles share a more recent common ancestor with each other than with other reptiles.

➢ **Constructing the Cladogram**:

- The cladogram would place **birds** within the broader clade of **reptilia**, suggesting that birds evolved from reptilian ancestors. However, birds form their own distinct clade because of their derived features, such as feathers, that are not shared by other reptiles.

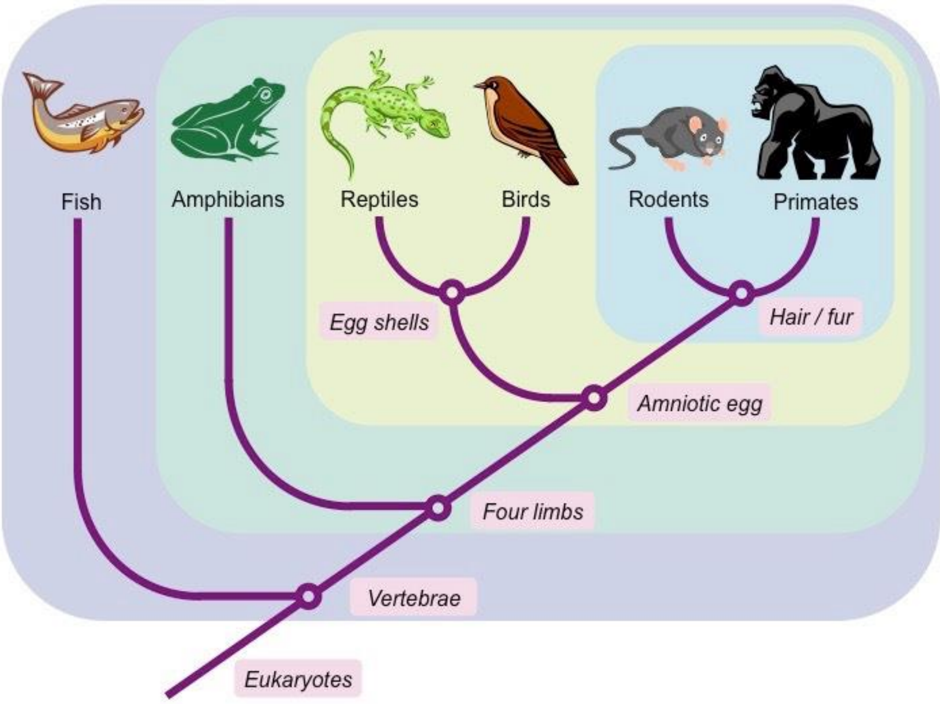

Fig. 6.6.3 Cladistic Classification (Reptiles vs. Birds)

6.7 SUMMARY

Systematics is the scientific study of the diversity of organisms and their evolutionary relationships. It provides a framework for organising biological diversity and includes several key components. The **species concept** defines what constitutes a species; the most widely used is the **biological species concept**, which considers a species as a group of interbreeding organisms that are reproductively isolated from others. **Taxonomy** is the branch of systematics that deals with the naming (nomenclature), identification, and classification of organisms into a hierarchical system (kingdom, phylum, class, etc.). **Classification** is the process of arranging organisms into groups based on similarities and differences in characteristics, traditionally based on morphology, but increasingly incorporating genetic data. **Phylogeny** refers to the evolutionary history and relationships among species or groups, often illustrated using **phylogenetic trees**. **Cladistic classification**, a modern approach in systematics, groups organisms based on shared derived characteristics (synapomorphies) and constructs **cladograms** to represent evolutionary relationships. Together, these elements help scientists understand biological diversity, trace evolutionary lineages, and create a standardised system for identifying and comparing organisms.

6.8 TECHNICAL TERMS

Lineage species concept, Speciation, Allopatric speciation, Artificial classification, Evolutionary paths, Monophyletic

6.9 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. What is Taxonomy, and explain its components?
2. Write in detail about the Species Concept and briefly about the types of Speciation.?

Short Notes

1. What are the differences between Taxonomy and Systematics?
2. Explain in detail about the Classification.?
3. Write a note on Phylogenetic tree?

6.10 SUGGESTED READINGS

1) Agarwal KC. 1998. Biodiversity. India.
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Dr. N Gopala Rao

LESSON-7
IDENTIFICATION

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to:

- Understanding the concept of taxonomical identification of species.
- Understanding the Importance of Keys.
- To gain knowledge about the Biodiversity Documents.
- Explore the use of Identification tools.

STRUCTURE

7.1 INTRODUCTION

Taxonomic studies are based on the studies of live or dead specimens, preserved in either a museum or elsewhere. Some specimens are found belonging to already known species, while others may be unknown. These new taxa are assigned to new species, subspecies or varieties. These taxa deserved to be described and named according to the rules of the International Codes of Zoological or Botanical Nomenclature. However, taxonomists also identify the specimen by assigning it to a known species.

Identification of taxa of any group of organisms remains very difficult unless there are convenient keys and manuals. The beginners may consult monographs, technical revisions, handbooks, checklists, recent literatures or illustrations. The specimens under study are run through keys, checked character by character with description, and compared with the available illustrations. Further, the specimens are compared with identified specimens or types, normally preserved in museums, institutes and other organizations.

A variety of devices are available where the specimen under study can be placed in a classification of respective groups. The most common device is to follow the key, which facilitates the identification of specimens by some diagnostic characters. Different authors in taxonomic papers normally use several types of keys. The most common key is the bracket key, and the other is the indented key. Keys may be formed separately for different taxonomic units, i.e., family, genus, species. Sometimes, composite or combined keys are also devised to recognise species, including higher taxa.

7.2 KEYS

A **taxonomic key** is a tool used in biology to identify and classify organisms based on their characteristics. It consists of a series of choices that lead the user to the correct identification of an organism. It is defined as a device consisting of a series of contrasting or contradictory statements or propositions that require the identifier to make comparisons and decisions based on the given statements as they relate to the material being identified. It helps in the quick identification of unknown plants by systematically narrowing down the possibilities. The key always presents a choice between two contradictory statements, where one is accepted and the other is rejected. A single pair of these contradictory characters is called a **couplet**, and each individual statement within the couplet is referred to as a **lead**. This structured approach ensures an organised and efficient method for classification and identification in taxonomy. By making the correct choice at each level, one can arrive at the name of the correct plant.

While using a key at each step, the user must answer a question about one or more features (characters) of the entity to be identified. If each step has only two alternatives, the key is said to be dichotomous (also called "sequential key", "analytical key", or "pathway key"), it is polytomous.

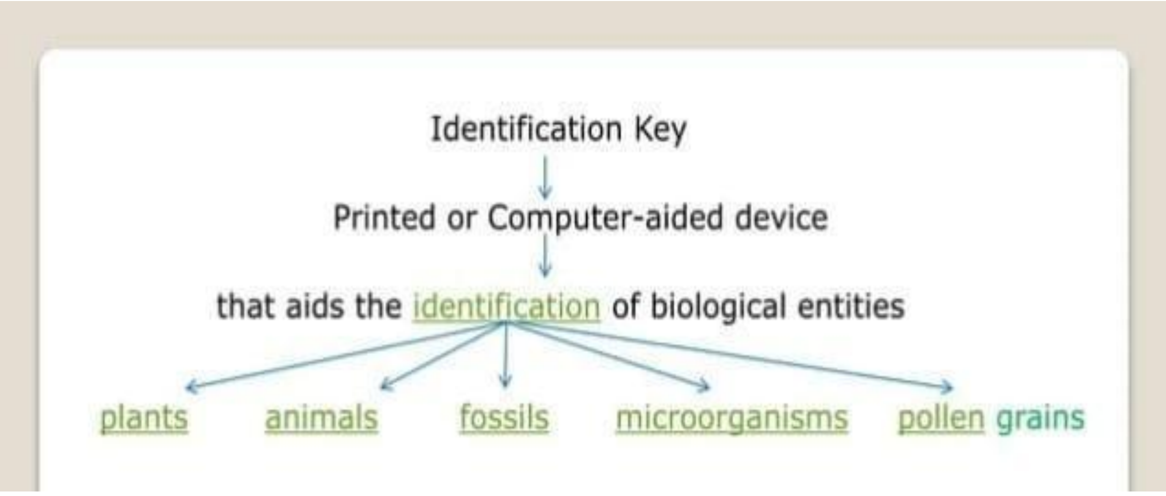

Fig: 7.2 Identification key

7.2.1 Importance of Keys

A key is essentially a printed information-retrieval system into which one puts information regarding a specimen in hand and from which one gets an identification of the specimen to whatever level the key is designed to reach.

In the absence of originally identified specimens of the species utilised for comparisons, the published description becomes the only tool. In larger groups, however, it is the most tedious task to compare specimens with hundreds of thousands of published descriptions.

The task can be solved if the keys to the main group are made available. The main purpose of the key is thus to facilitate identification or to distinguish one type of organism or object from another. A key may or may not reflect ideas of evolutionary or phylogenetic relationships. The construction of the keys is an important job of the systematist. The key that is used may not be all-inclusive of all the properties/variations that a species exhibits. In other words, just a word or a few words may not be able to specify all the characteristics the species possesses – variations of species may not be effectively covered. It can be based on the traits that are not seen in the season. All the species of interest or desired species might be not included. There is a tendency to commit mistakes while making a choice, with just one wrong decision, hence arriving at the wrong interpretation

7.2.2 Proper Use of Keys

1. Appropriate keys to be selected from floras, manuals, handbook, monograph, revision, etc. Cultivated plants- not usually given in floras. So, for these manuals, treat such plants as they are used.
2. Introductory comments are to be properly read first.
3. Both leads should be read before making a choice. Sometimes the first lead may seem to be correct, but the second lead may be more appropriate.
4. With the help of a glossary, check the meaning of unknown terms
5. Many specimens/materials would be required to measure when the measurement of fruit, leaves is used
6. Refrain from making decisions on the basis of a single observation
7. Verify and validate results after reading the description, equating specimens and the illustration with those of an authentic herbarium specimen

7.2.3 Construction of Keys

- Always use constant characters, not variables.
- Never use terms such as large/small; instead, make correct measurements.
- Characters are always available to be used rather than seasonal characters.
- Always use positive terms. E.g. Stipule is present - can be used, but the stipule is not present.
- As far as possible, both choices of a pair are to start with the same word.
- e.g. Seeds round, Seeds oblong
- If possible, different pairs of choices should start with different words
- E.g. Flowers white, Sepals free, Sepals fused

1.2.4 Types of Keys

i. **Dichotomous Key:** The most commonly used key, consisting of a series of paired, contradictory statements. Each step presents two choices, where one is accepted and the other is rejected.

ii. Example: a) Has fur → Go to 2
   a. b) Does not have fur → Go to 3

iii. **Polyclave Key (Multi-Access Key):** Allows users to select multiple characteristics at once instead of following a fixed sequence. More flexible and often used in digital or computerised identification systems.

iv. **Pictorial Key:** Uses images or illustrations instead of text descriptions to help with identification. Commonly used in field guides and educational materials.

v. **Bracketed Key:** Similar to a dichotomous key but presents both choices together instead of sequentially. Helps in avoiding confusion and makes the key more structured.

vi. **Serial Key:** Provides a series of steps in a linear sequence, guiding users step by step to the correct identification.

vii. Each type of key is designed to make identification easier and more efficient, depending on the user's needs and expertise.

7.3 BIODIVERSITY DOCUMENTATION

Biodiversity was first termed by E.O. Wilson in 1986. Documentation of Biodiversity is a foundation of any conservation action. Repeatable documentation protocols are necessary. The database should be linked to a network of local, national and international levels that make information accessible WCMC, IUCN, WWF and UNEP are examples of such a repository for information on global biodiversity. The Convention on Biological Diversity (CBD was negotiated and signed by nations at the LIV UNCED Earth Summit at Rio de Janeiro in Brazil in June 1992. The Convention came into force on December 29, 1993. India became a Party to the Convention in 1994. At present, there are 192 Parties to this Convention.

Biodiversity documentation refers to the systematic recording and cataloguing of the variety of life forms on Earth, including plants, animals, fungi, and microorganisms, as well as their ecosystems. This documentation is essential for understanding and preserving biodiversity. Which is crucial for ecological balance and human well-being. The documentation process typically involves collecting data on species distribution, abundance. Characteristics, habitats, and interactions within ecosystems.

7.3.1 Key elements of biodiversity documentation include

1. **Species Inventories**: These are comprehensive lists or databases that catalogue known species, their classification (taxonomy), and geographical locations. Species inventories help researchers track which organisms are present in an area, identify new species, and assess the health of ecosystems.
2. **Habitat and Ecosystem Surveys:** Recording the various ecosystems and habitats that species occupy is crucial for understanding biodiversity at a broader scale. Habitat surveys involve mapping and assessing the environmental conditions where species live, such as forests, wetlands, or marine ecosystems.
3. **Genetic Diversity Data:** Documenting genetic variation within species is vital for conservation efforts, as it helps ensure species can adapt to environmental changes and resist diseases.
4. **Conservation Status:** Biodiversity documentation often includes assessments of the conservation status of species, ecosystems, and genetic resources, typically through organisations like the International Union for Conservation of Nature (IUCN). This helps identify species at risk of extinction and prioritise conservation efforts.
5. **Ethno-botanical and Local Knowledge**: Indigenous and local knowledge about biodiversity is often documented. Especially in areas where communities rely on

natural resources for livelihoods. This knowledge can provide valuable insights into species' uses, behaviour, and ecological roles.

6. **Monitoring and Trend Analysis:** Biodiversity documentation also includes long-term monitoring programs that track changes in species populations. Ecosystem health, and the impacts of environmental changes, such as climate change or habitat destruction.
7. Biodiversity documentation is often carried out by researchers, conservationists. Environmental organisations and governments and it involved the use of technologies like GIS (Geographic Information Systems) and ONA sequencing to improve the accuracy and efficiency of data collection. The documentation aids in informed decision-making for conservation. Policy development and sustainable resource management.

7.4 SPECIES IDENTIFICATION

Species identification is the process of determining and classifying an organism based on its physical, genetic, or behavioural characteristics. It is a crucial aspect of taxonomy, ecology, and conservation.

7.4.1 Methods of Species Identification

1. **Morphological Identification:** Morphological identification is the traditional and most widely used method of species identification. It involves examining the physical features of an organism, such as size, shape, colour, structure, and pattern, to distinguish it from other species. Taxonomists compare these traits with known specimens or descriptions in literature. This method is especially useful for easily distinguishable organisms like insects, plants, and birds, although it can be challenging when dealing with very similar or cryptic species.

2. **Using Identification Keys**: Identification keys, such as dichotomous keys, are structured tools that guide users step-by-step through a series of choices based on observable characteristics. At each step, the user selects between two contrasting traits, gradually narrowing down the possibilities until the organism is identified. These keys are simple, practical, and widely used in fieldwork, botany, and zoology, making species identification more systematic and accessible.

3. **Genetic or Molecular Identification**: Genetic identification relies on analysing an organism’s DNA to confirm its species. Techniques like DNA barcoding allow scientists to compare genetic sequences from an unknown specimen with databases of known sequences. This method is highly accurate, even for organisms that look very similar externally, and is especially useful for microorganisms, cryptic species, or specimens that are damaged or incomplete.

4. **Behavioural and Ecological Clues**: Sometimes, species can be identified by observing their behaviour or the specific habitat they occupy. For example, the way birds sing, the feeding patterns of animals, or the blooming time of certain plants can help distinguish one species from another. These ecological and behavioural traits add another layer of information that supports identification, particularly when morphological traits are insufficient.

5. **Reference to Taxonomic Literature**: Taxonomists often consult existing taxonomic literature, including species descriptions, identification guides, and scientific illustrations, to confirm a species' identity. These references provide detailed comparisons with previously identified specimens and often include diagnostic features that are not obvious in the field. This method requires a good understanding of taxonomic terminology and access to scientific collections or publications.

6. **Expert Consultation**: When identification is difficult or uncertain, experts in specific taxonomic groups are often consulted. These specialists use their deep knowledge and experience to confirm the species, sometimes examining microscopic details or rare features. Expert identification is especially important for new, rare, or difficult-to-classify organisms and helps maintain accuracy in scientific research and biodiversity documentation.

7. **Use of Field Guides and Apps**: Modern species identification often involves the use of field guides or mobile apps. Field guides contain illustrations, photos, and key information about species found in a particular region. Identification apps (like iNaturalist or PlantNet) use image recognition and crowd-sourced data to help users identify plants, animals, and insects in real time. These tools are especially useful for students, nature enthusiasts, and citizen scientists.

8. **Geographic Distribution**: Knowing the geographic range of a species helps narrow down identification. Many species are only found in certain regions or habitats, so identifying where an organism was observed can eliminate unlikely options. For instance, a plant seen only in the Himalayas is unlikely to be a coastal species. This method supports and verifies other identification techniques.

9. **Seasonal Variations**: Species often change appearance with the seasons, especially plants and insects. Leaves, flowers, or plumage may vary depending on the time of year. Recognising these seasonal changes is important in identification, as a species may look very different in its flowering stage versus its dormant phase. This is particularly important in ecological field studies and plant taxonomy.

10. **Life Cycle Stage**: The life stage of an organism, such as larva, juvenile, or adult, can significantly affect its appearance and make identification harder. For example, a caterpillar looks completely different from the butterfly it becomes. Taxonomists must sometimes rear specimens or use knowledge of developmental stages to ensure correct identification across life cycles.

11. **Microscopic Examination**: For many tiny organisms like bacteria, fungi, or small insects, identification requires the use of microscopes. Microscopic features such as cell structure, spore shape, or wing venation patterns are often critical for distinguishing species. This technique is commonly used in microbiology, entomology, and mycology.

12. **Chemical and Biochemical Tests**: Some species are identified by their chemical makeup or metabolic properties. In microbiology, for example, bacteria can be identified using tests for enzyme activity or resistance to antibiotics. Similarly, secondary metabolites (like plant alkaloids or fungal toxins) can help differentiate species. These methods are often used in labs where visual identification alone is insufficient.

13. **Ecological Interactions**: Understanding an organism's role or interactions in its ecosystem can also aid identification. Some species are known to have specific symbiotic relationships, such as certain flowers that can only be pollinated by one insect species. Observing these interactions helps confirm the identity of both organisms involved.

7.5 IDENTIFICATION TOOLS

Various tools and techniques are used for species identification, ranging from traditional taxonomic methods to modern technological approaches. These tools help researchers, students, and conservationists classify organisms accurately.

1. Dichotomous Keys

Dichotomous keys are structured tools used to identify organisms by offering a sequence of two contrasting statements at each step (called a couplet). The user selects the option that matches the organism, which leads them to the next couplet, and so on, until a final identification is reached. These keys are ideal for students, field biologists, and taxonomists because they provide a systematic approach. There are two types: **indented keys**, which are visually nested for easier reading, and **bracketed keys**, which list options side-by-side. They work best for organisms with well-defined and observable features.

2. Polyclave (Multientry) Keys

Polyclave keys allow the user to input several characteristics at once, rather than following a fixed sequence. These are usually computer-based and use a database of traits. As you enter known features (like leaf shape, flower colour, number of legs, etc.), the tool filters the possibilities and displays only the species that match all selected traits. This flexibility makes polyclave keys ideal for large or complex groups where a linear key would be too long or confusing. They are commonly used in entomology, botany, and marine biology.

3. Field Guides and Manuals

Field guides are portable books or manuals that provide visual aids like photos or illustrations, along with short descriptions, habitat info, and sometimes keys. They're designed for use outdoors by birdwatchers, plant enthusiasts, and students. Taxonomic manuals are more technical and detailed, and are often used by professionals. These guides help with quick identification in the field and often cover local or regional species.

4. Identification Apps and Online Databases

Modern apps and online tools use image recognition, machine learning, and crowd-sourced data to help identify species. Apps like **iNaturalist**, **Seek**, **PictureThis**, or **PlantNet** allow users to take a photo of an organism and receive suggestions based on a global database. Online resources like **The Plant List**, **Catalogue of Life**, or **NCBI Taxonomy** provide detailed taxonomic data, synonyms, distribution maps, and references for further reading. These tools are especially useful when physical keys or literature are unavailable.

5. DNA Barcoding Tools

DNA barcoding identifies species by comparing a short genetic sequence from a standard part of the genome to a database of known sequences. For animals, the **COI gene** is often used; for plants, **rbcL** and **matK** are common. The sample's DNA is extracted, amplified using PCR, and sequenced. The resulting barcode is then compared to reference databases like **BOLD (Barcode of Life Data System)**. This method is highly accurate and useful for cryptic species, damaged specimens, and microorganisms that lack obvious physical differences.

6. Microscopes and Imaging Tools

Many organisms, such as fungi, algae, bacteria, and tiny invertebrates, cannot be properly identified without a microscope. Tools like **compound microscopes** and **dissecting microscopes** allow scientists to study fine structures—like spore size, cell shape, or insect antennae—that are crucial for identification. Imaging tools like scanning electron microscopes (SEM) provide high-resolution images of surface details, which are especially useful in taxonomy and detailed morphological studies.

7. Taxonomic Literature and Monographs

Taxonomic monographs are comprehensive studies on a specific group of organisms, often written by experts. They include detailed species descriptions, historical classifications, line drawings, photographs, and keys. These documents are essential references for professional taxonomists, especially when identifying rare, newly discovered, or poorly known species. They are often housed in libraries or scientific journals and form the foundation of formal scientific naming and classification.

8. Expert Consultation

When species cannot be identified using available tools, taxonomists may seek help from experts in that particular group. These specialists have years of experience and may recognize subtle features or have access to unpublished data. They often examine **type specimens** (the original specimen used to describe a species) in museums or herbaria to confirm identifications. Expert consultation ensures accuracy in biodiversity research and is especially important for describing new species.

7.6 SUMMARY

Identification keys are structured tools used to determine the identity of an organism by following a series of choices based on observable traits. The most common type is the dichotomous key, which offers two contrasting options at each step, leading the user to a specific species. Other keys like polyclave (multientry) keys allow more flexibility by letting users input multiple traits at once.

Biodiversity documentation is the process of recording and cataloguing all life forms in a given area. It involves identifying species, noting their distribution, abundance, and ecological roles. Proper documentation is essential for conservation, ecological research, and sustainable development. It also helps track endangered or invasive species and supports environmental policymaking.

To assist in species identification and biodiversity documentation, several identification tools are used. These include field guides, manuals, microscopes, DNA barcoding, and identification apps like iNaturalist and PlantNet. Digital tools and databases such as GBIF, BOLD Systems, and NCBI Taxonomy provide global access to taxonomic data. In cases where tools fall short, taxonomists may rely on expert consultation or detailed taxonomic literature. Together, these tools and methods play a crucial role in understanding and conserving the Earth's biodiversity.

7.7 TECHNICAL TERMS

Dichotomous keys, Polyclave Key, DNA Barcoding, Herbarium, Cryptic species, GBIF (Global Biodiversity Information Facility).

7.8 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. What is a Taxonomic key? Explain its importance.?
2. Define Species identification and write the various methods used for identifications.?

Short Notes

3. Explain in detail about Biodiversity documentation.?
4. What are identification tools and their significance in taxonomy?

7.9 SUGGESTED READINGS

1) **Principles of Taxonomy and Systematics"** – by V.V. Zolotuhin
   A comprehensive introduction to taxonomy, classification methods, and identification tools.
2) **"Plant Systematics: A Phylogenetic Approach"** – by Judd et al.
   Covers plant identification, classification systems, and modern phylogenetic methods.
3) **"Modern Textbook of Zoology: Vertebrates"** – by R.L. Kotpal
   Contains dichotomous keys and detailed taxonomy for vertebrate groups.
4) **"Biological Diversity"** – by M. P. Sharma
   Discusses biodiversity, conservation, species documentation, and field techniques.
5) **"Taxonomy of Angiosperms"** – by B.P. Pandey
   Especially good for Indian students learning plant identification and classification.

Dr. N Gopala Rao

LESSON-8
NOMENCLATURE

AIMS AND OBJECTIVES

At the end of the lesson, students will be able to:

- Understanding the Nomenclature and its significance.
- To gain knowledge of the International Code of Zoological Nomenclature.
- Understanding the key principles in ICZN
- Explore the types the nomenclature.

STRUCTURE

8.1 INTRODUCTION

People around the world give vernacular names to species, so they use different names for the same organism, and conversely, the same name may be given for different organisms. Scientific names are primarily a prerequisite for all biological disciplines, including biodiversity. The internationally recognised scientific name of a species is important for the Red Data List, export control, licenses or other legal aspects. Instability of scientific names causes immense problems in conservation and wildlife trade, including all biological purposes. However, taxonomic nomenclature is regulated by voluntary application of internationally agreed-upon rules or codes.

Nomenclature is a vital principle and practice of taxonomy that deals with the naming of different organisms. A single internationally recognised name is essential for particular taxa for the sake of communication among scientists. The vernacular names create difficulties in scientific communications. As a result, scientists would likely learn many languages for communication amongst themselves. To avoid this, biologists have adopted, by international agreement, a single language and a single set of names in a defined language to be used worldwide.

Taxonomic nomenclature is controlled by voluntary application of internationally agreed-upon rules or codes. Separate codes are framed and applied to animals, plants (including fungi) and bacteria.

8.2 INTERNATIONAL CODE OF ZOOLOGICAL NOMENCLATURE (ICZN)

The formation, rules and application of names at the rank of species (including sub species), genus and family of animals are regulated and stabilized by the International Codes of Zoological Nomenclature (ICZN) and by the use of types and specimens. Three major objectives are fulfilled by the codes in naming animals as quoted by Mayr (1969) "the objective of the code is to promote stability and universality in the scientific names of animals, and to ensure that each name is unique and distinct. All its provisions are subservient to these ends". All disputed issues are settled through submission to the ICZN names in use below the rank of subspecies (for polymorphic forms, seasonal variations, hybrids, etc.) and above the rank of super family (orders, classes, phyla, etc.) that lie outside the scope of the zoological code, and are simply regulated through usage. However, in taxonomy, major problem is tagged with the name of species and to lesser extent genera and families. Names are given only to taxa and all taxa contain populations or groups of populations. As such, only populations are named. Names given to individuals only are as representatives of populations.

The zoological code has two operational and fundamental rules or principles, viz. availability and priority. The valid name of a species is formed by two parts; a generic and a species name in latinized form in italics, such as Homo sapiens, which is known as binomial nomenclature. If a species has taxonomically distinct three subspecies, then it forms a trinomial nomenclature (e.g. Rattus rattus bullocki) for other subspecies as third name will be added.

The first fundamental rule of nomenclature is that 'no two species of animals or of plants can be assigned the same name'. However, it is allowed to give same generic name to a plant or animal. To cite an example, Alsophila is the name for both a fern and a moth.

Availability: A number of requirements are needed for availability of a name of a subspecies, species, genus, or family. If all these requirements are fulfilled, then the name is said to be available. If not, the name is treated as unavailable for the purpose of nomenclature. For name of the species, the requirements are a statement that a name is given to a new species; a comparison or indication of how the new taxa differs from others closely related species and the name must be in latinized binomial (i.e. in combination of generic and species names). All these should be included in the description of the species, which must be published in printed forms in a scientific journal.

Priority: Priority is the second fundamental rule of nomenclature. It means priority of publication, not priority of usage, as the valid name of a taxon is the oldest available name that has been applied to it. For example, if a single species, genus or family is given to two or more available names unknowingly or independently then the question is that which one would get the priority. The simple fundamental principle of priority dictates that whenever possible, the oldest or senior available name may be used in practice. Mention may be made that, Linnaeus is the first taxonomist to introduce binomial nomenclature for animals in the 10th edition of Systema Naturae published in 1758. Therefore, it becomes useless to consider zoological names published prior to 1758, with exception of single work on spiders published in 1757. Problem arises when the same species is given different names, then the older name is considered as senior synonymy. Conversely, when two or more species have a single name, then the oldest available name may be considered as valid after examining the original type specimen (vide below) designated by the original author.

However, both the problems of availability and priority can be solved by consulting the original description of species published in scientific journals. The original author's name and date of publication should also be provided in taxonomic literature, authentic taxonomic revision, treatise or catalogues. As an example, Homo sapiens Linnaeus, 1758.

8.2.1 Type (type-specimen) and its function

The type concept is another important feature of the code, which is applicable to all organisms except viruses. In earlier days, there was no designation of types. In the Aristotelian concept, all specimens of a new taxon were considered as the type of that taxon. Even Linnaeus never designated any specimen as type. The first quarter of the twentieth century witnessed the foundation of this concept. While describing a new taxon, the specimen on which the original author based his description of taxa, is designated as types (a zoological object). As such, type specimens are the official ones. Even the original author cannot change types once designated, but it can be only designated as Neotype by the special exercise of the planery powers of the International Commission (Articles 75 and 79). For example, a new species Indotermes maymensis Roonwal and Sen-Sarma, was described based on a soldier (Holotype) from Maymyo, Myanmar. Hence, the type of this nominal species is the specimen (soldier as referred here), that of the genus Indotermes R. and S. is the species Indotermes maymensis, and that of the family Indotermitidae R. and S. is the genus Indotermes R. and S.

Types have therefore, special status and are carefully preserved in museums or institutes for use in future study and to solve any complicacy concerning that taxon. The repository of types is mentioned either by the original or subsequent authors. Types may be of different categories depending on the status of their designation by appropriate authority from time to time.

8.2.2 Key Principles of ICZN

1. Principle of Binomial Nomenclature

This principle states that each animal species must be assigned a two-part scientific name consisting of a genus and a species epithet. The genus name is always capitalized and the species epithet is written in lowercase, both italicized (e.g., *Panthera tigris* for the tiger). This system, introduced by Carl Linnaeus, brings clarity, uniformity, and international acceptance to naming organisms.

2. Principle of Priority

According to this principle, the earliest valid name given to a species must be used, assuming it meets all the ICZN rules. If a species is described and named more than once, the first published name (chronologically) is recognized as the correct one. This principle prevents confusion caused by multiple names for the same species and promotes stability in nomenclature.

3. Principle of Homonymy

The ICZN does not allow the use of the same name (homonym) for two or more different taxa at the same rank. If such a duplication occurs, the later (junior) name becomes invalid and must be replaced. This ensures that each taxon has a unique and distinguishable name, eliminating ambiguity in scientific communication.

4. Principle of Typification

Each taxonomic name must be objectively linked to a physical reference, called a type. In species-level taxonomy, this is known as a type specimen—a preserved example stored in a recognised institution like a museum or herbarium. For genera, it is a type species. The type serves as the definitive standard for applying the name and resolving disputes about species identification.

5. Principle of Coordination

This principle ensures that names created at one rank in a taxonomic group automatically extend to other related ranks. For instance, if a genus is described, the subgenus name is also considered established, and vice versa. Similarly, family-level names are coordinated across ranks like subfamily, tribe, etc., using the same type. It brings consistency across hierarchical taxonomic levels.

6. Principle of the First Reviser

When two or more names or spellings are published simultaneously and both appear valid, the first subsequent author (called the First Reviser) to choose between them determines which name is officially recognised. This principle resolves conflicts that arise from simultaneous naming and allows a controlled way to select the valid name.

7. Principle of Stability

One of the core goals of the ICZN is to maintain stability and avoid unnecessary changes in names. Even if an earlier name exists, a widely used name may be conserved to avoid confusion and disruption in scientific communication. Stability ensures that scientific literature and research remain coherent and traceable across time.

8. Principle of Latinization

Scientific names governed by the ICZN must be treated as Latin regardless of their linguistic origin. This includes proper application of Latin grammar, such as correct endings and gender agreements. The universal use of Latin in nomenclature allows scientists from different regions and languages to communicate without ambiguity.

9. Availability

For a name to be valid under ICZN, it must be "available." This means it must be published in a recognised, accessible form (print or digital), contain a proper description or diagnosis, follow naming rules, and be linked to a designated type. Names that do not meet these criteria are considered unavailable and have no official status in zoological nomenclature.

8.2.3 Functions of ICZN

The main functions of the International Code of Zoological Nomenclature (ICZN):

I. **Standardises Zoological Names**
The ICZN serves as the official rulebook for naming animals, ensuring that scientists around the world follow a **standardised system of nomenclature**. By providing clear guidelines on how to name new species and how to refer to existing ones, it eliminates regional or personal variations. This standardisation allows researchers to communicate unambiguously across linguistic and national boundaries, making biological data universally accessible and scientifically credible.

II. **Ensures Uniqueness and Consistency**
One of the core responsibilities of the ICZN is to ensure that each animal taxon has a **single, unique, and consistent scientific name**. This eliminates problems caused by **homonyms** (the same name used for different taxa) and **synonyms** (multiple names for the same species). By applying strict rules, such as the principle of priority, the Code prevents taxonomic confusion and allows species to be referenced accurately and consistently in all scientific works.

III. **Maintains Stability in Nomenclature**
The ICZN places great importance on **nomenclatural stability**, which means keeping widely used names intact even when earlier or conflicting names are discovered. It includes mechanisms to conserve popular names and suppress obscure or outdated ones if changing them would cause confusion. This stability ensures that scientific literature remains consistent over time and reduces disruptions in biological databases, conservation policy, and ecological research.

IV. **Provides Rules for Naming New Species**
The ICZN outlines precise procedures for naming new species, ensuring that newly discovered animals are described, published, and named in a standardised way. This includes rules on **Latinization**, **proper publication**, **designation of type specimens**, and **formation of names**. These guidelines make sure that new names are valid, universally understandable, and compliant with historical and scientific standards, allowing them to be accepted globally.

V. **Acts as an Authority in Nomenclatural Disputes**
When conflicts arise, such as two scientists using different names for the same species, the ICZN serves as the **final authority to resolve such disputes**. The Commission (a body of appointed experts) has the power to make official decisions, including the **conservation or suppression of names**, to protect stability and prevent confusion. This role is essential in maintaining harmony and consensus in the global scientific community.

VI. **Regulates Use of Type Specimens**
The ICZN mandates that every species name be linked to a **type specimen**, which serves as the permanent reference point for identifying and comparing organisms. These type specimens are stored in recognised institutions and act as the standard against which all future identifications and classifications are measured. This

requirement ensures that names are anchored in **physical evidence**, making taxonomy reproducible and verifiable.

VII. Supports Taxonomic Research
By offering a structured and internationally accepted system of naming, the ICZN plays a vital role in **facilitating taxonomic and biodiversity research**. Accurate naming is essential for tracking species diversity, studying evolutionary relationships, implementing conservation strategies, and maintaining biological records. Without the ICZN's rules, communication in biology would become fragmented, and the integrity of biological sciences would be compromised.

8.3 TYPES OF NOMENCLATURE

- **Holotype:** It is defined as the 'sole element' used by the author of a name, or 'the element designated by the author as the type of the name. Thus, if the author uses only one element (a single plant specimen, or a single species, or a single genus) to name a new taxon, then this 'sole element' automatically becomes the holotype. Alternatively, if the author uses more than one element (two or more plant specimens, or two or more species, or two or more genera) and simultaneously designates any one of these as 'type', this designated element becomes the holotype.

- **Paratype**: This is any specimen or element other than (i) the holotype, and (ii) the isotypes, which has been listed in the original publication by the author. Thus, elements from one collection by an author may be selected to serve as holotypes and isotypes, while material from other collections (made by the author himself or by others) may also be mentioned in the original publication. These other elements listed in the original publication become paratypes,

- **Neotype:** When all original material is lost or destroyed, and no holotype. Isotype, syntypes, or paratypes are available, the code requires the selection of any element to serve as 'type' for nomenclatural purposes. Thus, taxonomists may select any element from amongst new material to serve as the nomenclatural type. This selected element is referred to as the cria neotype. Again, I must remember that the neotype is important only when no original material is available. Whenever any original arterial becomes available. Lectotype will have to be selected in case the holotype is unavailable.

- **Lectotype**: Whenever the holotype is lost or destroyed, it is necessary to recognise an alternative element to serve as nomenclatural type per the ICBN's requirements. In such circumstances, the code permits the use of any other 'original material' for fulfilling this requirement. Thus, any element selected (later from amongst original material) to serve as nomenclatural type in place of the original holotype will be referred to as lectotype.

- **Syntype**: When an author uses two or more elements from a single collection to name a new taxon, but does not designate any one of them as the holotype, and refers to all the elements as types, then these are collectively referred to as syntypes. They have the same status for nomenclatural purposes.

- **Synonyms and Homonyms:** If more than one name is given to a taxon, all these names are known as synonyms. Among these synonyms, the first published valid name is the senior synonym, and the subsequent ones are junior synonyms. There are two kinds of juniors. Synonyms: one kind is based on names proposed for the same specimens or new names for supposedly preoccupied names. These are known as 'Objective synonyms. The second kind of synonym is Synonyms, which are only in the opinion of one or more workers in the group. They are known as 'Subjective synonyms.'

8.4 SUMMARY

Nomenclature is the system of assigning standardised scientific names to organisms, which is essential for accurate communication in biological sciences. In zoology, this is governed by the International Code of Zoological Nomenclature (ICZN), a globally accepted set of rules that ensures each animal has a unique and universally recognised name. The ICZN promotes uniformity and stability by regulating how new species are named, published, and classified. There are several types of nomenclature in zoological taxonomy, including binomial nomenclature, which uses two names (genus and species); trinomial nomenclature, which adds subspecies; tautonyms, where both genus and species names are the same; homonyms, where different species share the same name (and one must be changed); and synonyms, where a single species has been named more than once. The principles of ICZN include the principle of binomial nomenclature, priority (oldest valid name is preferred), typification (each name must be linked to a type specimen), homonymy (no two taxa can have the same name), stability (widely accepted names are preserved), coordination (names at different ranks are automatically established), Latinization (names must follow Latin grammar), and the first reviser rule (conflicts are resolved by the first author who makes a choice). Together, these elements provide a robust framework for classifying and naming animals across the globe.

8.5 TECHNICAL TERMS

Binomial nomenclature, Species epithet, Tautonym, Homonym, Typification, First reviser, Latinization.

8.6 SELF-ASSESSMENT QUESTIONS

Essay Questions

1 What is zoological nomenclature, and why is it important in taxonomy?
2 What is the International Code of Zoological Nomenclature (ICZN)? What are its main objectives?
3 What do you understand by the principle of coordination in ICZN?

Short Notes

1. List and briefly explain the different types of nomenclature.
2. Define and explain the significance of typification in nomenclature
3. Explain the role of Latinization in scientific naming.

8.7 SUGGESTED READINGS

1) "Principles of Animal Taxonomy" by G.G. Simpson. A foundational text covering taxonomy, nomenclature, and classification systems.
2) "Modern Textbook of Zoology: Invertebrates" by R.L. Kotpal. Widely used in Indian universities, includes sections on taxonomy and nomenclature.
3) "Taxonomy of Angiosperms" by B.P. Pandey. Though focused on plants, the concepts of nomenclature and classification are well-explained and relevant.
4) "Fundamentals of Systematics" – T.S. Gill. Good for understanding taxonomic hierarchy, keys, and the basis of nomenclatural codes.

Dr. N Gopala Rao

LESSON-9

BIODIVERSITY MANAGEMENT AND CONSERVATION

AIM AND OBJECTIVES

At the end of the lesson, students will be able to

- Biodiversity Management and Conservation
- Biodiversity Threats
- In-situ and Ex-situ Conservation
- Wildlife Protection Act

STRUCTURE

9.1 INTRODUCTION

Conservation aims to restore biodiversity with the preservation and improvement of habitats. According to IUCN, conservation should aim at the maintenance of existing genetic diversity and viable populations of all taxa in the wild to maintain biological interactions, ecological processes and functions. Conservation is defined as the 'planned management of natural resources to retain natural balance, diversity and evolutionary changes in the environment'. The objective of conservation is to preserve biodiversity, maintain essential life-supporting ecological processes or ecosystem functions, preserve genetic resources, along with the utilisation of commercially important species in a sustainable way. To achieve these goals, the three main components of biodiversity, such as ecosystem diversity, species diversity and genetic diversity, are to be fully protected. Maintenance of the ecosystem is actually the maintenance of the population of the inhabiting species or their genetic base. On the other hand, conserving species is actually protecting and maintaining biological diversity. Moreover, conservation and sustainable development are closely connected to one another.

Ancient philosophers and religions emphasised the protection of nature and wildlife, but they prioritised the needs of human beings above all. Most of the conservatory programmes were centred around some large, charismatic animals, certain religious sites or only important natural resources, but not on biodiversity as a whole. Most people failed to realise the intrinsic value of all living organisms and destroyed their components. Conservation biology evolved as an appendix to environmental studies only during the twentieth century, but got fully recognised during the seventies. It currently focuses more on the sustainable and wise use of natural resources and also aims at maintaining biological diversity and ecological complexity. Loss of some species is inevitable, but measures to protect the entire natural system are a priority.

The objectives of living resource conservation are:

1. To maintain essential ecological processes and life support systems, which include soil regeneration or recycling of nutrients and others.
2. To preserve genetic diversity, which is required for breeding programmes and cultivation of crops.
3. To ensure the sustainable utilisation of species and ecosystems, such as fish, wildlife, and forests, which support rural communities and also provide raw materials for industries.

- **Conservation:** It is the management of a natural resource so that it can be sustained for a long time. Conservation programmes usually require active management to achieve long-term sustainability. Preservation and restoration are a subset of conservation practice.
- **Preservation**: It refers to protecting a resource by withdrawing it from human use.
- **Restoration:** It is the returning of a resource to its prior condition or to reestablish ecological processes and functions.
- **Restoration ecology:** Deals with the restoration of habitat, reintroduction of species and reestablishment of declining populations in the wild.

9.1.1 History of Conservation

The realisation that large-scale environmental degradation and unprecedented loss of species will ultimately put man's existence at stake was first evoked by a book, Silent Spring, written by Rachel Carson's in 1962. It expressed deep concern over the loss of natural elements and devastating actions of nuclear weapons or nuclear power on human life. With the advent of industrialisation and the advancement of urbanisation, the twenty-first century has faced environmental hazards associated with synthetic pesticides in the sixties, acid rain in the eighties, ozone depletion and deforestation in the nineties, and currently, the widespread problem of climate change. These issues have provoked scientists, philosophers and even public consciousness across the world, that led to the rise of several mass movements. These social movements started towards the end of the 1960s, which advocated for environmental protection and aimed at the prevention of species loss. "Ecology movement" is an umbrella term for different groups, ideologies and attitudes that evolved following the ecological crisis of the Earth due to demographic pressures.

Green parties like Greenpeace took direct action against environmental destruction. Its views on people’s behaviours and events are centred around the political and lifestyle implications of the science of ecology and the idea of nature as a value in itself.

It has been observed that maximum species extinctions have occurred between 1000 AD to 2000 AD, mostly due to undue anthropogenic activities and exponential human population growth. Human beings have exploited thousands of plants and animals for food, medicine or other needs, and their habitat has been reclaimed for their own. When species perish, the stability of the ecosystem decreases and is destined to collapse if the complexity is further reduced.

9.1.2 Conservation Ethics

The conservation ethics that evolved in North America towards the end of the nineteenth century and early twentieth century were initiated from the writings of John Muir, Grifford Pinchot and Aldo Leopod in response to the widespread destruction of nature's elements. The concern for maintaining the integrity of nature was echoed in their writings. Leopold's conservation ethic is the gradual evolution of the idea that 'it is antisocial to exploit and destroy natural systems'. Conservation involves the use, allocation, and protection of natural resources. It aims at maintaining the environment and the natural habitats for plants and animals, as well as materials and energy.

Conservation ethics have been followed from the Vedic times, as evidenced from '*Isho Upanishad*', which says that "the whole universe together with its creatures belong to the Lord (Nature). No creature is superior to any other, and human beings should not have absolute power over nature. Let no one species encroach on the rights and privileges of other species. One can enjoy bounties of nature by giving up greed". Atharva Veda (12.1.11) (800 BC) hymn, "O Earth; Pleasant be thy hills, snow-clad mountains and forests; O numerous coloured, firm and protected Earth; on this earth I stand, undefeated, unslain, unhurt".

9.2 IUCN CLASSIFICATION OF WILDLIFE

The **International Union for Conservation of Nature (IUCN)** categorises species based on their risk of extinction. The **IUCN Red List** is the world's most comprehensive source of information on the global conservation status of species. The International Union for Conservation of Nature (IUCN) is a global organisation that works to protect nature and promote sustainable use of natural resources. It was founded in **1948** and is headquartered in **Gland, Switzerland**. The IUCN brings together governments, scientists, and conservation organisations to develop solutions for environmental challenges.

It is an international organisation comprised of over 1300 government and non-government members and relying on the input of about 16000 experts. Its objective is to promote nature conservation and sustainable use of natural resources throughout the world. This organisation also focuses on issues such as poverty, gender equality, and sustainable business practices in order to address its core objective. To achieve its goal, the organisation engages in fieldwork, data collection and analysis, lobbying, and public education outreach. The IUCN provides knowledge and tools that enable and promote sustainable development at a global level (Cordoso et al., 2016). The present headquarters of IUCN are located in the United Kingdom.

9.3 FORMATION OF RED DATA BOOK

One of the historical works done by IUCN is its list of threatened species of plants and animals, also famous as the name of Red List. It is also known as the Red Data List. The IUCN Red List System was initiated in 1963, and since then, evaluation of the conservation status of species and subspecies has been continuing on a global scale. The IUCN Red List is arguably one of the most useful worldwide lists of species that are at risk of extinction. The Red List, established in 1964, provides the conservation status of plant and animal species around the world. Its usefulness is based on its reliance on several objective criteria. The IUCN members determine the risk of a species' extinction by utilising criteria such as population size, subpopulations, the number of mature individuals, generation, the decline in population size, extreme fluctuations in population size, fragmented populations and habitats, habitat area size, and distribution of the population. These rules have received international acceptance and have become one of the key decision tools in conservation biology for focusing attention on species of conservation concern (Gardenfors, 2001).

Besides, Regional Red Lists (RRL) are also prepared which are the reports of the threatened status of species within a certain country or region. Formation of Red List is an essential part of national and regional conservation planning. It determines the conservation status, distribution and trends of species decline. In 2003, IUCN developed a set of transparent, quantitative criteria to assess the conservation status of species at the regional and national level. This approach is now being applied in many countries throughout the world.

IUCN, along with the Species Survival Commission, assesses the status of species based on the observable decline in population, total number of living species and presence of the number of breeding pairs. The current and projected trend of decline and the probability of extinction in a certain number of years or generations are also measured. IUCN provides a standard and quantitative method of classification that provides data for conservation. Currently, a global network of countries and individuals working on regional red lists has developed a centralised online database where regional red list assessments and action plans are stored, managed, and made accessible. With this regional network, there will be opportunities to learn from each other's experiences in applying the IUCN categories and criteria, as well as in using this information for conservation planning and priority setting

Threatened species are assessed as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU), but extinct or non-threatened species are also assessed and listed. Besides extinction risk assessment, the Red List provides a plethora of useful information on each species assessed, including distribution, trends, threats and conservation actions. The quantity and quality of this information allows the Red List to be used in multiple ways, such as to raise awareness about threatened species, guide conservation efforts and funding, set priorities for protection, measure site irreplaceability and vulnerability, influence environmental policies and legislation and evaluate and monitor the state of biodiversity (Rodrigues et al., 2006; Baillie et al., 2008; Martin-Lopez et al.,2009).

9.3.1 IUCN Red List Categories (from least to most threatened):

Species are classified by the IUCN Red List into nine groups, specified through criteria such as rate of decline, population size, area of geographic distribution, and degree of population and distribution fragmentation. There is an emphasis on the acceptability of applying any criteria in the absence of high-quality data, including suspicion and potential future threats, "so long as these can reasonably be supported".

1. **Extinct (EX)** – Extinction is the termination of an organism by the death of its last member. A taxon may become functionally extinct before the death of its last member if it loses the capacity to reproduce and recover. As a species' potential range may be very large, determining this moment is difficult and is usually done retrospectively. This difficulty leads to phenomena such as Lazarus taxa, where a species presumed extinct abruptly "reappears" (typically in the fossil record) after a period of apparent absence.

   Mass extinctions are relatively rare events; however, isolated extinctions of species and clades are quite common and are a natural part of the evolutionary process. Only recently have extinctions been recorded, with scientists alarmed at the current high rate of extinctions. Most species that become extinct are never scientifically documented. Some scientists estimate that up to half of presently existing plant and animal species may become extinct by 2100. A 2018 report indicated that the phylogenetic diversity of 300 mammalian species erased during the human era since the Late Pleistocene would require 5 to 7 million years to recover.

According to the 2019 Global Assessment Report on Biodiversity and Ecosystem Services by IPBES, the biomass of wild mammals has fallen by 82%, natural ecosystems have lost about half their area, and a million species are at risk of extinction—all largely as a result of human actions. Twenty-five percent of plant and animal species are threatened with extinction. In a subsequent report, IPBES listed unsustainable fishing, hunting and logging as being some of the primary drivers of the global extinction crisis. In June 2019, one million species of plants and animals were at risk of extinction. At least 571 plant species have been lost since 1750. The main cause of the extinctions is the destruction of natural habitats by human activities, such as cutting down forests and converting land into fields for farming. A dagger symbol (†) placed next to the name of a species or other taxon normally indicates its status as extinct.

- Examples: Dodo
  Steller's sea cow
  Passenger pigeon
  Japanese Sea Lion
  Carolina parakeet

2. **Extinct in the Wild (EW)** – A species that is extinct in the wild (EW) is one that has been categorised by the International Union for Conservation of Nature as only consisting of living members kept in captivity or as a naturalised population outside its historic range. Classification requires exhaustive surveys conducted within the species' known habitat, with consideration given to seasonality, time of day, and life cycle. Once a species is classified as EW, the only way for it to be downgraded is through reintroduction.

   Not all EW species are rare. An example is the Brugmansia genus, where all seven species are widely cultivated, but none are found in the wild.[5] Ultimately, the purpose of preserving biodiversity is to maintain ecological function to prevent ecological extinction.

   - Examples: Northern white rhinoceros
     Socorro dove
     Spix's macaw
     Guam kingfisher
     Thylacine
3. **Critically Endangered (CR)** – An IUCN Red List critically endangered (CR or sometimes CE) species is one that has been categorised by the International Union for Conservation of Nature as facing an extremely high risk of extinction in the wild.[1] As of December 2023, of the 157,190 species currently on the IUCN Red List, 9,760 of those are listed as critically endangered, with 1,302 being possibly extinct and 67 possibly extinct in the wild.

The IUCN Red List provides the public with information regarding the conservation status of animal, fungi, and plant species. It divides various species into different categories of conservation that are based on-

- Population Size Reduction
- Reduction Across a Geographic Range
- Population Decline
- Probability of Extinction
- Restricted Population

Each category represents a different level of global extinction risk. Species that are considered to be critically endangered are placed within the "Threatened" category. As the IUCN Red List does not consider a species extinct until extensive targeted surveys have been conducted, species that are possibly extinct are still listed as critically endangered. IUCN maintains a list of "possibly extinct" and "possibly extinct in the wild" species, modelled on categories used by BirdLife International to categorise these taxa.

- Examples: Black Rhinos
  Amur Leopards
  Pygmy Hog
  Hawksbill Sea Turtle

4. **Endangered (EN)** – An endangered species is a species that is very likely to become extinct in the near future, either worldwide or in a particular political jurisdiction. Endangered species may be at risk due to factors such as habitat loss, poaching, invasive species, and climate change. The International Union for Conservation of Nature (IUCN) Red List lists the global conservation status of many species, and various other agencies assess the status of species within particular areas. Many nations have laws that protect conservation-reliant species, which, for example, forbid hunting, restrict land development, or create protected areas. Some endangered species are the target of extensive conservation efforts, such as captive breeding and habitat restoration. Human activity is a significant cause in causing some species becoming endangered.

   The conservation status of a species indicates the likelihood that it will become extinct. Multiple factors are considered when assessing the status of a species; e.g., such statistics as the number remaining, the overall increase or decrease in the population over time, breeding success rates, or known threats. The IUCN Red List of Threatened Species is the best-known worldwide conservation status listing and ranking system.

   Over 50% of the world's species are estimated to be at risk of extinction, but the frontier between categories such as 'endangered', 'rare', or 'locally extinct' species is often difficult to draw, given the general paucity of data on most of these species. This is notably the case in the world’s oceans, where endangered species not seen for decades may go extinct unnoticed.

   - Examples: Indian Rhinoceros
     African Forest Elephant
     Bengal Tiger
     Amur Leopard
     Giant Panda

5. **Vulnerable (VU)** – A vulnerable species is a species that has been categorised by the International Union for Conservation of Nature as being threatened with extinction unless the circumstances that are threatening its survival and reproduction improve. Vulnerability is mainly caused by habitat loss or destruction of the species' home. Vulnerable habitats or species are monitored and can become increasingly threatened. Some species listed as "vulnerable" may be common in captivity, an example being the military macaw. A taxon is Vulnerable when it is not critically endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future. Practices such as cryoconservation of animal genetic resources have been enforced in efforts to conserve vulnerable breeds of livestock specifically.

   The International Union for Conservation of Nature uses several criteria to enter species in this category.
   - Population estimated to number fewer than 10,000 mature individuals.
   - Area of occupancy estimated to be less than 2,000 $km^{2.}$
   - Estimated, inferred or suspected population size reduction of ≥ 50% over the last 10 years or three generations.
   - Examples: Himalayan Wolf
     Speckled Ground Squirrel
     Atlantic Salmon
     Asiatic cheetah
     Nilgiri tahr

6. **Near Threatened (NT)** – A near-threatened species is a species which has been categorized as "Near Threatened" (NT) by the International Union for Conservation of Nature (IUCN) as that may be vulnerable to endangerment in the near future, but it does not currently qualify for the threatened status. The IUCN notes the importance of reevaluating near-threatened taxa at appropriate intervals.

   The rationale used for near-threatened taxa usually includes the criteria of vulnerable which are plausible or nearly met, such as reduction in numbers or range. Those designated since 2001 that depend on conservation efforts not to become threatened are no longer separately considered conservation-dependent species. Categories and Criteria to assign conservation status, which included a separate category for conservation-dependent species ("Conservation Dependent", LR/cd). With this category system, Near Threatened and Conservation Dependent were both subcategories of the category "Lower Risk". Taxa which were last evaluated before 2001 may retain their LR/cd or LR/nt status, although had the category been assigned with the same information today, the species would be designated simply "Near Threatened (NT)" in either case.
   - Examples: Eurasian otter
     Maned wolf
     Gray bat
     Plains zebras
     Chilean flamingo

7. **Least Concern (LC)** – A least-concern species is a species that was widespread and abundant species and has been evaluated and categorised by the International Union for Conservation of Nature (IUCN) as not being a focus of wildlife conservation

because the specific species is still plentiful in the wild. They do not qualify as threatened, near threatened, or (before 2001) conservation dependent. Since 2001 the category has had the abbreviation "LC", following the IUCN 2001 Categories & Criteria (version 3.1).[1] Before 2001 "least concern" was a subcategory of the "Lower Risk" category and assigned the code "LR/lc" or lc. Around 20% of least concern taxa (3261 of 15,636) in the IUCN database still use the code "LR/lc", which indicates they have not been re-evaluated since 2000.

8. Species cannot be assigned the "Least Concern" category unless they have had their population status evaluated. That is, adequate information is needed to make a direct, or indirect assessment of its risk of extinction based on its distribution or population status.
   - Examples*:* Common domestic and wild animals
     House Sparrow
     Blue Kingfisher
     Brown Bear

9. **Data Deficient (DD)** – A data deficient (DD) species has been categorised by the International Union for Conservation of Nature (IUCN) as offering insufficient information for a proper assessment of conservation status to be made. This does not necessarily indicate that the species has not been extensively studied, but it usually indicates that little or no information is available on the abundance and distribution of the species. It can also indicate uncertainty about the taxonomic classification of an organism; for example, the IUCN classifies the orca as "data deficient" because of the likelihood that two or more types of the whale are separate species.

The IUCN recommends that care be taken to avoid classing species as "data deficient" when the absence of records may indicate dangerously low abundance: "If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

1. Not Evaluated (NE) – A not evaluated (NE) species is one that has been categorised under the IUCN Red List of threatened species as not yet having been assessed by the International Union for Conservation of Nature. A species that is uncategorized and cannot be found in the IUCN repository is also considered not evaluated. The category of not evaluated does not indicate that a species is not at risk of extinction, but simply that the species has not yet been studied for any risk to be quantified and published. The IUCN advises that species categorised as not evaluated should not be treated as if they were non-threatened. It may be appropriate to give them the same degree of attention as threatened taxa, at least until their status can be assessed.

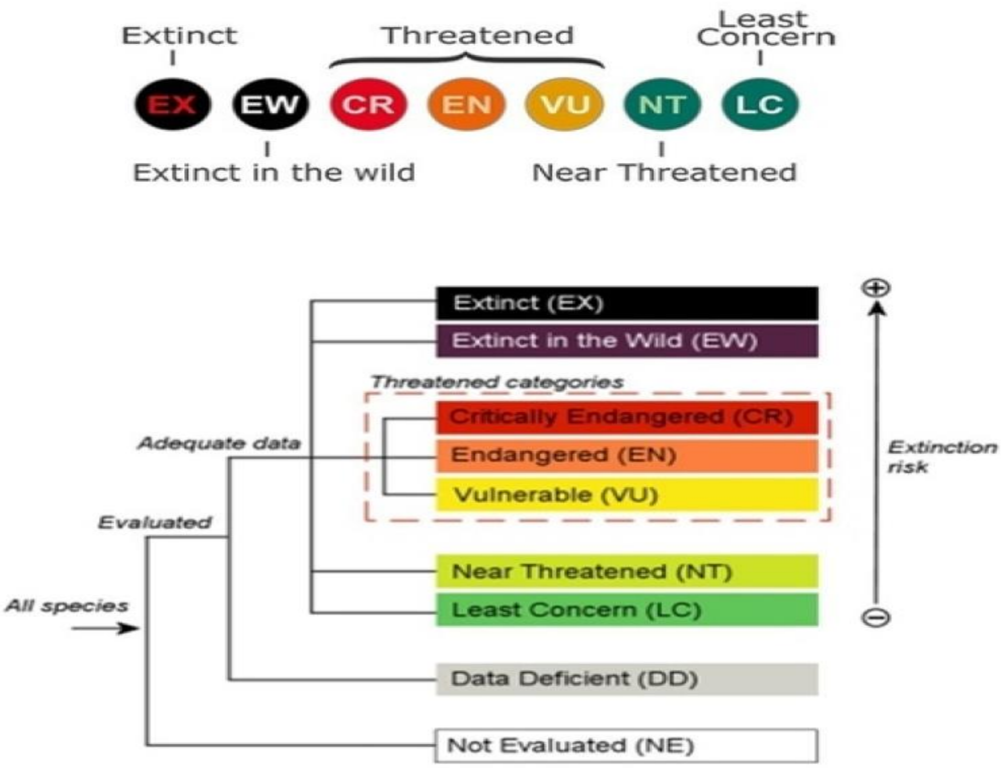

Fig. 9.3.1 IUCN Red List Categories

9.3.2 Key Functions of IUCN

1. **IUCN Red List of Threatened Species**: The most comprehensive inventory of the global conservation status of species. Categorises species based on extinction risk (e.g., Endangered, Vulnerable, Critically Endangered).
2. **Protected Areas and World Heritage Sites**: Help establish and manage national parks and conservation areas. Works with UNESCO to identify and protect World Heritage Sites.
3. **Ecosystem and Biodiversity Conservation**: Develops strategies to protect habitats such as forests, wetlands, and marine ecosystems. Works on restoring degraded ecosystems.
4. **Policy and Environmental Laws**: Provides scientific data to guide government policies on biodiversity, climate change, and sustainable development. Influences international treaties like the **Convention on Biological Diversity (CBD)** and **CITES** (Convention on International Trade in Endangered Species).
5. **Sustainable Development and Climate Action**: Promotes conservation-based solutions for climate change adaptation. Supports sustainable use of natural resources to balance economic development and environmental protection.
6. **Species Survival Commission (SSC)**: A network of experts focused on preventing species extinctions. Conducts research and conservation programs for endangered species.
7. **Raising Awareness and Influencing Policy:** The IUCN works to raise public awareness about environmental issues, including biodiversity loss and climate change, and influences national and global policies related to conservation and sustainable development.

9.3.3 Importance of IUCN Classification

1. **Identifies Species at Risk:** The IUCN Red List provides a systematic framework for classifying species based on their risk of extinction. It categorises species into groups such as Least Concern (LC), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), and Extinct (EX). This classification helps conservationists, researchers, and policymakers identify which species are at the greatest risk and require immediate protection measures. By doing so, it ensures that conservation efforts are directed where they are most needed.

2. **Guides Conservation Planning:** By supplying detailed data on species' population trends, habitat status, threats, and geographical distribution, the IUCN Red List serves as a crucial tool for conservation planning. It aids in the establishment of protected areas, the development of wildlife corridors, and the formulation of species recovery programs. Conservation organisations and governments rely on this data to allocate resources effectively and implement actions that can reverse species decline.

3. **Influences Environmental Policy:** The IUCN classification plays a central role in shaping environmental policies and regulations both nationally and internationally. Governments use Red List data to draft and amend wildlife protection laws. International conventions like the Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species (CITES) also incorporate IUCN assessments to regulate trade, habitat conservation, and species protection. This ensures that legally binding action is taken to safeguard biodiversity.

4. **Monitors Biodiversity Health:** The Red List functions as a global barometer for biodiversity. By regularly updating the extinction risk of thousands of species, it enables scientists and policymakers to track biodiversity trends over time. It also helps measure progress toward international conservation targets such as the Aichi Biodiversity Targets and the UN Sustainable Development Goals, especially Goal 15, which focuses on life on land.

5. **Raises Public Awareness:** One of the key strengths of the IUCN Red List is its ability to bring attention to the plight of endangered species. By publicly highlighting species on the brink of extinction, such as the Sumatran orangutan or the Vaquita, it fosters public interest and mobilises support for conservation initiatives. Media campaigns, educational programs, and fundraising efforts often rely on Red List information to drive public engagement and action.

6. **Supports Research and Funding:** The conservation status provided by the IUCN Red List helps prioritise species for scientific research and funding. Many funding agencies and governments require justification for support, and a species listed as endangered or critically endangered offers strong grounds for financial aid. Moreover, the Red List highlights knowledge gaps, encouraging targeted research to fill those gaps and refine conservation efforts further.

9.4 SUMMARY

Biodiversity management and conservation involve the protection, restoration, and sustainable use of the Earth's biological diversity. The goal is to maintain ecological balance, protect endangered species, and ensure ecosystem services such as food, water, air purification, and climate regulation. Conservation strategies play a vital role. Effective biodiversity management also relies on environmental policies, public participation, restoration efforts, and scientific research.

The IUCN Classification of Wildlife, formulated by the International Union for Conservation of Nature, is a globally recognised system that assesses the extinction risk of species. It helps identify threatened species and prioritise them for conservation efforts. This classification system is compiled in the IUCN Red List, which is the most comprehensive inventory of the global conservation status of species. These categories guide global conservation priorities, influence environmental policies, support research, and raise awareness about biodiversity loss.

9.5 TECHNICAL TERMS

IUCN Red List, Conservation Status, Species Recovery Programme, Biodiversity Management, Environmental Policy, International Trade in Endangered Species.

9.6 SELF-ASSESSMENT QUESTIONS

Essay Questions

1. What is the significance of the IUCN Red List?
2. Discuss the strategies used in biodiversity management and their effectiveness.?
3. Explain the importance of biodiversity conservation in sustainable development.?

Short Notes

1. What is meant by the term “endangered species”?
2. Explain in detail the importance of IUCN classification.?
3. Describe the role of international organisations like IUCN and conventions like CBD in global conservation efforts.?

9.7 SUGGESTED READINGS

1. “Biodiversity” by Edward O. Wilson
- A foundational book discussing the concept, value, and threats to biodiversity.

2. “Global Biodiversity Assessment” by UNEP
- A comprehensive guide on biodiversity assessment, management, and policy-level implications.

3. “Conservation Biology: Foundations, Concepts, Applications” by Fred Van Dyke
- Covers key concepts in biodiversity conservation, management strategies, and case studies.

4. “Essentials of Conservation Biology” by Richard B. Primack
- A well-structured introduction to conservation biology and biodiversity management techniques.

5. “Principles of Conservation Biology” by Groom, Meffe, and Carroll
- Combines theoretical foundations with real-world conservation practices.

Prof. K. Sumanth Kumar

LESSON-10
BIODIVERSITY THREATS

AIM AND OBJECTIVES

At the end of the lesson, students will be able to

- Understanding the biodiversity threats
- Explore the causes behind the threats
- To gain knowledge of In-situ and ex-situ conservation
- Understanding various types of conservation

STRUCTURE

10.1 INTRODUCTION

Biodiversity is essential for maintaining ecological balance, but it is increasingly threatened by human activities and environmental changes. Biodiversity threats refer to any factors or activities that lead to the decline or extinction of species, loss of ecosystems, or reduction in genetic diversity. These threats disrupt ecological balance and reduce the ability of nature to provide essential services like clean air, water, and climate regulation. During the last century, decreases in biodiversity have been increasingly observed. It was estimated in 2007 that up to 30% of all species will be extinct by 2050.

Of these, about one-eighth of known plant species are threatened with extinction. Estimates reach as high as 140,000 species per year (based on Species-area theory). This figure indicates unsustainable ecological practices, because few species emerge each year. The rate of species loss is greater now than at any time in human history, with extinctions occurring at rates hundreds of times higher than background extinction rates and expected to still grow in the upcoming years. As of 2012, some studies suggest that 25% of all mammal species could be extinct in 20 years. In 2020, the World Wildlife Foundation published a report saying that "biodiversity is being destroyed at a rate unprecedented in human history". The report claims that 68% of the population of the examined species was destroyed in the years 1970 – 2016.

10.2 MAJOR CAUSES OF BIODIVERSITY THREATS

1. Habitat Destruction and Fragmentation

- **Deforestation**: Deforestation or forest clearance is the removal and destruction of a forest or stand of trees from land that is then converted to non-forest use. Deforestation can involve the conversion of forest land to farms, ranches, or urban use. About 31% of Earth's land surface is covered by forests at present. This is one-third less than the forest cover before the expansion of agriculture, with half of that loss occurring in the last century. Between 15 million to 18 million hectares of forest, an area the size of Bangladesh, are destroyed every year. On average, 2,400 trees are cut down each minute. Deforestation results in habitat destruction, which in turn leads to biodiversity loss. Deforestation also leads to the extinction of animals and plants, changes to the local climate, and the displacement of indigenous people who live in forests. Deforested regions often also suffer from other environmental problems such as desertification and soil erosion.

- **Wetland Drainage**: A wetland is a distinct semi-aquatic ecosystem whose ground covers are flooded or saturated with water, either permanently, for years or decades, or only seasonally. Wetlands form a transitional zone between waterbodies and dry lands, and are different from other terrestrial or aquatic ecosystems due to their vegetation's roots having adapted to oxygen-poor waterlogged soils. Wetlands contribute many ecosystem services that benefit people. These include, for example, water purification, stabilisation of shorelines, storm protection and flood control. In addition, wetlands also process nutrients and water pollutants, and they can help with climate change mitigation. Humans are disturbing and damaging wetlands in many ways, including oil and gas extraction, building infrastructure, overgrazing of livestock, overfishing, alteration of wetlands, including dredging and draining, nutrient pollution, and water pollution. Wetlands are more threatened by environmental degradation than any other ecosystem on Earth, according to the Millennium Ecosystem Assessment from 2005.

- **Urban Expansion**: Also known as Urban sprawl or Urbanisation, defined as the spreading of urban development unrestrictedly. Land for sprawl is often taken from fertile agricultural lands, which are often located immediately surrounding cities; the extent of modern sprawl has consumed a large amount of the most productive agricultural land, as well as forest, desert and other wilderness areas. One of the major environmental problems associated with urban sprawl is land consumption, habitat loss, land pollution, subsequent reduction in biodiversity and destruction of local ecosystems. Urban sprawl is disruptive to native flora & fauna and introduces invasive plants into their environments, which are considered to be harmful to local biomes. Although the effects can be mitigated through careful maintenance of native vegetation, the process of ecological succession and public education, sprawl represents one of the primary threats to biodiversity.

- **Mining and Industrial Development**: Mining and industrial development significantly contribute to habitat loss through direct and indirect means, impacting ecosystems at various scales. The environmental impact of mining includes erosion, formation of sinkholes, loss of biodiversity, and contamination of soil, groundwater and surface water by chemicals from mining processes. In some cases, additional forest logging is done in the vicinity of mines to increase the available room for the storage of the created debris and soil. Even though plants need some heavy metals for their growth, excess of these metals is usually toxic to them. Plants that are polluted with heavy metals usually depict reduced growth, yield and performance.

2. Climate Change

- **Rising Temperatures**: Ongoing changes in climate have had no precedent for several thousand years. Multiple independent datasets all show worldwide increases in surface temperature, at a rate of around 0.2 °C per decade. Present-day climate change includes both global warming—the ongoing increase in global average temperature and its wider effects on Earth’s climate system. Climate change in a broader sense also includes previous long-term changes to Earth's climate. The current rise in global temperatures is driven by human activities, especially fossil fuel burning since the Industrial Revolution. Fossil fuel use, deforestation, and some agricultural and industrial practices release greenhouse gases. These gases absorb some of the heat that the Earth radiates after it warms from sunlight, warming the lower atmosphere. Carbon dioxide, the primary gas driving global warming, has increased in concentration by about 50% since the pre-industrial era to levels not seen for millions of years.

- **Extreme Weather Events**: Abnormally hot temperatures not only swell rivers and creeks directly through accelerated snowmelt, and cause Tidal flooding or sunny day floods. Rising temperatures and changing weather patterns often result in lower crop yields due to water scarcity caused by drought, heat waves, and hurricanes destroy ecosystems.

- **Melting Polar Ice Caps**: Threatens Arctic and Antarctic species. The long-term effects of climate change on oceans include further ice melt, ocean warming, sea level rise, ocean acidification and ocean deoxygenation. The timescale of long-term impacts are centuries to millennia due to CO_2's long atmospheric lifetime. The result is an estimated total sea level rise of 2.3 metres per degree Celsius (4.2 ft/°F) after 2000 years. Oceanic CO_2 uptake is slow enough that ocean acidification will also continue for hundreds to thousands of years. Deep oceans (below 2,000 metres (6,600 ft)) are also already committed to losing over 10% of their dissolved oxygen due to the warming which occurred to date.

- **Ocean Acidification**: Ocean acidification is the ongoing decrease in the pH of the Earth's oceans. Between 1950 and 2020, the average pH of the ocean surface fell from approximately 8.15 to 8.05. A lower ocean pH has a range of potentially harmful effects for marine organisms. Scientists have observed, for example, reduced calcification, lowered immune responses, and reduced energy for basic functions such as reproduction. Ocean acidification can impact marine ecosystems that provide food and livelihoods for many people. About one billion people are wholly or partially dependent on the fishing, tourism, and coastal management services provided by coral reefs. Ongoing acidification of the oceans may therefore threaten food chains linked to the oceans.

3. Pollution

- **Air Pollution**: The release of chemicals and particulates into the atmosphere. Common gaseous pollutants include carbon monoxide, sulphur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxides produced by industry and motor vehicles. Photochemical ozone and smog are created as nitrogen oxides and hydrocarbons react to sunlight, harming plant life, animal life and human health and disrupting ecosystems. Pollutants can be further classified into primary and secondary pollutants. The former are released directly into the troposphere in a potentially harmful, concentrated form, such as soot or carbon monoxide released from the burning of fossil fuels. Primary pollutants may react with each other to form compounds referred to as secondary pollutants, such as photochemical oxidants and acids. Ground-level ozone is one of the many harmful secondary pollutants that form photochemical smog.

- **Water Pollution**: Water pollution, caused by the discharge of industrial wastewater from commercial and industrial waste (intentionally or through spills) into surface waters; discharges of untreated sewage and chemical contaminants, such as chlorine, from treated sewage; and releases of waste and contaminants into surface runoff flowing to surface waters. Water pollution may affect either surface water or groundwater. This form of pollution can lead to many problems. One is the degradation of aquatic ecosystems. Another is spreading waterborne diseases when people use polluted water for drinking or irrigation. Water pollution also reduces the ecosystem services, such as drinking water provided by the water resource.

- **Soil Pollution**: Soil degradation is defined as a process that lowers the capacity of the soil to produce economically important goods and ecological services to man. Chemical or physical degradation of soil can be caused due to inappropriate land management practices, displacement of soil material by the natural process of erosion and addition of pollutants. Mechanised agriculture, livestock grazing, the addition of fertilisers and pesticides, or the dumping of garbage in the soil leads to widespread soil pollution. Dumping of solid wastes and other contaminants in the soil deteriorates its chemical nature, and this has a disastrous effect on soil faunal diversity.

- Heavy metal pollutants like chromium, copper and lead showed negative correlations with the total population of soil arthropods. The chemical has also been shown to upset the food chain of the soil fauna, but the chemical is lethal to the predatory birds and moles that prey on earthworms. Moreover, a rise in global temperature, as well as the presence of toxicants, may deplete microbes of the soil that leading to loss of soil fertility and quality. All these factors are responsible for biodiversity loss.

4. Overexploitation of Natural Resources

- **Overfishing**: The environmental impact of fishing can be divided into issues that involve the availability of fish to be caught, such as overfishing, sustainable fisheries, and fisheries management; and issues that involve the impact of fishing on other elements of the environment, such as by-catch and destruction of habitat such as coral reefs. According to the 2019 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services report, overfishing is the main driver of mass species extinction in the oceans. Populations of oceanic sharks and rays have been reduced by 71% since 1970, largely due to overfishing. More than three-quarters of the species comprising this group are now threatened with extinction.

- **Illegal Wildlife Trade**: Wildlife trade is a serious conservation problem, has a negative effect on the viability of many wildlife populations and is one of the major threats to the survival of vertebrate species. The illegal wildlife trade has been linked to the emergence and spread of new infectious diseases in humans, including emergent viruses. Global initiatives like the United Nations Sustainable Development Goal 15 have a target to end the illegal supply of wildlife. Many environmentalists, scientists, and zoologists around the world are against legalising the pet trade of invasive or introduced species, as their release into the wild, be it intentional or not, could compete with indigenous species and lead to their endangerment.

- **Overgrazing**: Overgrazing reduces the usefulness, productivity and biodiversity of the land and is one cause of desertification and erosion. Overgrazing is also seen as a cause of the spread of invasive species of non-native plants and weeds. Degrading land, emissions from animal agriculture and reducing the biomass in an ecosystem contribute directly to climate change between grazing events. This leads to poor soil conditions that only xeric and early successional species can tolerate. A meta-analysis of 148 studies found that the value of most ecosystem functions declines with increasing grazing intensity and that increasing aridity weakens the positive impacts of light grazing.

5. Invasive Species

- **Non-native Plants and Animals**: An invasive species is an introduced species that harms its new environment. Invasive species adversely affect habitats and bioregions, causing ecological, environmental, and/or economic damage. The term can also be used for native species that become harmful to their native environment after human alterations to their food web. Since the 20th century, invasive species have become serious economic, social, and environmental threats worldwide.

- **Diseases Spread by Introduced Species**: Invasive species can affect human health. With the alteration in ecosystem functionality (due to homogenization of biota communities), invasive species have resulted in negative effects on human well-being, which include reduced resource availability, unrestrained spread of human diseases, and recreational and educational activities, and tourism. Alien species have caused diseases including human immunodeficiency virus (HIV), monkey pox, and severe acute respiratory syndrome (SARS). Invasive species and accompanying control efforts can have long-term public health implications. For instance, pesticides applied to treat a particular pest species could pollute soil and surface water. Encroachment of humans into previously remote ecosystems has exposed exotic diseases such as HIV to the wider population.

- **Hybridisation**: In agriculture and animal husbandry, the Green Revolution's use of conventional hybridisation increased yields by breeding high-yielding varieties. The replacement of locally indigenous breeds, compounded with unintentional cross-pollination and crossbreeding (genetic mixing), has reduced the gene pools of various wild and indigenous breeds, resulting in the loss of genetic diversity. Since the indigenous breeds are often well-adapted to local extremes in climate and have immunity to local pathogens, this can be a significant genetic erosion of the gene pool for future breeding. Therefore, commercial plant geneticists strive to breed "widely adapted" cultivars to counteract this tendency.

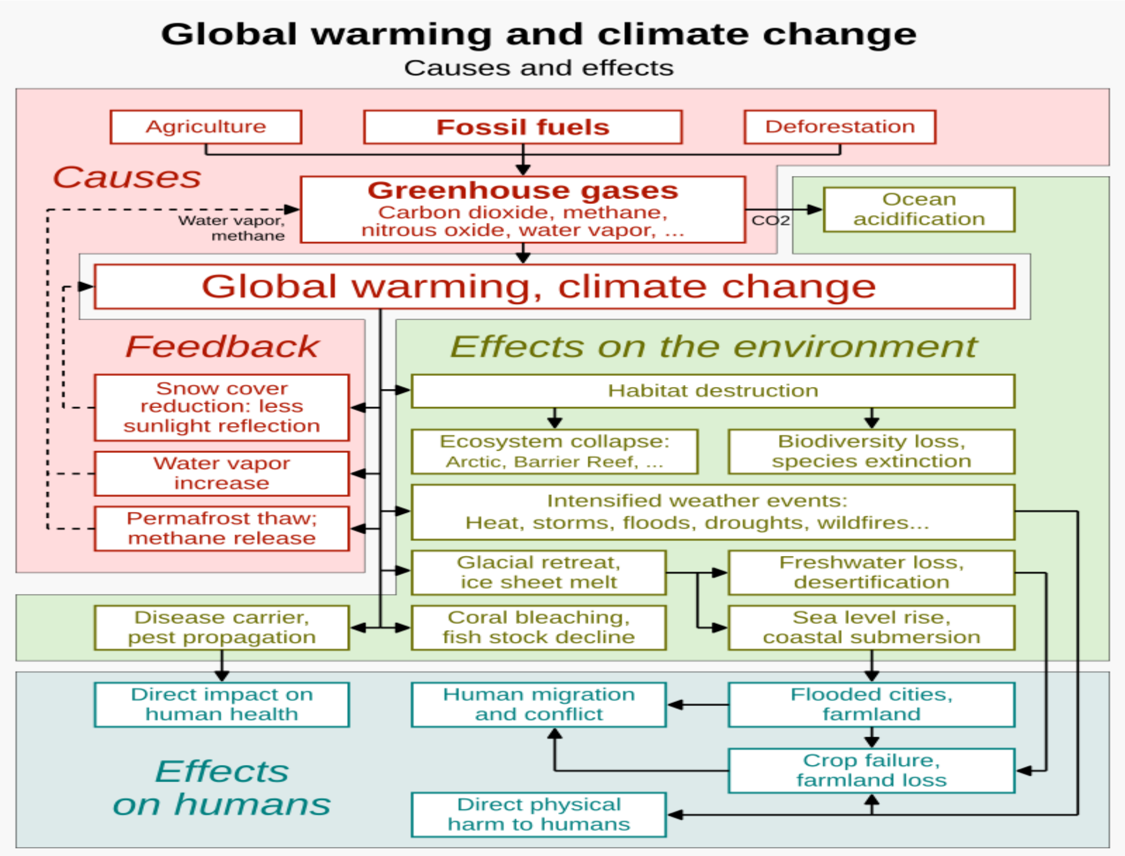

Fig. 10.2 Biodiversity Threats

10.3 IN-SITU CONSERVATION

10.3.1 In-situ Conservation (On-site Conservation)

In-situ conservation is an integrated approach for the protection of ecosystems supporting plants, animals, and microorganisms, including the atmosphere, hydrosphere and lithosphere. It is considered the best method of protecting, propagating and developing species and their habitat along with ecological processes with which they have evolved. Such protection provides effective conservation measures of genetic resources through their maintenance within the natural environment. The maintenance of biotic communities in harmony with their stable environment is a long-term conservation objective.

The in-situ conservation programme is cost-effective and a convenient way in which all the populations of a biotic community, as well as all the ecosystem types, are conserved. To achieve this, different categories of lands have been designated as Protected Areas or Management Areas. According to IUCN, a Protected Area (PA) is "An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity along with the natural and associated cultural resource and managed through legal or other effective means".

There are different types of protected areas, which are normally managed with different objectives in different countries. They often vary in size, design, purpose and effectiveness according to their geographical location, population pressure and socioeconomic conditions of that country. This also serves as the worldwide network of repositories for the entire biological diversity. About 10,000 protected areas are found across the map.
In the historical past, the concept of protected areas in India is found in Kautilya's Arthashastra, which makes reference of 'Abhyaranya (Sanctuaries) for protection of wildlife'.

Later, the first protected area was the Vedanthangal Bird Sanctuary in Tamil Nadu, established in 1878. In the third century BC, Sri Lanka was the first country in the world to set up a wildlife sanctuary. In the modern era, Yellowstone National Park, USA (1836) and the Royal National Park were set up in Australia. Closely followed was the II'menskii Zapovednik of Soviet Russia in 1920.

National Park	State	Known For
Jim Corbett	Uttarakhand	Tigers, oldest national park
Kaziranga	Assam	One-horned rhinoceros
Gir	Gujarat	Asiatic lions
Sundarbans	West Bengal	Mangrove forest, Bengal tiger
Kanha	Madhya Pradesh	Barasingha (swamp deer)
Bandipur	Karnataka	Tigers and elephants
Periyar	Kerala	Elephants and Periyar Lake

- **National parks**: National Parks are designated protected areas established to conserve wildlife, natural vegetation, ecosystems, landscapes, and cultural heritage. These areas are legally set aside to protect biodiversity and natural resources from exploitation or human interference. They serve both ecological and educational purposes and are open to the public for regulated tourism and awareness.

- **wildlife sanctuaries**: Wildlife sanctuaries are designated areas aimed at conserving wild animals and their habitats in a natural setting. These areas provide a safe refuge for wildlife by offering protection from hunting, poaching, and habitat destruction. Unlike national parks, wildlife sanctuaries allow certain regulated human activities such as livestock grazing or the collection of forest produce, depending on the specific rules of each sanctuary. The land within sanctuaries may be owned by the government, communities, or even individuals, but the activities on the land are governed by conservation laws. Tourism, education, and scientific research are generally permitted but are closely monitored to minimize disturbance to wildlife. Additionally, sanctuaries are more flexible in terms of boundary adjustments and land-use permissions, making them an adaptable tool for regional biodiversity protection.

Feature	Wildlife Sanctuary	National Park
Human Activity	Limited permitted (e.g., grazing)	Not allowed
Ownership	Can be private or community-owned	Entirely government-owned
Boundaries	Flexible	Legally fixed
Conservation Focus	Mainly animals	Animals + landscape/ecosystem
Tourism	Allowed with fewer restrictions	Regulated strictly

- **Biosphere reserves:** Biosphere reserves are expansive regions that include a variety of ecosystems such as forests, wetlands, grasslands, and coastal environments. Their main purpose is to conserve genetic diversity, species, and ecosystems while allowing sustainable development for local communities. Unlike national parks or wildlife sanctuaries, biosphere reserves are zoned into three parts: the core zone, which is strictly protected for biodiversity; the buffer zone, where research and limited human activity like environmental education and ecotourism are allowed; and the transition zone, where sustainable agriculture, settlements, and economic activities are promoted under regulation. This zoning helps manage conservation and development in an integrated way. Biosphere reserves often include one or more national parks or sanctuaries within their area and serve as sites for research, monitoring, and learning about ecosystem management.

Biosphere Reserve	State(s)	Key Features
Nilgiri	Tamil Nadu, Kerala, Karnataka	First BR in India; includes Silent Valley, Bandipur
Sundarbans	West Bengal	Largest mangrove forest; home to Bengal tiger
Nanda Devi	Uttarakhand	Himalayan biodiversity hotspot
Gulf of Mannar	Tamil Nadu	Coral reefs, seagrass beds, marine biodiversity
Pachmarhi	Madhya Pradesh	Central Indian forests, rich tribal culture

- **Biodiversity Hotspots**: Biodiversity hotspots are recognized for their extraordinary levels of plant and animal diversity and the critical threats they face due to habitat destruction, deforestation, agriculture, urbanization, and climate change. These regions are prioritized in global conservation strategies because protecting them can preserve a vast number of species in a relatively small area. Hotspots are typically located in tropical forests, islands, and mountain ranges where isolation and climatic stability over long periods have led to high species diversification. They include not only a rich number of species but also a high degree of **endemism**, meaning many species found in these areas are not found anywhere else on Earth. Conservation of these regions is vital for maintaining ecological balance, providing ecosystem services, and preserving the natural heritage of the planet. To qualify as a hotspot, a region must meet two criteria: it must contain at least **1,500 species of vascular plants as endemics**, and it must have **lost at least 70% of its original natural vegetation**.

➢ **Example:** Amazon rainforest (South America)
Sundaland (Southeast Asia)
Western Ghats and Sri Lanka (South Asia)
Himalayas
Indo-Burma region
Madagascar and Indian Ocean Islands
Caribbean Islands
Horn of Africa

Sacred Groves: Sacred groves are small forest areas preserved by local communities due to their spiritual significance. These patches are typically dedicated to a deity, spirit, or ancestor and are considered sacred, so any form of resource extraction—like cutting trees, hunting, or grazing—is strictly prohibited. As a result of this protection, sacred groves often harbor rare, endemic, or threatened plant and animal species. They act as **micro-reserves of biodiversity**, especially in areas that have undergone extensive deforestation. Many sacred groves also serve as sources of traditional knowledge, herbal medicine, and cultural practices. They play a crucial ecological role by preserving **native gene pools**, maintaining **water cycles**, preventing **soil erosion**, and acting as **carbon sinks**. Although they are not formally protected under national laws, the **community-based conservation** they represent makes them a vital component of India's informal biodiversity protection network.

Region	State	Notable Feature
Khasi and Jaintia Hills	Meghalaya	One of the highest concentrations of sacred groves
Kodagu (Coorg)	Karnataka	Known as “Devarakadu”
Aravalli Hills	Rajasthan	Sacred groves dedicated to local deities
Western Ghats	Maharashtra, Kerala	Rich in endemic flora

- **Marine Protected Areas**: Marine Protected Areas are regions of the marine environment where human activities are more strictly regulated than the surrounding waters to protect natural or cultural resources. These areas may allow for various levels of protection, ranging from complete **"no-take zones"**, where all extractive activities are prohibited, to **multiple-use zones**, where sustainable use of marine resources is allowed under guidelines. MPAs contribute to the conservation of endangered marine species, preserve breeding and nursery grounds, maintain the health of ecosystems like coral reefs and mangroves, and support the livelihoods of coastal communities by ensuring sustainable fisheries. They are often established under **national laws or international agreements**, such as the Convention on Biological Diversity (CBD) or the International Union for Conservation of Nature (IUCN) guidelines. MPAs also serve as vital reference sites for **scientific research**, **education**, and **eco-tourism**.

MPA Name	State/UT	Notable Features
Gulf of Mannar Biosphere Reserve	Tamil Nadu	Coral reefs, seagrass beds, dugongs
Malvan Marine Sanctuary	Maharashtra	Coral patches, estuarine biodiversity
Rani Jhansi Marine NP	Andaman & Nicobar	Coral reefs, turtles, rich marine fauna
Mahatma Gandhi Marine NP	Andaman Islands	Coral reefs, fish diversity, eco-tourism
Gahirmatha Marine Sanctuary	Odisha	Largest nesting site for Olive Ridley turtles

- **Agrobiodiversity Conservation**: Agrobiodiversity conservation involves the protection and sustainable use of the diversity of genetic resources found in crops, livestock, and associated ecosystems. It is critical for **ensuring food security**, **adapting to climate change**, and **preserving traditional knowledge**. Conservation can occur **in situ**, such as on farms where traditional crop varieties or local breeds are maintained by farmers, or **ex situ**, through gene banks and seed vaults where genetic material is stored for future use. Agrobiodiversity helps buffer agricultural systems against pests, diseases, and climate variability by providing genetic traits for resistance and resilience. Moreover, traditional farming practices and indigenous knowledge play a major role in conserving this diversity by selecting and cultivating diverse varieties adapted to local environments. Preserving agrobiodiversity also contributes to **nutritional diversity** and **cultural heritage**, especially among indigenous and rural communities.

Conservation Type	Description
In situ	Conservation in natural habitat or farm (e.g., traditional farming systems)
Ex situ	Conservation outside natural habitat (e.g., seed banks, tissue culture)
On-farm conservation	Farmers maintain and use traditional varieties in cultivation
Community seed banks	Local repositories of diverse seeds managed by farmers

10.4 EX-SITU CONSERVATION (Off-site Conservation)

Ex-situ conservation is defined as the conservation of the components of biological diversity outside their natural habitats. This involves diverse techniques and facilities for long-term storage of the genetic resource of wild or cultivated species or their parts. Maintenance and breeding of threatened fauna and flora are done either partially or wholly under controlled conditions in zoos, botanical gardens, nurseries and laboratories as a part of the off site conservation programme. "Ex-situ or off-site conservation" is thus, a process of protecting an endangered species by removing part of the population from a threatened habitat and placing it in a new location. The new habitat may be under laboratory conditions or a wild area within the care and vigilance of human being.

Both traditional and modern techniques are used for ex-situ conservation. Species almost on the verge of extinction with only few surviving individuals in the wild and those living in a threatened habitat are selected for ex-situ conservation. Moreover, rare species with, low dispersal ability, those who utilize only specialized resource and found only in patchy habitats are selected. Animals living in fragmented habitats are affected more by the changes in the environment. Predatory species at the higher trophic level and species with low adult survival rate are also chosen for this conservation practice. In-situ conservation or conservation of species in their natural habitats is considered to be the most appropriate way of conserving biodiversity, while ex-situ conservation is complementary to in-situ methods providing "insurance policy" against species extinction. So, vulnerability of the species and evaluation of its economic, ecologic or aesthetic value determines whether it needs ex-situ conservation or not.

10.4.1 Methods of Ex-situ Conservation

1. **Zoos & Safari Parks**: **Zoos** are typically enclosed environments that house a wide variety of animal species, including mammals, birds, reptiles, and amphibians, for conservation, education, and research purposes. They are often found in urban settings and provide opportunities for visitors to learn about wildlife conservation and the behaviour of different species. Modern zoos focus on creating more **naturalistic enclosures** that replicate the animals' natural habitats to ensure their well-being and promote breeding programs for endangered species. Additionally, zoos participate in **ex-situ conservation**, where they house and breed species that are at risk of extinction in the wild, offering a **safety net** for species that are endangered due to habitat loss, poaching, and other threats.

   On the other hand, **safari parks** are large, open areas designed to mimic natural habitats and allow animals to roam more freely. They are typically found on the outskirts of cities or in rural areas. Safari parks offer a more naturalistic experience for both the animals and the visitors. In a safari park, animals live in larger, more open spaces compared to the confined enclosures of traditional zoos. Visitors can drive through the park in vehicles or take guided tours, offering a more immersive experience of observing wildlife in a setting that is closer to their natural environment. Both zoos and safari parks have evolved beyond just exhibition and recreation. They play a critical role in **biodiversity conservation**, especially through **breeding programs**, such as the **Species Survival Plan (SSP)**, and by educating the public about wildlife issues like habitat destruction, climate change, and poaching.

Feature	Zoos	Safari Parks
Size	Smaller, often in urban settings	Larger, often in rural or semi-rural areas
Animal Enclosures	Cages or smaller enclosures	Open spaces where animals roam freely
Visitor Experience	Close-up views, sometimes through glass or barriers	Drive-through or walking tours in natural settings
Focus	Conservation, education, research	Wildlife conservation, education, and recreation in a natural setting
Species Focus	Wide range of species, often exotic	Focus on large mammals and animals native to the region

2. **Botanical Gardens**: Botanical gardens are carefully designed spaces where a diverse range of plant species is cultivated and displayed in an organized manner for public enjoyment, research, and conservation. Unlike conventional gardens, botanical gardens focus on **plant research** and the study of plant biology, ecology, and conservation. They are home to **rare, endangered, and threatened plant species**, some of which are not found in the wild anymore. Botanical gardens play an important role in **ex-situ conservation** by protecting plants from the risk of extinction due to habitat destruction, climate change, and over-exploitation. They house species from various regions, including tropical, subtropical, temperate, and arid zones, providing a **global collection of plants**.

   Many botanical gardens participate in **seed banks** and **plant breeding programs** to support the restoration of plant species and to ensure that genetic diversity is preserved for future generations. Additionally, botanical gardens promote **environmental awareness** by educating visitors about the importance of plants for oxygen production, climate regulation, and food security. Some also collaborate with universities and research institutions to conduct **scientific studies** on plant physiology, genetics, and conservation strategies.

Botanical Garden	Location	Notable Features
Royal Botanic Gardens	Kew, UK	UNESCO World Heritage Site, over 50,000 plant species
Kirstenbosch Botanical Gardens	Cape Town, South Africa	Famous for its indigenous flora, part of Table Mountain National Park
New York Botanical Garden	New York, USA	Home to over one million plants, research center for plant conservation
Singapore Botanic Gardens	Singapore	UNESCO World Heritage Site, largest collection of orchids
Indian Botanic Garden	Kolkata, India	Large collection of Indian and tropical plants, famous Banyan tree

3. **Seed Banks**: **Seed banks** are specialized facilities where seeds are collected, stored, and preserved for future use in **plant conservation**, **agriculture**, and **research**. The primary purpose of a seed bank is to safeguard the genetic diversity of plant species, especially those that are **endangered, rare**, or have **economic and ecological importance**. Seed banks are a critical tool in **ex-situ conservation** and help ensure the survival of plant species in case of **environmental changes**, **natural disasters**, **climate change**, or human activities that threaten plant habitats.

- **Example: Svalbard Global Seed Vault (Norway).**

4. **Gene Banks**: **Gene banks** (also known as **genetic resource banks**) are facilities or repositories that store genetic material of plants, animals, and microorganisms. These materials, such as **seeds**, **germplasm**, **DNA**, and **cell cultures**, are preserved for long-term use in research, breeding, and conservation. Gene banks play an essential role in **ex-situ conservation**, providing a safeguard against the loss of genetic diversity and helping to protect species from extinction due to habitat destruction, climate change, or other human-induced pressures.

- **Example: National Bureau of Plant Genetic Resources (India).**

5. **Cryopreservation**: **Cryopreservation** is a process of preserving biological material at extremely low temperatures to stop all biochemical and cellular activities, including the growth of microorganisms and cellular degradation. This technique is commonly used to store cells, tissues, sperm, embryos, and even entire organisms for **long-term conservation**. Cryopreservation allows for the **preservation of genetic material** without the need for living organisms to be maintained. It is widely used in various fields such as **medicine**, **agriculture**, and **conservation**, playing a crucial role in preserving genetic resources, such as endangered species or crop varieties, and enabling **reproductive technologies**.

- **Example: Frozen Zoo (San Diego).**

6. **Captive Breeding & Reintroduction**: **Captive breeding** and **reintroduction** are key strategies used in wildlife conservation aimed at preserving species at risk of extinction. **Captive breeding** involves breeding endangered species in controlled environments such as **zoos**, **safari parks**, and **wildlife reserves** to increase population numbers. The ultimate goal is to create a **self-sustaining** population of species that can eventually be reintroduced into their natural habitats. **Reintroduction** refers to the process of releasing species that have been bred in captivity or whose populations have been significantly reduced or extirpated in the wild. This method helps restore

balance to ecosystems by bringing back species that play a crucial role in the environment.

- **Example: The Arabian Oryx was reintroduced in Oman.**

10.5 COMPARISON: IN-SITU VS. EX-SITU CONSERVATION

Feature	**In-situ Conservation**	**Ex-situ Conservation**
Definition	Protecting species in their natural habitat.	Conserving species outside their natural habitat.
Examples	National parks, wildlife sanctuaries, biosphere reserves.	Zoos, seed banks, gene banks, botanical gardens.
Cost	Generally lower.	Higher due to maintenance and artificial environments.
Species Adaptation	Species continue to evolve naturally.	Species may lose natural behaviors.
Threat Protection	Limited protection from poaching and climate change.	Stronger protection from threats.
Genetic Diversity	Maintained through natural selection.	Risk of inbreeding and reduced genetic diversity.

10.6 SUMMARY

Biodiversity is under severe threat globally due to a combination of natural and especially human-induced factors. Major threats to biodiversity include habitat destruction, deforestation, overexploitation of resources, pollution, climate change, invasive species, and urbanization. These threats lead to a rapid decline in the number and diversity of species, disrupt ecosystems, and can result in extinction. Loss of biodiversity not only impacts the environment but also threatens food security, health, and livelihoods. Together, **in-situ and ex-situ conservation** approaches provide a complementary framework to preserve biodiversity, ensuring both immediate protection and long-term survival of species and ecosystems.

10.7 TECHNICAL TERMS

Habitat Fragmentation, Invasive Species, Endangered Species, Reintroduction, Overexploitation.

10.8 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. List the major threats to biodiversity.?
2. What is the process of reintroduction in wildlife conservation?
3. What are the impacts of habitat destruction on ecosystems?

Short Notes:

1. Explain the concept of overexploitation with examples.
2. What is in-situ conservation? Give examples.
3. What are the roles of zoos and botanical gardens in conservation?

10.9 SUGGESTED READINGS

1. "Fundamentals of Ecology" – *Eugene P. Odum & Gary W. Barrett*
- Comprehensive coverage of ecological principles, conservation, and biodiversity management.

2. "Environmental Biology" – *P.D. Sharma*
- Contains detailed chapters on biodiversity, conservation strategies, and human impacts on the environment.

3. "Biodiversity and Conservation" – *M.P. Arora*
- Covers biodiversity values, threats, and both in-situ and ex-situ conservation methods.

4. "Essentials of Ecology and Environmental Science" – *S.V.S. Rana*
- Good for understanding threats to biodiversity and principles of conservation biology.

5. NCERT Class 12 Biology Textbook (Unit on Biodiversity and Conservation)
- Excellent for foundational understanding; useful for school and entrance exam preparation.

Prof. K. Sumanth Kumar

LESSON-11

GENE BANKS AND WILDLIFE PROTECTION ACTS

AIMS AND OBJECTIVES

- Understanding types of gene banks and their significance
- To gain knowledge of genetic resources conversion
- Explore how wildlife protection acts work
- Understanding the organisations in biodiversity protection.

STRUCTURE

11.1 GENEBANK

Gene banks (also known as genetic resource banks) are facilities or repositories that store genetic material of plants, animals, and microorganisms. These materials, such as seeds, germplasm, DNA, and cell cultures, are preserved for long-term use in research, breeding, and conservation. Gene banks play an essential role in ex-situ conservation, providing a safeguard against the loss of genetic diversity and helping to protect species from extinction due to habitat destruction, climate change, or other human-induced pressures.

11.1.1 Key Features of Gene Banks

Gene banks focus on preserving the **genetic material** of a wide range of species, including **wild plants**, **domestic animals**, **crop varieties**, and even **microorganisms**. The primary objective of a gene bank is to maintain the **genetic diversity** of species, ensuring that they can be repopulated or reintroduced into their natural environments when necessary. Gene banks store genetic material in various forms, including **seeds**, **tissues**, **embryos**, **sperm**, **eggs**, **DNA**, and **cryopreserved cells**. These materials are preserved under controlled conditions, often in **freezing** or **cryopreservation**, to maintain their viability for long periods, sometimes even centuries.

The most well-known type of gene bank is a **seed bank**, which primarily preserves plant genetic material for agricultural or conservation purposes. However, gene banks also store **animal genetic material**, such as **sperm** or **embryos** from endangered species, which can be used for **breeding programs** or reintroduction efforts. Gene banks also support **scientific research**, including studies on genetics, crop improvement, disease resistance, and the development of new strains of plants and animals. The **International Gene Bank Network** (a global initiative for gene banks) helps ensure that genetic diversity is preserved across the world and that access to these resources is available for **sustainable development** and **food security**.

11.1.2 Types of Gene Bank

1. **Seed Banks**: Preserve seeds from a wide range of plant species, particularly crop varieties, to protect against genetic erosion and ensure food security.
   Example: The Svalbard Global Seed Vault in Norway, which stores seeds from around the world as a backup to safeguard against natural disasters and climate change.
2. **Cryobanks:** Store genetic material such as sperm, eggs, embryos, and seeds at very low temperatures (cryogenic storage) to maintain genetic diversity for future breeding or restoration programs.
   Example: Animal gene banks that store semen for endangered species breeding programs

3. **Microbial Gene Banks:** A Microbial Gene Bank is a specialised facility that collects, preserves, and stores genetic material of microorganisms such as bacteria, fungi, algae, viruses, and archaea. These banks are vital for research, agriculture, medicine, biotechnology, and environmental sustainability.
   Example: NCIM (National Collection of Industrial Microorganisms), India

- ATCC (American Type Culture Collection), USA
- DSMZ (German Collection of Microorganisms and Cell Cultures), Germany

4. **DNA Banks:** A DNA Bank is a specialized repository that stores extracted and purified DNA samples from various organisms, including plants, animals, microorganisms, and even humans. These banks are essential for genetic research, biodiversity conservation, forensic science, medicine, and biotechnology.
   Example: The Global Genome Biodiversity Network (GGBN) maintains DNA samples from across the globe for biodiversity studies.
5. **Animal Gene Banks:** Store genetic material from animals (such as sperm, eggs, embryos, and DNA) to preserve genetic diversity in livestock or endangered species.
   Example: The National Animal Germplasm Program (NAGP) in the U.S. preserves genetic material from livestock animals.
6. **In Vitro Gene Banks**: Preserve plant cells, tissues, or organs in controlled environments (e.g., liquid nitrogen) for long-term storage, often for rare or endangered plants that cannot be stored as seeds.
   Example: The International Rice Research Institute (IRRI) maintains in vitro cultures of rice for conservation.
7. **Pollen Banks:** Store pollen from plants for breeding and conservation purposes, particularly for species that have short pollen viability.
   Example: Pollen storage programs for endangered plant species or crops with difficult reproduction processes.

Each type of gene bank plays a crucial role in preserving genetic resources to support biodiversity, agriculture, and scientific research.

Fig. 11.1 Seed bank

Fig. 11.1 DNA bank

Fig. 11.1 in vitro gene bank

11.1.3 Importance of Gene Banks

- **Conservation of genetic diversity:** Gene banks protect the genetic material of endangered species and threatened crops, ensuring that genetic resources are available for future use.
- **Food security:** By storing diverse crop varieties, gene banks help protect against agricultural failures caused by pests, diseases, or environmental changes.
- **Breeding programs**: Gene banks provide resources for developing more resilient and productive plants and animals, such as pest-resistant crops or disease-resistant livestock.
- **Research:** Genetic material stored in gene banks is invaluable for scientific research on genetics, plant and animal breeding, and improving agricultural practices.
- **Climate change adaptation:** Gene banks support the development of plants and animals that can better withstand changing climate conditions, such as drought or extreme temperatures.

11.1.4 Notable Gene Banks Around the World

Gene Bank	Location	Notable Features
Svalbard Global Seed Vault	Svalbard, Norway	A global backup facility, preserving the world's crop genetic material in case of global crises
International Rice Research Institute (IRRI) Gene Bank	Philippines	Holds over 100,000 varieties of rice seeds for food security and research
The National Animal Germplasm Program (NAGP)	USA	Preserves the genetic material of farm animals to protect livestock diversity
Global Crop Diversity Trust (Crop Trust)	Global	Focuses on securing genetic resources for crop plants from around the world
Kew Royal Botanic Gardens Gene Bank	London, UK	Preserves seeds, DNA, and other plant genetic material for conservation and scientific research

11.1.5 How Gene Banks Operate

1. **Collection of Genetic Material**: The first step is to collect genetic material from plants, animals, or microorganisms, often from wild populations or valuable breeds.
2. **Processing and Testing**: The genetic material is cleaned, tested for viability, and stored in a stable form (e.g., seeds, sperm, DNA).
3. **Storage**: Materials are stored in controlled conditions—often frozen at ultra-low temperatures (cryopreservation)—to prevent deterioration over time.
4. **Repopulation and Breeding**: When needed, genetic material is regenerated or reintroduced for breeding programs, research, or restoration of endangered species.
5. **Scientific Research**: Gene banks collaborate with research institutions to study genetic diversity, enhance breeding programs, and develop strategies for improving plant and animal resilience.

11.2 CONSERVATION OF GENETIC RESOURCES

Conservation of genetic resources refers to the preservation and management of the genetic diversity of plants, animals, and microorganisms. This diversity is crucial for the sustainability of ecosystems, the resilience of species, and for human needs, including agriculture, medicine, and industry. The conservation of genetic resources ensures that future generations can continue to benefit from the genetic potential of species for breeding, food security, environmental sustainability, and biotechnological advances.

11.2.1 Key Methods of Genetic Resource Conservation:

1. In Situ Conservation

Definition: In situ conservation is the protection and management of species and their habitats in their natural environment, ensuring the preservation of their genetic diversity in the wild.

Examples: Protected Areas, Wildlife Corridors, Conservation of Indigenous Species.

2. Ex Situ Conservation

Definition: Ex situ conservation involves preserving species outside their natural habitats, typically in controlled environments such as gene banks, zoos, botanical gardens, or aquariums.
Examples: Seed Banks, Gene Banks, Zoos and Botanical Gardens

3. Cryopreservation

Definition: The storage of genetic material (such as sperm, eggs, embryos, seeds, and other tissues) at ultra-low temperatures to prevent degradation and preserve genetic information for long periods.
Examples: Animal Sperm Banks, Plant Tissue Culture

4. Breeding Programs and Managed Gene Flow

Definition: These programs involve carefully managing the genetic diversity of populations through controlled breeding to avoid inbreeding and genetic bottlenecks
Examples: Livestock Breeding Programs, Reintroduction and Restocking.

5. Agrobiodiversity Conservation

Definition: Agrobiodiversity focuses on the genetic diversity within crops, livestock, and other agricultural species that are critical for food security and sustainable agriculture.
Examples: Crop Varieties Preservation, Livestock Genetic Diversity, Soil Microbial Diversity.

6. Molecular and Genomic Techniques

Definition: The use of biotechnology and genomics to study, monitor, and manage genetic diversity.
Examples: Genetic Mapping, DNA Barcoding, Marker-Assisted Selection

11.2.3 Importance of Genetic Resource Conservation:

1. **Biodiversity and Ecosystem Health**: Genetic diversity is critical for the adaptation and survival of species, especially in the face of environmental changes, diseases, and climate change. It helps species evolve and respond to challenges in their environment.
2. **Agricultural Security:** Preserving the genetic diversity of crops and livestock ensures food security by enabling the development of more resilient varieties that can withstand pests, diseases, and climate extremes.
3. **Medicine:** Genetic resources from plants, animals, and microorganisms provide raw materials for pharmaceuticals, vaccines, and biotechnology. Many drugs, including life-saving ones, are derived from natural sources.
4. **Economic Benefits:** The conservation of genetic resources supports industries like agriculture, forestry, and pharmaceuticals. Moreover, it opens up opportunities for future biotechnological innovations.
5. **Cultural and Ethical Importance:** Traditional farming systems and indigenous knowledge often rely on the conservation of local biodiversity. Furthermore, the loss of genetic resources can lead to the erosion of cultural identity and knowledge systems.

11.3 CRYOPRESERVATION

Cryopreservation is the process of preserving biological material by cooling it to sub-zero temperatures, typically below -150°C, where cellular activity and metabolic processes stop. This technique is primarily used to preserve cells, tissues, organs, embryos, or even whole organisms for future use, ensuring their viability and integrity are maintained over long periods of time.

11.3.1 Key Aspects of Cryopreservation:

1. **Cryoprotectants**: Chemicals (often antifreeze agents like glycerol or dimethyl sulfoxide) are used to prevent the formation of ice crystals during freezing, which could damage the cells' structures. These cryoprotectants reduce the risk of osmotic shock and freezing damage.

2. **Freezing and Thawing Process**: The cooling process typically involves controlled slow freezing, which allows water inside the cells to move out, minimising ice formation. The material is then stored at ultra-low temperatures, usually in liquid nitrogen tanks (-196°C), which can preserve biological samples indefinitely without degradation. Upon thawing, the biological material must be warmed carefully to avoid thermal shock, which can cause damage.

3. **Applications of Cryopreservation**:

- **Human Medicine**: Used for preserving sperm, eggs, embryos, and tissues for fertility preservation or medical treatments. It is also used in organ transplantation and stem cell therapies.
- **Agriculture**: Cryopreservation is applied to store genetic material such as seeds, plant tissues, and pollen for long-term conservation of genetic diversity and breeding programs.
- **Wildlife Conservation**: To protect endangered species, sperm, embryos, or genetic material from animals can be cryopreserved, aiding in breeding programs and genetic diversity maintenance.
- **Microbial and Genetic Resources:** Microorganisms, including bacteria, fungi, and viruses, are often cryopreserved for research, industrial uses, or environmental studies.
- **Research:** Used in various fields, such as genetic research, where cell lines or tissue samples need to be preserved for experiments over extended periods.

4. **Advantages:**

- Long-term preservation of biological materials.
- Ability to restore viable cells, tissues, or organisms after thawing.
- Preservation of genetic diversity in agriculture, wildlife conservation, and medical research.

5. **Challenges:** The formation of ice crystals, even with cryoprotectants, can still cause damage to cells and tissues. The thawing process needs to be controlled precisely to prevent loss of cell viability. Some materials, like certain plant species or complex tissues, are harder to cryopreserve successfully.

11.4 WILD LIFE PROTECTION ACTS

Wildlife protection acts are laws designed to safeguard wildlife and their habitats from exploitation, destruction, or endangerment. These acts typically address issues such as poaching, illegal trade, habitat loss, and the preservation of endangered species.

11.4.1 Wildlife protection acts from around the world:

1. The Wildlife Protection Act of 1972 (India)

This act is one of the most important environmental laws in India. It provides for the protection of wild animals, birds, and plants. It establishes protected areas such as national parks, wildlife sanctuaries, and biosphere reserves.
It prohibits hunting of endangered species and regulates the trade of wildlife products.

2. Endangered Species Act (USA)

Enacted in 1973, this act provides a framework to protect endangered and threatened species and their habitats. It also prohibits unauthorised taking, possession, sale, or transport of endangered species.
Managed by the U.S. Fish and Wildlife Service, it has been key to the recovery of several species.

3. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

An international agreement signed in 1973 that aims to ensure that international trade in wild animals and plants does not threaten their survival.
CITES regulates trade in over 35,000 species of animals and plants, providing a legal framework for the protection of biodiversity.

4. The Wildlife and Countryside Act 1981 (UK)

This act provides a framework for the protection of wildlife in Great Britain, including prohibiting the killing or harming of certain species and protecting their habitats.
It also controls the sale and possession of wild birds and animals.

5. The Nature Conservation Act 1992 (Australia)

This act protects Australia’s biodiversity by regulating the conservation of national parks, reserves, and threatened species.
It focuses on ensuring that national parks and nature reserves are properly managed.

6. The Biodiversity Conservation Act 2016 (New South Wales, Australia)

Aims to protect biodiversity through the regulation of land clearing, species conservation, and habitat protection.

7. The National Environmental Policy Act (NEPA) (USA)

While not solely focused on wildlife, NEPA, passed in 1970, requires that any federal agency planning a project must assess the environmental impact, including effects on wildlife and their habitats.

8. The African Convention on the Conservation of Nature and Natural Resources (1968)

This regional treaty aims to protect Africa's wildlife and ecosystems. It provides guidelines for conserving biodiversity, controlling the exploitation of natural resources, and combating wildlife crime.

11.5 ORGANISATIONS INVOLVED IN PROTECTION OF BIODIVERSITY

Several organisations around the world focus on the protection and conservation of biodiversity, playing vital roles in research, policy advocacy, habitat preservation, and species protection.

11.5.1 Key organisations involved in biodiversity protection:

1. World Wildlife Fund (WWF)

Focus: WWF works globally to conserve the world's most vulnerable species and ecosystems, promote sustainable development, and address climate change.
Activities: Species protection, habitat preservation, environmental education, and policy advocacy.

2. Convention on Biological Diversity (CBD)

Focus: The CBD is an international treaty aimed at conserving biodiversity, ensuring sustainable use of biological resources, and fair sharing of benefits arising from genetic resources.
Activities: Facilitates international cooperation, sets global biodiversity targets (such as the Aichi Targets), and provides guidance for national conservation strategies.

3. International Union for Conservation of Nature (IUCN)

Focus: IUCN is the world’s largest environmental network, focused on assessing the status of biodiversity, conserving species and ecosystems, and promoting sustainable development.
Activities: Produces the Red List of Threatened Species, offers guidelines for conservation, and supports global biodiversity initiatives.

4. The Nature Conservancy (TNC)

Focus: TNC works globally to conserve the lands and waters upon which all life depends, focusing on protecting ecosystems and biodiversity.
Activities: Conservation projects in priority areas, habitat restoration, environmental education, and climate change mitigation.

5. Wildlife Conservation Society (WCS)

Focus: WCS is dedicated to saving wildlife and wild places across the globe, focusing on habitat preservation, species conservation, and sustainable wildlife management.
Activities: Protects biodiversity through scientific research, habitat preservation, and community engagement.

6. Bird Life International

Focus: A global partnership of conservation organizations dedicated to the protection of birds and their habitats.
Activities: Conservation efforts for bird species, habitat protection, and supporting the implementation of the Convention on Migratory Species.

7. Global Environment Facility (GEF)

Focus: The GEF is an international partnership that funds projects to address global environmental issues, including biodiversity loss, climate change, and pollution.
Activities: Funds biodiversity conservation projects in developing countries, promoting sustainable development and ecosystem preservation.

8. United Nations Environment Programme (UNEP)

Focus: UNEP is the leading global environmental authority within the UN system, focused on supporting countries in addressing environmental challenges, including biodiversity loss.
Activities: Works on policy advocacy, awareness, and implementation of international environmental agreements such as the CBD and the Convention on International Trade in Endangered Species (CITES).

9. CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)
Focus: CITES is an international agreement aimed at ensuring that international trade in wild animals and plants does not threaten their survival.
Activities: Regulates and monitors international trade in endangered species through a system of permits and legal frameworks

10. Fauna & Flora International (FFI)

Focus: FFI works to conserve threatened species and ecosystems worldwide, focusing on both in-situ and ex-situ conservation.
Activities: Species protection, ecosystem restoration, sustainable livelihoods, and capacity building.

11. Earth watch Institute

Focus: Earth watch is an international environmental nonprofit organization that engages people in scientific field research and education to promote environmental conservation.
Activities: Involves volunteers in research expeditions, conservation efforts, and biodiversity monitoring.

12. International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)

Focus: This treaty ensures the conservation and sustainable use of plant genetic resources for food and agriculture.
Activities: Facilitates the sharing of plant genetic material and promotes sustainable agricultural practices.

13. The Global Seed Vault (Svalbard Global Seed Vault)

Focus: Located in Norway, it is a global backup storage facility for the preservation of seeds from around the world, safeguarding biodiversity against climate change and other threats.
Activities: Secures plant genetic material to maintain biodiversity and provide seeds for future generations in case of disaster.

14. African Wildlife Foundation (AWF)

Focus: AWF focuses on protecting Africa's wildlife and wildlands, supporting sustainable development and helping people and wildlife coexist.
Activities: Protects endangered species, creates conservation areas, and supports community-based conservation initiative
These organizations work at various levels, from local to global, to protect ecosystems, prevent species extinction, and ensure the sustainable use of natural resources. They collaborate with governments, local communities, researchers, and other stakeholders to achieve these goals.

11.6 SUMMARY

Biodiversity conservation relies on various strategies and tools, both in situ (within natural habitats) and ex situ (outside natural settings), to safeguard the genetic resources of the planet. Gene banks are crucial ex situ facilities that preserve genetic material such as seeds, tissues, DNA, embryos, and microorganisms. They serve as long-term storage systems for agricultural, medicinal, and ecological species, ensuring that genetic diversity is maintained for future use in research, crop improvement, animal breeding, and ecosystem restoration. One of the key techniques used in gene banks is cryopreservation, which involves storing biological materials at extremely low temperatures (typically –196°C in liquid nitrogen). This halts all metabolic activity and allows for indefinite preservation of viable cells and tissues.

The conservation of genetic resources is essential for maintaining species diversity, ensuring food security, and adapting to climate change and environmental challenges. It encompasses both the collection of genetic material and its sustainable use. To provide legal protection to wildlife and their habitats, countries implement legislation such as the Wildlife Protection Act of 1972 (India), which prohibits hunting, regulates trade in endangered species, and establishes protected areas like national parks, sanctuaries, and biosphere reserves.

Various national and international organisations work together to protect biodiversity. Globally, institutions like the IUCN (International Union for Conservation of Nature), WWF (World Wide Fund for Nature), CBD (Convention on Biological Diversity), and UNEP (United Nations Environment Programme) promote conservation policies, raise awareness, and fund biodiversity-related projects. In India, the National Biodiversity Authority (NBA)

plays a key role in regulating access to biological resources and ensuring the equitable sharing of benefits arising from their use. Together, these efforts form a comprehensive framework for protecting biodiversity and ensuring its sustainable management for future generations.

11.7 TECHNICAL TERMS

Germplasm, Clonal Repository, Cryogenics, Vitrification, Poaching, Endangered Species, CITES, CBD (Convention on Biological Diversity), Biosafety.

11.8 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. Describe briefly about Wildlife Protection Act? And write about the organization involved in it?
2. What is the Wildlife Protection Act of 1972, and why was it enacted?
3. Define cryopreservation and explain its significance in conservation biology.

Short Notes:

1. Write about Biodiversity Threats.?
2. Discuss about Gene banks and their types and primary functions.?
3. Write a note on Cryopreservation.?

SUGGESTED READINGS

1. “Principles of Conservation Biology” – Martha J. Groom, Gary K. Meffe, and C. Ronald Carroll

2. “Biodiversity and Conservation” – Michael J. Jeffries

3. “Conservation Genetics in the Age of Genomics” – George Amato et al.

4. “Wildlife Ecology, Conservation, and Management” – Anthony R.E. Sinclair et al.

5. “Plant Genetic Resources: Characterisation and Utilisation” – R. K. Tyagi & M.S. Swaminathan

Prof. K. Sumanth Kumar

LESSON-12
BIODIVERSITY AND BIOTECHNOLOGY

AIMS AND OBJECTIVES

- Understanding the significance of biodiversity and biotechnology
- Benefits of DNA-based Wildlife Forensics
- To gain knowledge of genetically modified organisms

STRUCTURE

12.1 INTRODUCTION

Biodiversity is the variety of life found on Earth, encompassing genetic diversity, species diversity, and ecosystem diversity. It is the foundation of ecosystem services, agriculture, medicine, and the overall health of the planet. On the other hand, **biotechnology** is the science of using living organisms or biological systems to develop products and technologies for human use. It includes fields such as genetic engineering, molecular biology, and microbiology.

When these two domains intersect, biotechnology becomes a powerful tool for exploring, utilising, and conserving biodiversity. It enables scientists to study organisms at the molecular level, develop new medicines and crops, and even protect endangered species through advanced conservation methods. However, it also raises important ethical and legal questions regarding genetic ownership, access to natural resources, and fair benefit-sharing with local communities.

This interrelationship between biodiversity and biotechnology holds immense potential for sustainable development, but also demands careful management to ensure long-term ecological balance and social equity.

12.2 DNA-BASED WILDLIFE FORENSICS

DNA-based wildlife forensics is a powerful tool used to combat wildlife crime, including poaching, illegal trade, and habitat destruction. It involves using genetic analysis to identify species, individuals, and geographic origins of seized wildlife products, such as ivory, rhino horn, bushmeat, and animal skins.

The field of conservation genetics has developed over the past 20 yr to support the application of molecular genetic analysis to problems and questions encountered in species conservation. Research is primarily undertaken by academic scientists and has led to new approaches for the collection, analysis and interpretation of biological samples in addition to generating information relevant to the management of target populations. The breadth of possible applications requires conservation geneticists to draw on a wide range of established biological subjects, including population genetics, molecular ecology, molecular phylogenetics, phylogeography and taxonomy. Their principal objective is to synthesise this knowledge and develop best practice solutions to specific challenges faced in conservation. One area of conservation genetics that has long been recognised but is now receiving increasing attention is the development of analytical techniques capable of providing DNA evidence to assist in conservation law enforcement, commonly termed 'wildlife DNA forensics'. Wildlife DNA forensics is essentially concerned with the identification of evidence items in order to determine the species, population, relationship or individual identity of a sample. The subject has developed in parallel to human forensic genetics and has benefited from the horizontal transfer of molecular and statistical techniques; however, it remains a highly specialist area with its own distinct set of challenges, situated between wildlife conservation research and applied forensic science. With the development of national and international legislation to protect ever diminishing habitat and species diversity, DNA forensics is now becoming a key investigative tool to combat wildlife crime.

12.2.1 Key Applications of DNA in Wildlife Forensics

1. **Species Identification** – The use of genetic analysis to identify the species of an evidence sample is the most common application in wildlife DNA forensics. Species identification may be used in cases of illegal poaching in order to identify trace evidence in the field or from a suspect's possessions. DNA analysis can accurately identify the species of traded animals and plants, even from small samples like feathers, hair, or scales, which is crucial for identifying poached animals and preventing the illegal trade of endangered species. The primary method of identifying a DNA sequence is through the use of a reference database search, whereby the unknown sequence is compared to those of known samples: a measure of the similarity between sequences is calculated, and the most similar species is attributed to the sample. The most commonly used reference databases for comparative species identification searches are the NCBI/EMBL/DDBJ database collaboration (www.insdc.org) and BOLD, part of the Consortium for the Barcoding of Life (CBOL, www.barcodinglife.com). For species that are well represented in such public databases, it is common to encounter a 100% sequence match between the unknown sample and its reference species. However, due to sequence variation within species, no exact match may be observed, resulting in a species identification based on, for example, a 98.5% match. Closely related species may have sequence similarities of 90 to 95% or higher. The total length of the sequence that is being matched also affects the confidence of identification. It is therefore left to the experience and judgement of the forensic scientist to evaluate the strength of evidence when undertaking a sequence similarity match.

2. **Individual Identification** – Helps link specific animals to crime scenes, similar to human forensic DNA fingerprinting. The use of DNA profiling for the individual identification of genetic evidence has revolutionised human forensic analysis over the past 20 years. In contrast, the identification of individual animals and plants has often been less relevant to the protection of endangered species. However, for certain issues such as poaching, where it may be necessary to demonstrate that a horn, tusk, bone or skin has originated from a specific individual, DNA profiling techniques can provide key

evidence to wildlife crime investigations. Other applications include the identification of stolen animals and the authentication of legally traded wildlife products. DNA profiling works by targeting genetic markers that are highly variable within species and are therefore likely to show differences among individuals. As with geographic origin identification, multiple microsatellite or SNP markers are used to create a profile that consists of a series of alleles. The greater the number of markers used, the less likely it is that another individual has the same series of alleles. This probability is affected by the number and variability of markers in the profile, how common the alleles are in the species (their frequency), and how closely related individuals are in the population where the samples were taken. Evaluating these factors requires a representative sample of DNA profiles from the population.

3. **Geographic Origin Tracing**—This method determines where an animal was poached, aiding in tracking illegal trade routes. Geographic origin identification is based on our ability to assign a sample to a particular population, requiring the source population to be sufficiently genetically distinct from other candidate populations and relying on the existence of population data from multiple areas. Despite these limitations, a wealth of existing academic and conservation management research focusing on population assignment is now being transferred to address the urgent need for enforcement techniques capable of identifying geographic origin. The methods employed are largely dictated by the degree of genetic differentiation between populations. Within some species, populations may be so isolated from one another that there is effectively no exchange of genetic material between them. Genetic differences will gradually accumulate over evolutionary time to a point where members of an isolated region share the same types of genetic markers (alleles) within their population, but exhibit different alleles from those of any other population. Markers that exhibit such discrete variation are very useful for identifying populations and, therefore, for assigning an individual to a geographic region with a high degree of confidence.

4. **Parentage Analysis** – Identifies breeding patterns and helps monitor captive breeding programs to prevent illegal laundering of wild animals into legal trade. The ability to verify or refute familial relatedness is the fourth principle application of wildlife DNA forensic techniques. Establishing levels of relatedness is important for many aspects of conservation genetics, but for forensic investigation, the focus lies primarily on the differentiation of captive-bred from wild-caught animals. Captive breeding programmes are now commonplace throughout the world and focus on either sustaining global populations of highly endangered species or the production of animals and plants of commercial value. Problems arise when the 2 drivers cross over, as they often do, and rare species become highly prized commodities with large profits to be made from their commercial trade. This situation may lead to unscrupulous ‘breeders’ laundering animals or plants taken from the wild and re-selling them as captive-bred individuals. Examples of current issues include the trade in parrots, birds of prey, tortoises and orchids.

5. **DNA Analysis** – The successful recovery of DNA from biological evidence is the most important stage in any forensic genetic investigation. The diversity of DNA sources available to human forensic scientists has been well publicised and includes soft body tissues, bones, teeth, hair, saliva, sweat, urine and faeces. The methods used to extract DNA from these sample types can often be transferred to other species; however, wildlife forensic geneticists may be faced with quite different sample types such as fish scales, feathers, fruits or processed timber. Conservation geneticists have developed techniques

for recovering DNA from a remarkable array of sample types (e.g. snake venom, moulted feathers, fish scales, porcupine quills, historic eggs), enabling genetic information to be recovered from almost any biological material. Sample types can be characterised in terms of the quantity of DNA initially present, its protection from environmental degradation and the ease with which purified DNA can be recovered. For example, hard materials such as bone, tooth, horn and ivory may contain relatively little DNA, which is difficult to extract, but which is preserved in the sample for many years.

12.2.2 Techniques Used in DNA Wildlife Forensics

i. **DNA Barcoding** – Species identification using DNA barcodes has been widely adopted by forensic scientists as an effective molecular tool for tracking adulterations in food and for analysing samples from alleged wildlife crime incidents. DNA barcoding is an approach that involves sequencing of short DNA sequences from standardised regions and comparison to a reference database as a molecular diagnostic tool in species identification. In recent years, remarkable progress has been made towards developing DNA metabarcoding strategies, which involve next-generation sequencing of DNA barcodes for the simultaneous detection of multiple species in complex samples. Metabarcoding strategies can be used in processed materials containing highly degraded DNA, e.g. for the identification of endangered and hazardous species in traditional medicine.

ii. **Microsatellite Analysis** – Microsatellite analysis has become a pivotal tool in various scientific fields, offering insights into genetic diversity and evolutionary relationships. These short, repeating sequences of DNA are highly polymorphic, making them ideal markers for studying genetic variation within populations. Their utility extends beyond basic research, with implications for practical applications.

iii. **Mitochondrial DNA (mtDNA) Analysis** –The analysis of mtDNA has become crucial in forensic investigations as it can recover evidence from burnt remains, ancient carcasses, or decayed wildlife. It is used in the Maternal Lineage. There are some limitations to using mitochondrial DNA for forensic purposes. A major limitation is that mitochondrial DNA provides limited information compared to nuclear DNA. For example, using mitochondrial DNA cannot provide much information about individuals, such as eye colour, hair colour, or any physical features.

iv. **Next-Generation Sequencing (NGS)** – Next-generation sequencing (NGS) technology, with its high-throughput capacity and low cost, has developed rapidly in recent years and has become an important analytical tool for many genomics researchers. New opportunities in the research domain of forensic studies emerge by harnessing the power of NGS technology, which can be applied to simultaneously analysing multiple loci of forensic interest in different genetic contexts, such as autosomes, mitochondrial and sex chromosomes. Furthermore, NGS technology can also have potential applications in many other aspects of research. These include DNA database construction, ancestry and phenotypic inference, monozygotic twin studies, body fluid and species identification, and forensic animal, plant and microbiological analyses.

12.2.3 Notable Cases & Impact

- DNA analysis has helped trace illegal ivory trade networks by linking elephant tusks to specific poaching hotspots in Africa.

- Rhino horn seizures have been traced back to their origins, aiding law enforcement in targeting poaching operations.
- DNA testing has identified illegally traded shark fins, turtle shells, and pangolin scales, strengthening conservation efforts.

12.2.4 Challenges faced in Wildlife Forensics:

DNA-based wildlife forensics is a game-changer for conservation, enabling stronger legal action against poachers and traffickers while helping to protect endangered species. Wildlife forensics faces several significant challenges, both technical and practical. Here's a breakdown of the major ones:

1. Species Identification Difficulties

- **Lack of reference databases**: Many species, especially lesser-known or endangered ones, don't have sufficient genetic data available for comparison.
- **Degraded samples**: Wildlife crimes often involve old, decayed, or processed biological material (like dried meat or powdered bone), which complicates DNA analysis.
- **Morphological similarity**: Some species look very similar (e.g., closely related birds or reptiles), making visual identification hard.

2. Limited Resources and Expertise

- **Shortage of trained personnel**: There’s a global shortage of specialists trained in wildlife forensics, especially in developing countries.
- **Underfunding**: Wildlife crime units often operate with limited budgets, affecting lab equipment, staff training, and casework capabilities.

3. Legal and Regulatory Barriers

- **Jurisdictional issues**: Wildlife crimes often cross borders, and laws vary widely between countries, complicating enforcement and cooperation.
- **Lack of standard protocols**: There is often no universal standard for collecting, analysing, and interpreting forensic evidence in wildlife cases.
- **Evidence admissibility**: Scientific evidence must meet legal standards, and sometimes forensic findings are challenged in court due to procedural flaws or unclear guidelines.

4. Technological and Methodological Gaps

- **Non-human DNA complexity**: Wildlife forensics must handle a broader range of species than human forensics, requiring diverse techniques and primers.
- **Insufficient development of markers**: For many species, reliable genetic markers for individualisation or population assignment are still lacking.

5. Chain of Custody and Crime Scene Management

- **Remote or dangerous locations**: Crime scenes are often in remote forests, oceans, or protected areas, making evidence collection and preservation tough.

- **Improper handling**: Poor collection methods can lead to contamination or degradation, weakening forensic analysis.

6. Rapid Evolution of Wildlife Crime

- **Sophisticated trafficking networks**: Poachers and smugglers use advanced tactics, including falsified documentation and hidden trade routes.
- **Online wildlife trade**: Illegal sales increasingly occur via social media and dark web platforms, making tracking and evidence collection harder.

12.3 GENETICALLY MODIFIED ORGANISMS (GMO'S)

Genetically Modified Organisms (GMOs) are organisms—plants, animals, or microorganisms—whose genetic material has been altered using genetic engineering techniques. This is done to introduce desirable traits such as resistance to pests, improved nutritional content, or increased crop yields. In some cases, the genes occurring are modified for the expression of desired characteristics in them.

Genetically Modified Organism (GMO), an organism whose genome has been engineered in the laboratory in order to favour the expression of desired physiological traits or the generation of desired biological products. Gene technology endows new properties to the organism by transferring genes from one organism to another or by making interference in the genetic structure. When the genetic structures of food-producing organisms are changed, they are referred to as genetically modified foods. Biotech companies have attempted to combine Herbicide Tolerance (HT) and Insect Resistance (IR) genes in a single crop. Monsanto and Dow Company have developed a variety of maize, or SmartStax, that expresses both qualities.

GM crops have developed maximally between 1997 and 1999 in the developed countries, which induced rapid growth of agriculture and chemical farms. Large-scale farmers, of the developed countries and the multinational companies, are maximally benefited as they own the intellectual property rights of these crops. Thus, it leads to privatisation of genetic resources to a certain sector of people who have started exerting control over the distribution of these crops to the poorer sectors of the developing countries.

12.3.1 Types of GMOs

1. **Genetically Modified Crops**

- **Bt Crops**: Contain genes from *Bacillus thuringiensis* (Bt), a bacterium that produces insecticidal proteins (e.g., Bt cotton, Bt corn). Field studies conducted in India in which Bt cotton was compared with non-Bt cotton demonstrated a 30–80 percent increase in yield from the GM crop. This increase was attributed to a marked improvement in the GM plants' ability to overcome bollworm infestation, which was otherwise common.
- **Herbicide-Tolerant Crops**: Engineered to withstand specific herbicides, allowing farmers to control weeds more efficiently (e.g., Roundup Ready soybeans). Herbicide-resistant crops (HRC) have been available since the mid-1980s; these crops enable effective chemical control of weeds, since only the HRC plants can survive in fields treated with the corresponding herbicide. Many HRCs are resistant to glyphosate (Roundup), enabling liberal application of the chemical, which is highly effective against weeds.

- **Drought-Resistant Crops**: Drought-resistant crops are genetically enhanced or selectively bred plant varieties that can survive and yield well under limited water conditions. These crops are especially important in regions experiencing frequent droughts due to climate change or water scarcity. Through biotechnology, scientists can introduce genes from drought-tolerant species into major food crops, improving their ability to maintain productivity with less water.

For example, transgenic crops like drought-tolerant maize (e.g., DroughtGard) or rice have been developed using gene editing and genetic engineering to enhance root depth, reduce water loss, and regulate stress-response genes such as DREB (Dehydration-Responsive Element Binding).

In addition to genetic modification, marker-assisted selection is also used in traditional breeding programs to develop drought-tolerant varieties without introducing foreign DNA. These crops not only help in stabilizing food production during dry spells but also promote sustainable agriculture by reducing the dependency on irrigation and conserving freshwater resources.

- **Golden rice:** GM crop is golden rice, which originally was intended for Asia and was genetically modified to produce almost 20 times the beta-carotene of previous varieties. Golden rice was created by modifying the rice genome to include a gene from the daffodil Narcissus pseudonarcissus that produces an enzyme known as phytoene synthase and a gene from the bacterium Erwinia uredovora that produces an enzyme called phytoene desaturase. The introduction of these genes enabled beta-carotene, which is converted to vitamin A in the human liver, to accumulate in the rice endosperm—the edible part of the rice plant—thereby increasing the amount of beta-carotene available for vitamin A synthesis in the body.

2. **Genetically Modified Animals**

- **AquaBounty Salmon**: AquaBounty Salmon is the world's first genetically modified (GM) animal approved for human consumption. Developed by AquaBounty Technologies, this Atlantic salmon has been genetically engineered to grow faster than conventional salmon, reaching market size in about half the time (approximately 18 months instead of 36).
- **Disease-Resistant Livestock**: Pigs resistant to Porcine Reproductive and Respiratory Syndrome (PRRS). Genetically Modified (GM) Pigs are pigs whose DNA has been altered using genetic engineering techniques to enhance certain traits, benefit human health, or serve specific scientific or medical purposes. These modifications can involve inserting, deleting, or editing genes for various outcomes.
- **GloFish:** GloFish are genetically modified fluorescent fish developed primarily for ornamental purposes. They were the first genetically engineered animals to be sold as pets and are popular in the aquarium trade due to their bright, glowing colours. The fluorescence is achieved by inserting genes from naturally bioluminescent organisms, such as jellyfish or coral, into the DNA of regular fish species like zebrafish, tetras, or barbs.

3. **Genetically Engineered Microorganisms**

- **GM E. coli:** One of the first and most revolutionary uses of GM E. coli was the production of recombinant human insulin. GM E. coli is used to manufacture other important medical substances such as Human growth hormone (HGH), Erythropoietin (EPO), which stimulates red blood cell production and Interferons, used in antiviral and cancer therapies.

- **Genetically Modified (GM) Yeast:** Yeast strains whose DNA has been altered using genetic engineering techniques to enhance their natural abilities or introduce new functions. Yeast, especially *Saccharomyces cerevisiae* (baker's yeast), is widely used in **biotechnology, medicine, food processing, and industry** due to its safety, ease of cultivation, and well-understood genetics.

12.3.2 Benefits of GMOs

GM crops are of superior variety and are high-yielding, which caters sufficiently to the rising global population. These crops can be grown in smaller land fragments; hence, less forest land is required to be cleared. According to the UN projection, the world population will reach 8.15 billion, so GM crops are a better option for food to mitigate the global food crisis. Scientists claim that they are nutritionally superior, endowed with rich vitamins and minerals, with better flavour and taste. According to some, GMOs could reduce allergens from foods. GMO plants are resistant to pests, weeds and infectious diseases and require lower use of herbicides or pesticides. These crops can be grown in an eco-friendly manner that might slow down global warming. Moreover, farming will be cost-effective and is supposed to be affordable to poor or resource-limited farmers. As food prices will be low, modified crops can effectively fight poverty and mitigate the problem of undernourishment. Several varieties of engineered crops and vegetables are nutritious and disease-resistant. Some have a longer shelf life, hence, suitable for international trade and transport. GMO crops are safe as they are strictly tested before marketing, conforming to the complete international standards.

Some GM plants can produce active ingredients for new medicines and give rise to superior foods. These are cheap, grow fast and are highly nutritious. Besides humans, livestock and animals also benefited from these highly nutritious foods.

Modified crops are often tolerant of environmental extremes. A strain of tomato has been developed that tolerates high soil salinity. Thus, they can survive in poor soil and adverse climatic conditions. Hence, farming becomes less labour-intensive with reduced energy inputs and low machinery requirements. For example, decaffeinated coffee beans can also be grown naturally by gene transfer technology. As more crops are grown, global warming is likely to decrease from the increased release of oxygen. We can have enhanced smell and taste with an increased size of the crop in a short period as their maturation time is shorter. So, early harvesting is also possible hence, multiple cropping can be done in a year. GMO foods have a longer shelf life, resulting in shorter factory processing, where the use of fewer chemical additives is required. Further, eco-friendly bioherbicide and bioinsecticide plants can be produced through genetic engineering.

12.4. CONCERNS AND CONTROVERSIES

GMOs can be potentially harmful to human and animal health, have serious consequences on all exposed living organisms and pose unforeseen environmental hazards. Food manipulation has its own deleterious effects, both on human health and biotic communities. New strains of allergens may develop in these crops that are difficult to detect. Introduction of novel proteins synthesised by recombinant DNA technology in humans can lead to unpredictable and unforeseen problems.

Development and use of transgenic crops has raised several biological, ethical and environmental issues and spurred up controversy, of which safety is the most important one. At the initial stage, adverse effects on health and the environment are to be thoroughly screened and tested. Although some organisations like 'Greenpeace' and 'World Wildlife Fund' claim that the modified crops are not adequately tested and labelled. GMOs need to be adequately labelled with detailed information to address the need and preserve the choice of consumers. Growing GMO crops is particularly beneficial to private companies, who own the patents for the products, depriving the small-scale farmers of third-world countries. Royalties for these crops paid to these companies would increase international debt, intensifying social and economic problems.

There has always been a risk of uncertainty associated with GMO crops, as they can induce allergies in consumers. Moreover, altering the genetic structure of an organism may render the species unstable in future. Ethically, man does not have the right to alter or manipulate the genetic structure of an organism, as all living beings on earth have their own intrinsic value. This also works against natural speciation and evolution.

12.4.1 Genetically Modified Crops: Ethical Issues

GM crops can mitigate the world food crisis. Proper utilisation of GMOs could only happen if distributed to the poverty-stricken people of the world to provide them with sufficient food and medicine. This can only be possible through a proper market-based economy. The technology involved in creating GMOs is potentially invaluable for the evolution of cultivars. Devastating effects can result from improper application of this technology. A governmental organisation establishing the safety of GMO crop strains will provide better security. Changes in the law will protect farmers in choosing to avoid GM crops by clearly outlining the legal responsibility of farmers growing GMOs.

There should be an objective for the assessment of genetically modified organisms in order to minimise the risks associated with them. Every nation should strictly abide by its biotechnology policy that relates to biodiversity and biosecurity. International trials or testing centres of GMO should strictly follow national laws and regulations.

12.5 SUMMARY

Biodiversity refers to the variety of life at the genetic, species, and ecosystem levels, while biotechnology involves the use of living organisms or biological systems to develop products and technologies for human benefit. The integration of these fields has led to significant advances in areas such as agriculture, medicine, environmental management, and conservation.

Biotechnology helps in conserving biodiversity through techniques like tissue culture, cryopreservation, DNA barcoding, and molecular markers, which aid in identifying, preserving, and restoring endangered species and genetic diversity. It also facilitates the development of genetically modified (GM) crops that are more resistant to pests, diseases, and environmental stress, reducing the need for chemical inputs and preserving agro-biodiversity.

In the pharmaceutical industry, biotechnology explores the biochemical potential of biodiversity for discovering new drugs, antibiotics, and therapeutic compounds, especially

from microbes, plants, and marine organisms. Bioprospecting—the systematic search for valuable genetic and biochemical resources—is a growing area connecting biodiversity with biotech innovation.

However, ethical issues like biopiracy and intellectual property rights (IPR) must be addressed to ensure fair sharing of benefits, particularly with indigenous communities. The Convention on Biological Diversity (CBD) and the Nagoya Protocol play key roles in regulating access to genetic resources and ensuring equitable benefit-sharing.

Thus, biotechnology serves as both a tool for exploiting and conserving biodiversity, making responsible, sustainable innovation critical in the biodiversity-biotech interface.

12.6 TECHNICAL TERMS

Bioprospecting, Biopiracy, Tissue Culture, PCR (Polymerase Chain Reaction), Genetic Barcoding, Transgenic Organism, Herbicide Tolerance, Gene Editing (CRISPR-Cas9).

12.7 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. What is the role of biotechnology in biodiversity conservation?
2. Explain the concept of genetically modified organisms and their applications in agriculture.?
3. Describe the techniques and importance of DNA-based wildlife forensics.

Short Notes:

1. What is cryopreservation? Describe the process and advantages.?
2. Describe the use of PCR in wildlife forensics.?
3. Define bioprospecting and biopiracy

12.8 SUGGESTED READINGS

1. "Biodiversity and Conservation" by M.P. Arora
- Covers fundamentals of biodiversity, threats, conservation strategies, and management.
2. "Principles of Biotechnology" by A. K. Sharma
- A comprehensive introduction to core biotechnology techniques and applications.
3. "Molecular Biology and Biotechnology" by John M. Walker and Ralph Rapley
- Offers insight into molecular tools used in biotechnology and their role in biodiversity research.
4. "Textbook of Environmental Studies" by Erach Bharucha (UGC-recommended)
- Includes chapters on biodiversity, GMOs, conservation strategies, and biotechnology applications.
5. "Biotechnology and Biodiversity: Scientific and Ethical Perspectives" by B. A. Lustig
- Explores ethical, legal, and scientific connections between biotechnology and biodiversity.

Prof. P. V. Krishna

LESSON-13
BIOREMEDIATION

AIM AND OBJECTIVES

- Understanding the bio-remediations and its significance.
- Explore different types of bio-remediation
- To gain knowledge of applications of bioremediation.

STRUCTURE

13.1 INTRODUCTION

This is the process that uses green plants and consortia of microorganisms (fungi, algae, bacteria) or their enzymes to break down relatively non-degradable pollutants, rendering them safe in the environment. Bioremediation with green plants is often referred to as green-clean or phytoremediation, whereas those with fungi are known as myco-remediation. Bioremediation uses natural or recombinant microorganisms to break down toxic and hazardous substances accumulated in the environment. Biotreatment is a broader term that refers to all biological treatment processes, including bioremediation. Biotreatment can be used to detoxify wastewater before its disposal. This approach involves careful selection of organisms, known as biocatalysts, which release enzymes to degrade specific toxicants and accelerate the degradation process. Bioremediation takes place in two steps:

- **Bio stimulation:** This is the process by which oxygen and nutrients in liquid or gaseous form are added to the contaminated water or soil to enhance the growth of indigenous microbes.

- **Bioaugmentation:** This includes the addition of specific microorganisms (either naturally occurring or genetically engineered) to the contaminated site for effective breakdown of pollutants.

- Persistent contaminants like hydrocarbons of petroleum products, Polychlorinated Biphenyl (PCB), Polyaromatic Hydrocarbons (PAH), metals, radio nucleotides and pharmaceuticals that pollute soil and ground water, can be effectively degraded by specific microorganisms. However, chlorinated organic aromatic hydrocarbons are even resistant to microbial attack. Oil spills, sewage waste, industrial waste and agricultural wastes containing persistent chemicals like molinate, thiobencarb, carbofuran, methyl parathion, and atrazine that travel along the food chain and bioaccumulate at the trophic level can be degraded by microbes. Bioremediation is effective in removing these pollutants with minimum environmental impact. The existence of microbial population, availability of contaminants to the microbes, the presence of oxygen, electron acceptors and nutrients, or other environmental factors like the type of soil, water, temperature, and pH largely influence the process of bioremediation.

- Diverse catabolic activities of microbes transform chemical pollutants, amino acids and toxic drugs into simpler forms that are taken up as nutrients, and biotransformation takes place by oxidation, reduction and alkylation. Bacteria can precipitate dissolved organic pollutants, remove free-swimming bacteria and precipitate metals in aqueous solution. This process of breakdown and biotransformation of pollutants leads to an increase of microbial biomass with the liberation of carbon dioxide and water. Sometimes, pollutants are even modified into mineral compounds by the process of biomineralisation. Aerobic bacteria like *Pseudomonas, Alcaligenes, Sphingomonas, Rhodococcus,* and *Mycobacterium* degrade pesticides, alkalis, polyaromatic hydrocarbon compounds, and remove metals. Anaerobic bacteria degrade polychlorinated biphenyl in the absence of O_2. Parathion is degraded by P. aeruginosa and P. stutzeri. Pseudomonas breaks down a wide range of persistent pollutants, including hydrocarbons, polychlorinated PCB, phenolics, polycyclic aromatics, radioactive uranium, naphthalene and organophosphates. Alcaligenes degrade benzene, PCB and polycyclic aromatic compounds. Arthrobacter are used for the degradation of hydrocarbons and polycyclic aromatic compounds, while Nocardia attack polycyclic aromatic compounds and hydrocarbons. Bacterial plasmids degrade surfactants.

- Microbial degradation may occur in two phases: initially in the absence of oxygen, and then aerobic breakdown of compounds takes place. It has been observed that aliphatic compounds (saturated and unsaturated) are easily degraded than the aromatic ones. Increased branching, polymerisation, presence of polycyclic and heterocyclic residues, halogen, nitrogen and sulfonate substitutions make a compound more stable. However, unsaturated compounds are broken down by anaerobes.

13.2 IMPORTANCE OF BIOREMEDIATION

Bioremediation is a natural process utilising specific microbes for the degradation of relatively non-degradable pollutants. The wide variety of naturally occurring microbes utilise organic waste for metabolism, where the compounds are broken down into simpler, non-toxic substances such as carbon dioxide, water, ammonia, methane and hydrogen sulphide. This process is referred to as mineralisation. Biotransformation occurs when the compound is not fully broken down.

EPA recognises this process that brings down high levels of pollutants to environmentally safe levels. Microbes occur naturally in soil and water as part of the food chain that helps in the degradation of pollutants. This natural, passive, invasive and cost-effective process requires neither elaborate mechanical help nor labourers. The bioremediation process involves both the removal and subsequent bio-recovery of metals from the environment, which can be recycled for any industrial use. The method is thus economic and eco-friendly, and does not require digging up soil and water with the help of elaborate types of equipment. It eliminates pollutants for sustainable development, with low environmental impacts.

13.3 IN-SITU BIOREMEDIATION

In-situ bioremediation is the on-site treatment of contaminated soil and groundwater that employs the following processes:

- **Bio inventing:** This process involves supplying air and nutrients through wells to soil or groundwater contaminants for stimulating the growth of indigenous bacteria.
- **Bio-sparing:** The technology deals with an injection of air under pressure below the water table to provide excess O_2 for indigenous bacterial growth. The process increases the surface of contact between microbes with soil and groundwater, enhancing the rate of degradation.
- **Bioaugmentation:** In this process of in situ bioremediation, the addition of natural or exogenous microorganisms are made for enhancing the degradation of pollutants.

13.3.1 Advantage of in-situ bioremediation

In-situ bioremediation is non-invasive, passive and a natural process for degradation of relatively persistent contaminants. So, it is a cost-effective system requiring only basic agricultural types of equipment. It hardly requires excavation of soil and can be used for the treatment of both soil and groundwater.

13.3.2 Disadvantages of in-situ bioremediation

The process is relatively long and time-consuming. Sometimes, complete removal of toxicants may not be possible, and the end products might be more toxic.

13.4 EX-SITU BIOREMEDIATION

Ex-situ bioremediation involves off-site treatment of excavated soil, and the process is relatively time-consuming. The following are the various methods of ex-situ bioremediation:

- **Land farming**: It is a process of excavation and spreading over contaminated soil on a prepared bed containing the desired microbes. The soil is filtered from time to time. Aeration is done by regular turning of soil with occasional addition of fertilizers. This process is effective in volatilizing organic chemicals in large isolated sites. Composting: This is a process of combining pollutant laden soil with manure and agricultural wastes that support extensive microbial growth in aerobic condition at an elevated temperature. Composting or humus formation involves the use of decomposed plants and animals, and is widely used in agriculture, gardening, soil structure improvement and treatment of contaminated soil.
- **Bio-piles:** These are basically a combination of land farming and composting, generally used for treatment of soil surface with high hydrocarbons from petroleum products. The

process is performed by heaping of contaminated soils in impermeable containers and stimulating microbial activities in pressure of O_2 by pumping in air.

- **Bioreactors:** For bioremediation, slurry bioreactors or aqueous reactors are used to pump up plumes of solid soil material (sludge, sediment) or water which are then passed through an engineered contaminated system. The rate of remediation proceeds relatively faster and is more manageable and predictable.
- **Bio-stimulation:** In this process, nutrients and oxygen in liquid or gaseous forms are added to contaminated water or soil to encourage the growth and activity of microbes.
- **Bioaugmentation:** In this process, microorganisms are added to the contaminated soil or water, so they can clean up the toxicants.
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13.4.1 Advantages of ex-situ bioremediation

Ex-situ bioremediation is a relatively passive and naturally attenuated process that treats both soil and water. The process is cost-effective and non-toxic in nature. However, it requires a longer time, depending on several environmental constraints and is also difficult to monitor.

13.5 TYPES OF FORMS OF BIOREMEDIATION

13.5.1 Mycoremediation

Mycoremediation involves the use of fungi and fungal mycelia to degrade various types of environmental pollutants. The term was first coined by Paul Stamets.

Fungal mycelia secrete enzymes and acids that target specific pollutants of soil and also break down lignin and cellulose of plants that are otherwise non-degradable. Nerve gas (sam VX and sarin), diesel oil (PAH) can be degraded by oyster mushrooms (especially wood-degrading fungi). Ligninolytic (*Phanaerochyte*) white rot fungi break down polyaromatic hydrocarbons, DDT and penta-chlorophenol fungicide by secreting lignase, while *Chrysosporium* (white rot fungi) breaks down a wide range of other pollutants. Some of them secrete oxalic acid that helps in the precipitation of metal oxalate crystals, hence, can be suitably used in waste biotreatment. Fungi, *Actimomycetes* are commonly employed for mycoremediation. Fungi also take up radionucleotides from contaminated soil. Methylotrophs use methane as a source of energy, hence degrade chlorinated compounds. Fungi like *Aspergillus, Penicillium, Rhizopus, Mucor* and *Neurospora* can remove phenolics and heavy metals from polluted sites. Moreover, common mushrooms, such as *Pleurotus, Agaricus* and *Volvariella,* are removers of uranium, thorium. *Aspergillus fumigatus* is used as a deterrent and propelled for minimising ballistic performance. Mycorrhizal fungi depend on host plants for carbon and also help plants to absorb soil nutrients and water with greater efficiency, while plants provide rich organic nutrients to the fungi. *Gliocladium virens,* a saprophytic soil fungus, decolourises paper and pulp mill effluents.

Mycofiltration is a process of filtering toxic waste and microorganisms from water and soil with the help of fungal mycelia. This is a low-cost process for the treatment of oil spills, removing hydrocarbons or chlorinated solvents in contaminated groundwater. Toxic tannins that commonly occur in tannery effluents are completely broken down *by Aspergillus, Penicillium, Fusarium* and a species of edible fungus, *Calvatia*. *Saccharomyces cerevisiae* and *Sporobolomyces salmoni* even remove radioactive uranium and cobalt. Fungus takes up radionucleotides, preventing toxic buildup in plants. Fungi *Pleurotous eryngii,* take up caesium, while *Hebeloma cylindrosporum* absorbs excess cobalt.

13.5.2 Phytoremediation

According to McCutcheon et al. (2003), "phytoremediation is the process that uses vascular plants, algae, and fungi either to remove and control wastes or to spur waste breakdown by microorganisms in the rhizosphere."

It also involves the use of selected green or engineered plants for removal and degradation of contaminants from soil, air, water and sediments. It is a phytotechnology that includes biochemical and physical processes by which plants clean up environmental pollutants.

The process is highly effective in cleaning pesticides, metalloids, metals, toxic gas, chlorinated solvents, explosives and oil from soil, and pollutants from ground water. It is used to remove, transfer, stabilize or destroy toxic outputs in the environment. Plants may additionally help to maintain ecological balance, conserve biodiversity, maintain hydrological control and prevent spreading of pollutants by wind, rain, groundwater to the unpolluted sites. It is restoration of the quality of environment 'Green Clean Technology' by plants. However, the method is most useful in low to medium range of pollutants (PAH, PCB, Petrol HC and pentachlorophenol). As roots take up water and nutrients for their vital activities, they tend to take up metals, chemicals and organic pollutants that are either stored in roots, stems and leaves or transformed into simpler harmless forms within the plant itself. Sometimes, pollutants are converted into gaseous form that are soon released with transpiration. On the other hand, chemicals may be either absorbed on to the roots or microbially transformed into simpler forms. The process is effective for both in-situ or ex-situ remediation of soils, sludge, sediments, or groundwater.

a. **Phytoextraction (Phytoaccumulation):** This is the uptake of metals by plant roots and their subsequent translocation to other parts for storage. Thus, pollutants are effectively removed from the contaminated sites. Depending on the type of pollutant present, one or more specific accumulator plants are allowed to grow. After a given period of time plants are harvested during which a large share of pollutants are also removed. "This process is repeated several times for rendering the site free of metals.

b. **Rhizo-filtration:** This is a process of metal removal from contaminated water where the pollutants are either adsorbed or absorbed by the roots. Generally, some specific plants are grown in the greenhouse under water. For remediation to occur, the clean water is replaced by contaminated water. This method re-stabilises the plant community in polluted landscapes, prevents the leaking of soil pollutants and promotes recycling of metals for industrial use. This system also removes metals in wetlands and estuarine systems.

c. Phyto-stabilisation: Some plants tend to immobilise pollutants by accumulating or preening pollutants within their root zone. This prevents seeping or spreading of pollutants to groundwater or to the surrounding soil. The process is effective in stabilising vegetation cover, preventing of soil erosion, and also remedial for metal pollution.

d. Phytodegradation (Phyto-transformation): Organic pollutants from soil and water are degraded metabolically by plants or enzymatically by microbes. These pollutants are broken down, transformed and finally taken up by plants as nutrients. This process reduces soil and groundwater pollution and enhances micro-degradation in the rhizosphere.

e. **Rhizo-degradation:** Recalcitrant organic pollutants like PCB and PAH are degraded by microorganisms that remain symbiotically associated with plant roots and release enzymes for degradation.

f. **Phytovolatilization:** This is a process where organic contaminants, taken up by plants, are volatilized or transformed into gaseous forms and released through leaves. These occur mostly in growing plants and trees.

g. **Hydraulic control or plume control:** Some plants take up a large amount of water (300 gallons) for transpiration, thus acting as a hydraulic pump. This helps to control the dispersal of contaminated water and leaching in the surrounding soil.

13.6 APPLICATIONS OF BIOREMEDIATION

Bioremediation is widely used to clean up pollutants from various environments, including soil, water, and air. Below are some of its key applications:

13.6.1 Key Applications

1. Oil Spill Cleanup

- **Application:** Microbes break down hydrocarbons in oil spills.
- **Example:** *Alcanivorax borkumensis* bacteria were used to clean up the Deepwater Horizon oil spill (2010).
- **Method:** Bioaugmentation (adding oil-degrading bacteria) or Bio stimulation (enhancing native microbes with nutrients like nitrogen and phosphorus).

2. Heavy Metal Removal from Soil & Water

- **Application:** Plants and bacteria absorb or transform toxic metals like lead (Pb), mercury (Hg), and arsenic (As).
- **Example:** Indian mustard (*Brassica juncea*) is used to absorb heavy metals from polluted soil (Phytoremediation).
- **Method: Phytoremediation** (using plants to absorb metals).
- **Microbial bioremediation** (bacteria convert toxic metals into less harmful forms).

3. Industrial Waste Cleanup

- **Application:** Bacteria and fungi degrade toxic chemicals from industrial sites.
- **Example:** *Pseudomonas putida* is used to break down solvents, pesticides, and petroleum-based contaminants.
- **Method:** Bioaugmentation (introducing specialized microbes to break down specific pollutants).

4. Plastic Degradation

- **Application:** Microbes break down synthetic plastics into biodegradable compounds.
- **Example:** *Ideonella sakaiensis* bacteria can digest PET plastic (used in bottles and packaging).

- **Method:** Enzymatic degradation (using microbes to produce enzymes that break down plastics).

5. Wastewater Treatment

- **Application:** Bacteria remove organic waste, heavy metals, and toxins from sewage and industrial effluents.
- **Example:** *Bacillus* and *Pseudomonas* species break down organic matter in sewage treatment plants.
- **Method:** Bio stimulation (adding oxygen and nutrients to enhance microbial activity).

6. Pesticide and Herbicide Degradation

- **Application:** Microbes break down toxic pesticides like DDT, atrazine, and glyphosate.
- **Example:** *Arthrobacter* bacteria degrade herbicides in agricultural soils.
- **Method:** Bioaugmentation (adding pesticide-degrading bacteria to contaminated sites).

7. Cleaning Up Radioactive Waste

- **Application:** Certain bacteria and fungi absorb or transform radioactive materials.
- **Example:** *Deinococcus radiodurans* can survive high radiation and help in nuclear waste cleanup.
- **Method:** Microbial bioremediation (using bacteria that bind and neutralize radioactive particles).

13.6.2 Future Potential of Bioremediation

- ➢ **Microbial Engineering** – Scientists are developing genetically modified bacteria to enhance bioremediation.
- ➢ **Enzyme-Based Bioremediation** – Using isolated enzymes from microbes for faster pollutant breakdown.
- ➢ **Nanotechnology & Bioremediation** – Combining nanomaterials with microbes to improve pollutant removal efficiency.

13.7 SUMMARY

Bioremediation is a biological process that uses living organisms—primarily microorganisms, fungi, and plants—to degrade, detoxify, or remove environmental pollutants from soil, water, or air. It is considered a natural, eco-friendly, and cost-effective approach to clean up contaminants like oil spills, heavy metals, pesticides, and industrial waste. Bioremediation can be classified into two major types: in-situ, where the treatment occurs at the contamination site (e.g., bioventing, biosparging, phytoremediation), and ex-situ, where the contaminated material is excavated and treated elsewhere (e.g., bioreactors, composting, land farming). Specific techniques such as bioaugmentation (adding specialized microbes), biostimulation (enhancing conditions to support native microbes), and mycoremediation (using fungi) further enhance the efficiency of bioremediation.

Despite its many advantages—like being cost-effective, less disruptive, and environmentally safe—bioremediation may be slower and less effective in extreme or highly toxic

environments. However, with proper monitoring and supportive conditions, it holds great promise as a sustainable method of pollution control and ecosystem restoration.

13.8 TECHNICAL TERMS

Bioaugmentation, Mycoremediation, Bioventing, Bioreactor, Peroxidase Enzymes, Xenobiotics

13.9 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. Explain the different types of bioremediation with suitable examples.?
2. What are the environmental and economic benefits of using bioremediation over chemical treatment methods?
3. Compare and contrast in-situ and ex-situ bioremediation techniques.

Short notes:

1. What is mycoremediation?
2. Define phytoremediation with an example.?

13.10 SUGGESTED READINGS

1. "Environmental Microbiology" by Maier, Pepper & Gerba
2. "Bioremediation: Principles and Applications" by Ronald L. Crawford and Don L. Crawford.
3. "Introduction to Environmental Biotechnology" by A.K. Chatterjee
4. "Environmental Biotechnology: Principles and Applications" by Bruce E. Rittmann and Perry L. McCarty
5. "Biotechnology for Waste and Wastewater Treatment" by Nicholas P. Cheremisinoff

Prof. P. V. Krishna

LESSON-14
MOLECULAR TAXONOMY

AIM AND OBJECTIVES

- Understanding the concept of Molecular Taxonomy
- To gain knowledge of DNA fingerprinting
- Understanding the applications of DNA fingerprinting

STRUCTURE

14.1 INTRODUCTION

Taxonomists generally face an array of problems that can be resolved because of variations on four basic themes. These are (i) determination of the identity of specimens of known species; (ii) discovery of new species, (iii) delimitation of species boundaries, and (iv) phylogenetic reconstruction. Molecular methods are helpful in resolving each of these problems.

With the development of Molecular Biology and the PCR technique, a new tool has been developed in taxonomic studies, especially for phylogenetic analysis. This new discipline is known as molecular taxonomy. The purpose of molecular taxonomy is to establish similarities and dissimilarities between genomes of organisms that help in developing an understanding of the taxonomic relationship among them. Traditional taxonomic methods use the phenotype as the basis of phylogeny. The advantage of the molecular method is it uses the genotypes that can be read directly. Further, organisms can be compared even if they are morphologically different. Closely related organisms have similar molecular structures (DNA, RNA and protein), on the basis of these molecules, molecular clocks may be constructed where the molecule accumulates mutations at a constant rate and diverges from the ancient one.

Diverse molecular methods have been used in taxonomy:

i. **Dominant method:** DNA sequencing involves sequencing of known regions of DNA that are sufficiently conserved to allow the use of 'universal primers', which at the same time have a sufficiently rapid mutation rate.

ii. **Mitochondrial DNA**: This is widely used to identify species and to trace the genealogical histories of populations. Recent emphasis on mt DNA-based identification as DNA barcoding methods helps in the identification of biodiversity at the species level.

iii. **DNA fingerprinting:** It assumes the VNTR or Variable Number of Tandem Repeats in DNA. It is more widely used in determining a child's paternity and reveals new facets in criminal forensics.

14.1.1 Advantages in Molecular Taxonomy

1. **High Accuracy in Species Identification:** Molecular taxonomy allows scientists to identify organisms with a high degree of precision by analyzing genetic material. Unlike traditional methods that rely on observable traits (which can vary due to age, environment, or sex), DNA sequences remain consistent and provide a reliable basis for classification. This is particularly valuable for identifying species that look very similar (cryptic species) or exhibit high morphological variability.

2. **Identification at Any Life Stage:** One of the most powerful advantages of molecular taxonomy is that it can be used to identify organisms at any stage of their life cycle—egg, larva, juvenile, or adult. This is especially useful in fields like entomology, parasitology, or marine biology, where immature forms of organisms are difficult or impossible to identify using morphological features.

3. **Detection of Cryptic and New Species:** Molecular tools can uncover cryptic species—organisms that are genetically distinct but appear nearly identical morphologically. This has led to the discovery of numerous new species across various taxa. It enhances biodiversity documentation, particularly in complex ecosystems like rainforests and coral reefs, where visual identification is challenging.

4. **Clarification of Evolutionary Relationships:** By comparing DNA or protein sequences, scientists can construct accurate phylogenetic trees that reflect true evolutionary relationships. Molecular taxonomy resolves ambiguities in traditional classification systems and can correct misclassifications based on outdated or misleading morphological data.

5. **Rapid and Scalable:** With the advancement of DNA sequencing technologies, molecular identification has become faster and more cost-effective. Techniques such as DNA barcoding and high-throughput sequencing allow for the analysis of thousands of samples simultaneously, which is highly beneficial for large-scale biodiversity assessments, environmental monitoring, or invasive species detection.

6. **Independence from Environmental Influence:** Morphological traits can be influenced by environmental conditions (phenotypic plasticity), making identification unreliable in some cases. Molecular taxonomy bypasses this limitation, as DNA remains unaffected by external environmental factors, ensuring consistency and objectivity.

7. **Supports Conservation Efforts:** Molecular data help identify genetically distinct populations and endangered species, allowing for targeted conservation strategies. It also aids in tracking the genetic health of populations and detecting hybridization or inbreeding, all of which are important for preserving biodiversity.

14.1.2 Limitation of Molecular Approach

One of the immediate constrain is how to store all the tissue samples and DNA extracts that have emerged in the course of molecular study. The second problem for the molecular method is how to achieve comprehensive sampling.? Thirdly, the cost involved in processing the samples is huge. Lastly, molecular systematics is largely based on a cladistic approach that corresponds to phylogenetic descent. Therefore, valid taxa must be monophyletic.

14.2 KEY FEATURES OF MOLECULAR TAXONOMY

1. **DNA Sequencing**: By comparing specific gene sequences (like mitochondrial COI or ribosomal RNA), scientists can determine evolutionary relationships between organisms.
2. **Molecular Markers**: These include microsatellites, RAPD, AFLP, and SNPs used to differentiate between closely related species or populations.
3. **Barcoding of Life**: A standardized DNA region (such as the COI gene in animals) is used as a “barcode” to identify species, especially useful in biodiversity studies and cryptic species identification.
4. **Phylogenetic Analysis**: Molecular data are used to construct phylogenetic trees, helping to infer evolutionary history and relatedness among species.
5. **Applications**: Used in systematics, conservation biology, environmental monitoring, agriculture, epidemiology, and forensic science.

14.3 DNA FINGERPRINTING

DNA fingerprinting, also known as DNA profiling, is a powerful technique used to identify individuals based on their unique genetic makeup. It has widespread applications in forensic science, paternity testing, criminal investigations, wildlife conservation, and medical diagnostics. The process begins with DNA sample collection from sources such as blood, saliva, hair, or skin cells. The extracted DNA is then amplified using Polymerase Chain Reaction (PCR) if needed, followed by cutting the DNA into fragments using restriction enzymes. These fragments are separated through gel electrophoresis, producing a distinct banding pattern—an individual’s unique "DNA fingerprint."

In forensic science, DNA fingerprinting plays a crucial role in crime scene investigations, helping to match biological evidence to suspects and exonerate wrongfully accused individuals. It is also essential in paternity and maternity testing, confirming biological relationships by comparing DNA patterns. Wildlife conservationists use this technique to track illegal poaching and the trade of endangered species, such as elephant ivory and rhino horn. Additionally, DNA profiling aids in diagnosing genetic disorders by identifying disease-related mutations and is instrumental in identifying victims of disasters or unclaimed bodies.

One of the major advantages of DNA fingerprinting is its high accuracy, as no two individuals (except identical twins) share the same DNA pattern. It also works with minimal biological samples, making it a reliable forensic tool. However, challenges such as privacy concerns, contamination risks, and ethical debates over government DNA databases persist. With advancements like Next-Generation Sequencing (NGS), DNA fingerprinting is becoming even faster and more precise, paving the way for personalised medicine and improved forensic investigations. Despite ethical concerns, DNA fingerprinting remains one of the most revolutionary scientific breakthroughs, transforming various fields and ensuring justice, security, and better healthcare.

14.3.1 How DNA Fingerprinting Works

DNA fingerprinting is a multi-step process that involves extracting, analysing, and comparing DNA to establish a unique genetic identity. The method relies on analysing specific regions of DNA that vary between individuals, making it an effective tool for identification. Below is a step-by-step explanation of how DNA fingerprinting works:

1. DNA Sample Collection:

The first step involves collecting a DNA sample from biological materials such as blood, saliva, hair, skin cells, semen, bones, or even old tissues from crime scenes or archaeological remains. In forensic investigations, DNA can be extracted from objects like cigarette butts, toothbrushes, or clothing with biological traces.

2. DNA Extraction:

Once a sample is collected, DNA is extracted from the cells. This is done by breaking open the cells (lysis) using chemical solutions or enzymes, which release the DNA. The extracted DNA is then purified to remove unwanted cellular components such as proteins and lipids.

3. DNA Amplification (PCR - Polymerase Chain Reaction):

If the sample contains only a small amount of DNA, it is amplified using the **Polymerase Chain Reaction (PCR)**. PCR is a technique that creates millions of copies of specific DNA segments, making even tiny samples sufficient for analysis. This is especially useful in forensic cases where the DNA evidence is minimal or degraded.

4. Cutting DNA with Restriction Enzymes (RFLP Method - Restriction Fragment Length Polymorphism):

In earlier DNA fingerprinting techniques, **restriction enzymes** were used to cut the DNA at specific sequences. This process created different-sized DNA fragments unique to each person. However, this method is slow and requires large amounts of DNA, so it has largely been replaced by newer techniques.

5. STR Analysis (Short Tandem Repeats) – The Modern Approach:

Modern DNA fingerprinting relies on **Short Tandem Repeats (STRs)** instead of RFLP. STRs are short sequences of DNA (2-6 base pairs long) that are repeated multiple times in specific regions of the genome. The number of repeats varies between individuals, making them useful for identification. By analysing 13-20 STR markers, forensic scientists can create a unique genetic profile with high accuracy.

6. Gel Electrophoresis & DNA Banding Pattern:

Once the DNA fragments are prepared, they are separated using **gel electrophoresis**. In this process, DNA fragments are placed in a gel and an electric current is applied. Since DNA is negatively charged, it moves towards the positive electrode. Smaller fragments move faster, while larger ones move more slowly, creating a distinct pattern of DNA bands.

Alternatively, **Capillary Electrophoresis (CE)** is used in modern labs for faster and more precise separation of STR markers. The final result is a visual representation of DNA fragments, which form an individual's unique DNA fingerprint.

7. DNA Matching & Interpretation:

The obtained DNA fingerprint is compared with reference samples. In forensic investigations, the DNA profile from crime scene evidence is compared with that of a suspect. In paternity testing, the child's DNA pattern is compared with that of the alleged parents. If the DNA bands match, it confirms a biological relationship or identity with high accuracy.

8. DNA Databases & Automated Analysis:

Forensic agencies use large DNA databases like **CODIS (Combined DNA Index System)** in the U.S. to store and compare DNA profiles from crime scenes, criminals, and missing persons. AI and automated software are now being used to match DNA profiles quickly and efficiently.

14.3.2 Techniques Used in DNA Fingerprinting

1. **RFLP (Restriction Fragment Length Polymorphism)** – Older method, requires large DNA samples, slower.
2. **PCR (Polymerase Chain Reaction)** – Used to amplify small DNA samples.
3. **STR (Short Tandem Repeats) Analysis** – The most widely used method in modern DNA profiling.
4. **Mitochondrial DNA (mtDNA) Analysis** – Used for degraded or ancient DNA (useful in archaeology and missing person cases).
5. **Y-Chromosome & X-Chromosome Testing** – Used to trace paternal or maternal lineage.

14.4 APPLICATIONS OF DNA FINGERPRINTING

1. Forensic Science

DNA fingerprinting is a crucial tool in forensic science, used extensively for criminal investigations. When biological evidence such as blood, hair, or saliva is found at a crime scene, it can be analyzed and compared with DNA from suspects. The unique DNA profile can link a suspect to the crime or exonerate an innocent person. It is also useful in identifying victims when traditional methods fail, especially in mass disasters or decomposed remains. Additionally, DNA evidence is often revisited in cold cases, helping to solve crimes that have remained unresolved for years.

2. Paternity and Kinship Testing

DNA fingerprinting is commonly used to determine biological relationships, especially paternity and maternity. This has applications in legal cases related to child custody, inheritance, and adoption. In immigration, DNA testing can confirm family ties when documents are lacking. The accuracy of DNA profiles allows courts to resolve disputes regarding lineage and familial connections with high confidence.

3. Biodiversity and Conservation Biology

In biodiversity and conservation biology, DNA fingerprinting is used to identify species and monitor genetic variation within populations. This is particularly important for endangered species, where maintaining genetic diversity is critical for long-term survival. DNA tools help conservationists track individual animals in the wild, plan breeding programs in zoos, and investigate illegal trade in wildlife products like ivory or tiger skins. It also assists in the restoration of habitats by ensuring reintroduced animals are genetically appropriate for the region.

4. Agriculture and Livestock

DNA fingerprinting has revolutionized plant and animal breeding programs. In agriculture, it helps identify desirable traits such as disease resistance or drought tolerance, speeding up crop improvement. In livestock management, DNA testing ensures the accuracy of breed records and helps improve traits like milk yield or meat quality. It is also used to detect the presence of genetically modified organisms (GMOs) in food products, which is important for labeling and regulation.

5. Medical and Genetic Research

In the medical field, DNA fingerprinting is used to detect genetic disorders and identify mutations that may lead to inherited diseases. It is valuable in prenatal diagnostics and in screening for conditions like cystic fibrosis or sickle cell anemia. Additionally, it plays a role in organ transplantation by ensuring donor-recipient compatibility, reducing the risk of rejection. The technique is also used in pharmacogenomics to tailor medications based on an individual's genetic makeup, enhancing drug effectiveness and safety.

6. Evolutionary Biology and Anthropology

DNA fingerprinting provides insights into human ancestry and evolutionary relationships. It helps researchers understand how modern humans evolved, migrated, and adapted over time. Ancient DNA from archaeological remains is analyzed to learn about extinct populations and their connections to present-day groups. In comparative genomics, DNA profiling is used to study the divergence and speciation of organisms, contributing to our understanding of evolutionary biology.

14.5 SUMMARY

Molecular Taxonomy is a modern approach to biological classification that uses molecular data—mainly DNA, RNA, and protein sequences—to identify and classify organisms. Unlike traditional taxonomy, which relies on observable physical traits, molecular taxonomy provides highly accurate, objective, and quantifiable methods for determining evolutionary relationships, detecting cryptic species, and assessing genetic diversity. Techniques such as DNA barcoding, gene sequencing, and the use of molecular markers like RAPD and microsatellites play a crucial role in constructing phylogenetic trees and improving species identification at all life stages. This has significant applications in conservation biology, systematics, agriculture, and environmental monitoring. **DNA Fingerprinting**, also known as DNA profiling, is a molecular technique used to identify individuals based on their unique DNA patterns. It is widely used in forensic science, paternity testing, conservation,

agriculture, and medical genetics. The process involves extracting DNA, amplifying target regions (often non-coding or repetitive), and comparing banding patterns or sequences. DNA fingerprinting helps solve crimes, trace lineage, identify endangered species, and manage breeding programs. Its precision and reliability make it an indispensable tool in both scientific research and practical applications across multiple disciplines.

14.6 TECHNICAL TERMS

DNA Barcoding, Genetic Marker, RAPD (Random Amplified Polymorphic DNA), Polymerase Chain Reaction (PCR), STR (Short Tandem Repeats), Gene Sequencing, Mitochondrial DNA.

14.7 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. Describe the importance of genetic diversity in conservation biology and how molecular taxonomy aids in its assessment.
2. How can DNA fingerprinting be applied in the identification of paternity or biological relationships?
3. What are the advantages of using DNA fingerprinting over traditional morphological identification methods?

Short Notes:

1. What are the advantages of molecular taxonomy in classifying organisms at any life stage?
2. Explain the concept of Short Tandem Repeats (STRs) and how they are used in DNA fingerprinting.

14.8 SUGGESTED READINGS

1. "Molecular Systematics" by David M. Hillis, Craig Moritz, and Barbara K. Mable
- This book provides a comprehensive overview of molecular methods in taxonomy and systematics, including gene sequencing, phylogenetic analysis, and molecular markers.
2. "Molecular Evolution and Phylogenetics" by Masato T. S.
- A deep dive into the molecular aspects of evolutionary biology, providing insights into how molecular data can inform evolutionary history and species classification.
3. **"Molecular Systematics"** by David M. Hillis, Craig Moritz, and Barbara K. Mable
- This book provides a comprehensive overview of molecular methods in taxonomy and systematics, including gene sequencing, phylogenetic analysis, and molecular markers.
4. **"Molecular Evolution and Phylogenetics"** by Masato T. S.
- A deep dive into the molecular aspects of evolutionary biology, providing insights into how molecular data can inform evolutionary history and species classification.
5. **"Molecular Taxonomy: A Phylogenetic Perspective"** by J. A. Cameron
6. A resource exploring how molecular data, particularly genomic and transcriptomic data, is used to generate phylogenetic trees and understand species relationships.

Prof. P. V. Krishna

LESSON-15

SATELLITE REMOTE SENSING AND GIS PROGRAMS

AIM AND OBJECTIVES

- Understanding the significance of Satellite remote sensing.
- To gain knowledge of Satellite Missions for Biodiversity Monitoring.
- Understanding the importance of Geographic Information Systems.
- Explore the applications of GIS

STRUCTURE

15.1 SATELLITE REMOTING SENSING

Satellite remote sensing plays a crucial role in **biodiversity monitoring** by providing comprehensive, large-scale, and frequent observations of ecosystems, wildlife habitats, and environmental changes. This technology offers a way to track and assess the health of biodiversity without the need for constant on-the-ground fieldwork, which can be costly and logistically challenging. Satellite remote sensing is a powerful and advanced technique used to collect information about the Earth's surface without physical contact. It involves the use of satellites equipped with sophisticated sensors that detect and measure electromagnetic radiation reflected or emitted from objects on the Earth. These sensors can be either passive (which rely on sunlight, like cameras or thermal detectors) or active (which emit their own signals, like radar or LiDAR). The satellites orbit the Earth in different paths — primarily geostationary (fixed over a point) or polar orbits (scanning the entire globe in successive passes) — allowing continuous and repeated observation of vast areas. Remote sensing plays a crucial role in a wide range of applications such as environmental monitoring, agricultural crop analysis, forest cover change detection, urban expansion, water resource management, and biodiversity conservation. It is particularly vital in monitoring natural disasters like floods, cyclones, wildfires, and droughts, where real-time satellite imagery helps authorities respond quickly and effectively. Commonly used satellite systems include Landsat (USA), Sentinel (EU), IRS (India), and MODIS (NASA). These platforms provide multi-spectral and hyper-spectral data that can be processed and analysed using Geographic Information Systems (GIS) to extract meaningful insights. One of the greatest advantages of remote sensing is its ability to cover large and inaccessible regions efficiently and repeatedly, enabling long-term environmental monitoring and planning. It is a non-invasive, cost-effective, and highly valuable tool for sustainable development, scientific research, and decision-making at global, national, and local levels.

15.1.1 Key ways satellite remote sensing contributes to the study and conservation of biodiversity:

1. Habitat Mapping and Monitoring:

- **Mapping Ecosystems**: Satellites can capture high-resolution imagery that helps map ecosystems, forest cover, wetlands, grasslands, and marine habitats. These maps provide essential data on habitat distribution and quality, which is crucial for understanding biodiversity patterns.
- **Detecting Habitat Loss**: Remote sensing allows scientists to monitor changes in land cover, such as deforestation, urbanization, or agricultural expansion, which directly impact biodiversity. Early detection of these changes helps in the implementation of conservation measures.
- **Tracking Wetlands and Coastal Areas**: Satellite imagery is especially useful in monitoring sensitive wetland and coastal ecosystems that are home to a wide range of species, allowing for the assessment of water quality, vegetation health, and ecosystem fragmentation.

2. Monitoring Vegetation and Forest Health:

- **Forest Dynamics**: Remote sensing helps track forest cover, vegetation type, and forest health over time. **Vegetation indices** like the **Normalized Difference Vegetation Index (NDVI)** are widely used to measure plant health, biomass, and productivity. This is valuable for understanding how forests, which are biodiversity hotspots, are changing in response to climate change, deforestation, and other human activities.
- **Identifying Biodiversity Hotspots**: Satellites can be used to locate and monitor **biodiversity hotspots**, areas of the world that are rich in species but are under threat from human activities.
- **Monitoring Invasive Species**: By analysing changes in vegetation, remote sensing can help detect the spread of invasive species, which often threaten native biodiversity by outcompeting local species or altering ecosystems.

3. Tracking Species Distribution and Behaviour:

- **Wildlife Habitat Monitoring**: Satellites provide information on vegetation cover, water bodies, and climate, which are key factors in determining wildlife habitats. By tracking these factors, researchers can identify areas where wildlife is most likely to be found, supporting species conservation efforts.
- **Movement of Migratory Species**: Satellites can also track the movement of migratory species like birds and marine animals. For example, **MODIS (Moderate Resolution Imaging Spectroradiometer)** can provide data on sea surface temperature, which is crucial for monitoring the habitats of marine species such as whales and fish.
- **Monitoring Poaching and Illegal Activities**: Remote sensing is also used to detect illegal activities such as poaching or deforestation within protected areas. Monitoring

changes in land cover around conservation areas can help authorities respond quickly to illegal activities that threaten wildlife.

4. Climate Change and Biodiversity Impact:

- **Studying Climate Change Effects**: Satellites provide critical data on temperature, precipitation, and sea-level rise—factors that affect biodiversity. **Thermal remote sensing** and **climate models** allow scientists to observe the impacts of climate change on ecosystems and species distributions.
- **Monitoring Coral Reefs**: Satellites are used to monitor the health of **coral reefs**, which are highly sensitive to temperature changes and ocean acidification. Satellite data on sea surface temperature, turbidity, and chlorophyll levels can help assess the state of coral reefs and predict bleaching events.
- **Vegetation and Carbon Dynamics**: Remote sensing data can be used to monitor how vegetation is responding to changing climates, including shifts in plant species composition, which ultimately affects biodiversity. Satellite measurements of forest biomass can also contribute to global carbon budgets, linking biodiversity conservation with climate action.

5. Biodiversity Conservation and Protected Areas:

- **Monitoring Protected Areas**: Remote sensing helps in the management of protected areas and national parks by providing consistent monitoring of land use, habitat degradation, and encroachment. High-resolution satellite images allow park authorities to monitor illegal logging, land clearing, or mining activities.
- **Assessing Restoration Projects**: Satellites can be used to track the progress of ecological restoration efforts, such as reforestation, wetland restoration, and habitat restoration. By monitoring vegetation cover, species recovery, and land use changes, conservationists can assess whether restoration goals are being met.

6. Marine and Coastal Biodiversity:

- **Marine Ecosystem Monitoring**: Satellites can monitor oceans, coastal zones, and marine protected areas to assess water quality, pollution levels, and the health of marine ecosystems. Remote sensing data, such as sea surface temperature, salinity, and chlorophyll concentration, is used to monitor the health of marine life, including coral reefs, seagrass meadows, and fish populations.
- **Oil Spill Detection**: Satellites equipped with radar sensors (e.g., **Synthetic Aperture Radar - SAR**) are used to detect oil spills and track their spread across the ocean surface. This helps mitigate the negative impact on marine biodiversity by providing timely information for response efforts.

7. Data Integration for Biodiversity Assessments:

- Satellite remote sensing data is often integrated with **ground-based surveys**, **biodiversity databases**, and **species distribution models** to provide a more comprehensive picture of biodiversity. This combination allows for more accurate predictions about the future of ecosystems and species populations, helping guide conservation planning and decision-making.

15.2 KEY SATELLITE MISSIONS FOR BIODIVERSITY MONITORING

1. **Landsat (NASA & USGS)**: Provides high-resolution multispectral imagery that is essential for monitoring land cover, vegetation health, and ecosystem changes over time.
2. **MODIS (NASA)**: A key satellite for observing vegetation, land cover, ocean productivity, and climate variables, contributing valuable data for global biodiversity assessments.
3. **Copernicus Sentinel Satellites (ESA)**: Offer a suite of data on land, water, and atmospheric conditions. Sentinel-1 (SAR), Sentinel-2 (optical imagery), and Sentinel-3 (oceans and land) support biodiversity monitoring.
4. **Worldview Satellites (Maxar)**: Provide high-resolution imagery for monitoring deforestation, urban expansion, and other activities that impact biodiversity.

15.2.1 Advantages of Using Satellite Remote Sensing in Biodiversity Conservation

- **Large-Scale Monitoring**: Satellite remote sensing allows for the monitoring of vast and often inaccessible areas, such as remote forests, oceans, and mountain ranges. It provides data on ecosystems at regional, national, and global scales, which is vital for tracking biodiversity and ecosystem health over large landscapes.
- **Cost-Effective**: Traditional field surveys can be time-consuming, costly, and sometimes logistically challenging, especially in remote or dangerous locations. Satellite remote sensing provides a more cost-effective solution for large-scale and long-term biodiversity monitoring.
- **Real-Time Data**: Satellites continuously orbit the Earth, offering frequent and repeatable observations of the same location. This is crucial for tracking changes in biodiversity over time, such as habitat loss, deforestation, and the impacts of climate change. Remote sensing provides up-to-date data, which is essential for informed conservation decision-making.
- **Early Warning Systems**: Satellite remote sensing can provide early warnings of environmental threats, such as forest fires, droughts, or floods, which can directly affect biodiversity. By monitoring environmental stressors, authorities can take proactive conservation measures to mitigate the impact on ecosystems and species.
- **Integration with Other Data**: Remote sensing data can be combined with other environmental data, such as climate models or biodiversity databases, to create comprehensive conservation strategies. Geographic Information Systems (GIS) and other analytical tools can integrate satellite data to provide detailed spatial insights that support conservation planning.
- **Global Coverage**: With satellites orbiting the Earth, data can be collected from anywhere on the planet, providing global coverage. This is particularly useful for monitoring biodiversity in regions with limited field access due to political, geographical, or security constraints.
- **Monitoring of Protected Areas**: Remote sensing technology can be used to assess the effectiveness of protected areas (like national parks and wildlife reserves) in conserving biodiversity. It helps monitor illegal activities such as poaching or logging, tracks habitat degradation, and evaluates the impact of conservation measures.

15.3 GIS PROGRAMS

Geographic Information Systems (GIS) are powerful tools used for mapping, analysing, and interpreting spatial data. GIS integrates hardware, software, and data to visualise, analyse, and interpret patterns and trends on Earth. It has a wide range of applications across industries like urban planning, environmental management, disaster response, agriculture, and more. GIS is widely used across many fields, including environmental management, urban planning, disaster response, agriculture, and biodiversity conservation. The primary function of GIS is to map and analyse spatial data in ways that would be difficult or impossible to do manually.

Top GIS programs that are commonly used for spatial analysis, map creation, and data visualisation:

1. ArcGIS (Esri)

- **Features**: Comprehensive tool for mapping, spatial analysis, and data management. Includes desktop software (ArcMap, ArcGIS Pro) and cloud-based solutions (ArcGIS Online).
- **Applications**: Urban planning, environmental conservation, and disaster response.

2. QGIS (Quantum GIS)

- **Features**: Open-source, free GIS with strong data analysis and mapping tools. Supports various plugins and cross-platform use.
- **Applications**: Land use planning, environmental monitoring, and education.

3. GRASS GIS

- **Features**: Open-source software for complex geospatial modelling, hydrology, and environmental analysis.
- **Applications**: Environmental research, land use analysis, and urban planning.

4. MapInfo Professional

- **Features**: Desktop GIS for mapping, spatial analysis, and visualization.
- **Applications**: Marketing analysis, transportation, and land management.

5. Google Earth Engine

- **Features**: Cloud-based platform for large-scale environmental monitoring, especially satellite imagery analysis.
- **Applications**: Climate change research, deforestation monitoring, and agriculture.

6. AutoCAD Map 3D

- **Features**: Combines GIS with CAD tools for detailed maps and 3D modelling.
- **Applications**: Urban infrastructure planning and land surveying.

7. Map Server

- **Features**: Open-source platform for creating interactive web maps.
- **Applications**: Public information systems and geospatial data sharing.

8. ERDAS IMAGINE

- **Features**: GIS and remote sensing software focused on satellite imagery and environmental modelling.
- **Applications**: Remote sensing analysis, land use planning, and resource management.

9. CartoDB (CARTO)

- **Features**: Cloud-based GIS for data visualisation and interactive mapping.
- **Applications**: Data visualisation and urban planning.

10. GeoServer

- **Features**: Open-source GIS server for sharing geospatial data and creating web maps.
- **Applications**: Web-based GIS, data sharing, and environmental monitoring.
- The GIS programs mentioned above represent just a few of the leading tools available for spatial analysis, mapping, and geospatial data management. Choosing the right GIS program depends on your specific needs, whether it's advanced geospatial modelling, satellite image analysis, creating interactive web maps, or integrating GIS into urban planning and infrastructure projects.

15.3.1 Key Components of GIS:

1. **Hardware**: The physical devices, including computers, GPS units, and servers, required to collect, store, and process spatial data.
2. **Software**: The programs that allow users to input, manipulate, analyse, and display geographical data (e.g., ArcGIS, QGIS, MapInfo).
3. **Data**: Geographic data is the core of GIS, and it can come from various sources like satellites, field surveys, aerial imagery, and existing databases. Data can be **vector** (points, lines, polygons) or **raster** (gridded data, such as satellite imagery).
4. **People**: Users who manage, analyse, and interpret the data to derive insights for decision-making in various fields.
5. **Methods**: The processes and techniques used to analyse spatial data, such as overlay analysis, proximity analysis, and spatial modelling.

15.3.2 Applications of GIS in Biodiversity Conservation:

1. **Habitat Mapping and Monitoring:** GIS can create detailed maps of natural habitats, such as forests, wetlands, grasslands, and marine ecosystems. By integrating satellite data with species location data, conservationists can monitor habitat changes over time (e.g., deforestation or land-use changes) and identify areas of critical importance for species conservation.
2. **Biodiversity Hotspot Identification:** GIS helps in identifying biodiversity hotspots by mapping regions with high species richness and endemism. It aids in prioritizing conservation efforts by highlighting areas that are most at risk.
3. **Protected Area Management:** GIS is used to monitor and manage protected areas such as national parks, wildlife sanctuaries, and biosphere reserves. It helps track habitat boundaries, biodiversity trends, and human activities that may threaten these areas, such as poaching or illegal logging.

4. **Species Distribution Modelling:** GIS combined with data on environmental variables (such as climate, vegetation, and elevation) can help predict species' potential distributions under current or future conditions. This is useful for understanding how climate change, land-use changes, and other factors might affect species and ecosystems.
5. **Conservation Planning:** GIS is an essential tool in spatial conservation planning, where decision-makers use the data to create strategic plans for conserving biodiversity. GIS enables the assessment of connectivity between habitats, the identification of corridors for wildlife movement, and the evaluation of the effectiveness of conservation efforts.
6. **Tracking and Monitoring Biodiversity:** GIS supports long-term biodiversity monitoring by tracking changes in species populations, habitat quality, and environmental health. It provides an efficient way to monitor conservation projects and assess their success over time.

15.3.3 Benefits of GIS in Biodiversity Conservation:

1. **Spatial Analysis**: GIS enables the analysis of spatial patterns in biodiversity, helping conservationists identify the relationships between species and their environments.
2. **Real-Time Monitoring**: GIS integrates real-time data from field observations, satellites, and sensors, allowing for quick responses to biodiversity threats, such as illegal activities, poaching, or forest fires.
3. **Efficient Resource Management**: By visualising and analysing data, GIS helps allocate resources more effectively, ensuring that conservation efforts are targeted where they are most needed.
4. **Public Awareness and Education**: GIS-based maps and visualisations can be used for public outreach, helping to raise awareness about biodiversity conservation efforts and garnering support from local communities and stakeholders.

15.4 SUMMARY

In summary, satellite remote sensing is a transformative tool in biodiversity conservation. It provides an efficient, cost-effective, and scalable way to monitor and protect ecosystems and species across large areas, making it an essential component of modern conservation strategies. It also enhances decision-making by providing reliable, accurate, and up-to-date data on environmental and biodiversity changes. Geographic Information Systems (GIS) provide a robust and flexible platform for managing and analysing spatial data, making it an indispensable tool in biodiversity conservation. By enabling the visualisation and interpretation of complex ecological data, GIS helps conservationists make informed decisions, prioritise areas for protection, and monitor biodiversity trends. Whether it's tracking species habitats, managing protected areas, or predicting environmental changes, GIS plays a critical role in safeguarding the planet's biodiversity.

15.5 TECHNICAL TERMS

Remote Sensing, Spectral Resolution, Spatial Resolution, Radiometric Resolution, Hyperspectral Imaging, NDVI (Normalized Difference Vegetation Index), Georeferencing, Digital Elevation Model (DEM)

15.6 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. Explain how GIS and remote sensing work together in biodiversity monitoring and conservation.?

2. What are some limitations of satellite remote sensing in ecological applications, and how can they be mitigated?

Short Notes:

1. What are the key differences between GIS and remote sensing?
2. How can satellite remote sensing help in tracking deforestation?
3. How can GIS be used in mapping biodiversity hotspots?

15.7 SUGGESTED READINGS

1. "Remote Sensing and GIS for Environmental Sciences" by *Andrew Skidmore* – A comprehensive guide on how to apply remote sensing and GIS tools to environmental and biodiversity monitoring.
2. "Principles of Geographical Information Systems" by *Peter A. Burrough and Rachael A. McDonnell*
– Fundamental concepts of GIS explained with environmental applications.
3. "Remote Sensing of the Environment: An Earth Resource Perspective" by *John R. Jensen*
– A classic book for understanding remote sensing technologies and interpretation of satellite data.
4. "Fundamentals of Remote Sensing" by *George Joseph*
– Good for students and beginners to understand sensor systems and satellite data analysis.
5. "GIS Fundamentals: A First Text on Geographic Information Systems" by *Paul Bolstad*
– A clear, introductory-level book focused on GIS tools, data formats, and analysis.

Prof. P. V. Krishna

LESSON-16
ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

AIMS AND OBJECTIVES

- Understanding the concept of Environmental Impact Assessment.
- To gain knowledge of management plans in EIA
- Explore Application of EIA
- Understanding of the guidelines of EIA

STRUCTURE

16.1 INTRODUCTION

Environmental Impact Assessment (EIA) is a process used to evaluate the potential environmental effects of a proposed project or development before it begins. It helps identify any significant impacts and provides recommendations to avoid or minimize adverse effects on the environment. Developmental activities deplete natural resources and dispose wastes that deteriorate the quality of the environment. Thus, developmental projects (dams, factories) should aim at optimal use of natural resources, with minimum impact on the ecosystem and biotic communities or on the life and livelihood of human being. To meet these objectives, it is necessary to develop environmental impact assessment, to evaluate a project's impact on the environment.

Environmental impact assessment is a formal study process used to predict the environmental consequences of a proposed, major developmental project. It concentrates on the problems, conflicts or natural resource constraints that could affect the viability of a project. It also examines how a project might cause harm to people, their homeland, livelihood and natural resource.

EIA is a management tool for incorporating environmental concerns in developmental process that aid in improved decision making. Sound environmental management practice can be done through preparation of Environmental Management Plans (EMPs). The programme of EIA in the Ministry of Environment and Forest for the last two decades was initiated with the appraisal of River Valley Projects. The scope of appraisal was subsequently enlarged to cover other sectors like thermal power plants, mining schemes river dams and others.

Environment Impact Assessment (EIA) is a process for evaluating and predicting the impact of an action on the environment. International Association for the Impact Assessment (IAIA) defines EIA as a method used for evaluating and predicting the impact of developmental process on the environment. The conclusions are intended to be used in decision making. It aims to prevent environmental degradation by providing better information to decision makers about the possible impact of the project on the environment. It deals with policies, plans and programmes. Environment Impact Assessment (EIA) is a process for evaluating and predicting the impact of an action on the environment. International Association for the Impact Assessment (IAIA) defines EIA as a method used for evaluating and predicting the impact of developmental process on the environment. The conclusions are intended to be used in decision making. It aims to prevent environmental degradation by providing better information to decision makers about the possible impact of the project on the environment. It deals with policies, plans and programmes.

Environmental impact assessment is required for prediction and analysis and the questionnaires which are updated and published for various sectors. Further, for facilitating preparation of EIA reports, a manual on EIA has been prepared which is also useful to apprising agencies and decision makers, both at Central and State levels. The Ministry has initiated a number of activities to streamline the appraisal process in terms of simplification of procedures, involvement of stakeholders through public hearing, and regular meetings of expert committees. Developmental activities exert negative influence on natural systems, depleting natural resources and end up by adding pollutants to the environment. Forest lands are cleared or wetlands are drained for setting up of industries, hydroelectric projects and highways. All these destroy habitat for diverse flora and fauna, deteriorating the quality of environment. Damming of rivers prevent fish migration and interfere with the livelihood of aquatic animals. Deforestation depletes biodiversity. Overall, developmental projects lead to biodiversity loss and affect those who live in its vicinity. Therefore, it is important to keep an account of the status of the environment while planning for developmental or infrastructure projects.

National Environmental Policy Act (NEPA) (1969) initiated the formation of EIA, Sec 102(2) in the United States. Later it was adopted by Canada (1973), Australia (1974), West Germany (1975) and France (1976). Rio conference of Biological Diversity in 1992, strongly recommended EIA for any economic activity. In India, impact assessment started after the UN conference on Human Environment in Stockholm, in 1972 with the active participation of the then Prime Minister Mrs. Indira Gandhi. The National Committee on Environmental Planning and Coordination (NCEPC) was formed as a part of the Department of Science and Technology.

The objectives of EIA are to control degradation and pollution, promote conservation and formulate environmental management and planning strategies. EIA aims to protect the environment from any adverse effect of developmental projects and provides suggestions for any alternative or modified action. This is to reduce environmental stress which helps in shaping up of projects that may suit the local environment. The ministry has a set of conditions that are needed to be followed, such as, dumping of waste or debris and, controlled blasting, while construction. It analyses the problems, conflicts and the constraints on the wildlife and their habitats, natural resources, status and distribution of the endangered species as well as on the livelihood and health of the affected people. EIA provides planning strategy and useful mitigation which is compulsory to the developer. Through improved technology and management plans, EIA suggests for optimal utilization of natural resources and also focuses on the disposal of wastes that leads to environmental degradation. Studies related to EIA are useful in policy making, planning and administration. EIA is an integral part of planning and is mandatory before taking decisions on developmental or infrastructure projects.

16.1.1 Impact of Developmental Project on the Environment

A project might change the attributes of the location, and contributes to pollution. Construction of the project can degrade the environment temporarily or permanently and its impact may be felt after the completion of the project. Further some projects require shifting of human colony.

EIA addresses the following problems:

a) Whether the developmental project spurs sensitive and controversial issues,
b) Whether it will deplete natural resource or human properties for only short-term economic benefit.
c) Whether the project fits into the regional development plan, consistent with the national policies or national foreign exchange policies.
d) Whether the project will exert any negative impact on the fauna and flora of the region.
e) Whether there is provision for setting up of any alternate projects to meet with similar desired developmental objectives.

Any person, who desires to start a new project (or wish to expand and modernize the existing one) should submit an application to the secretary of Ministry of Environment and Forests, New Delhi.

The project authority will intimate the location of the project site to the Central Government. The site clearance shall be granted for a maximum period of five years for starting of the project. The report submitted with the application shall be evaluated and assessed by the Impact Assessment Agency (IAA) and they may even consult with the committee of experts chosen from various fields. They have the full right of entry and inspection of the site. The IAA shall prepare a set of recommendations based on the technical data furnished by the project authorities, supplemented with those collected during the visit of the site and further, by interaction with affected groups of people. The summary of the project report is to be made public by conducting a public hearing (publishing in a newspaper). The assessment has to be completed within 90 days of the receipt of the project proposal from the authorities. The completion of a public hearing and the decision has to be conveyed within 30 days. After completion of the mandatory steps and the appraisal of documents by the committee of experts, the project is granted environmental clearance. Such clearance is valid only for 5 years. If, however, no comments are received from the Ministry within the given time, the project would stand cancelled.

16.2 KEY COMPONENTS OF EIA

1. **Screening**: Determines whether a project requires an EIA based on its potential impact.
2. **Scoping**: Identifies the key environmental issues and determines the scope of the assessment.
3. **Impact Prediction**: Estimates the potential environmental effects of the project, including air, water, soil, and biodiversity impacts.
4. **Mitigation Measures**: Suggests actions to reduce or avoid negative impacts.
5. **Public Participation**: Involves stakeholders, including local communities, in the decision-making process.
6. **Reporting**: Provides a detailed report on the findings and suggested mitigation strategies.
7. **Monitoring and Management**: Ensures that the mitigation measures are implemented and that impacts are monitored throughout the project's lifecycle.

16.2.1 Purpose of EIA:

- **Identify environmental risks** early in the planning process.
- **Ensure sustainable development** by minimising negative impacts.
- **Promote informed decision-making** by policymakers, stakeholders, and the public.
- **Enhance public awareness** of environmental issues.

16.3 MANAGEMENT PLANS

Management of liquid effluents or solid waste and the level of air pollution near projects shall conform with the pollution control standards. According to Environmental (Protection) Rules in 1986, an environmental clearance has to be accorded by the Central or State Government, where a manual on EIA has to be prepared for both the apprising agency and decision makers. Cases may be rejected due to submission of insufficient data. Environmental clearance is the Environmental Impact Statement (EIS) and Environment Management Plan (EMP) based on EIA.

Ministry has initiated a number of actions involving stakeholders through public hearing and meeting of the expert committees. Reports submitted are evaluated and assessed by the Impact Assessment Agency (IAA) along with a committee of experts. Impact Assessment Agency, have full right of entry into the proposed site. Questionnaires for EIA are updated and has to be published for public. The project must be advertised in two local newspapers. The district coordinators and experts consist of scientists, economists, engineers, policy makers and representations of the affected groups should be involved.

The EIA findings should be initially done to improve and improvise the basic designs of the project. It should propose technologies to control pollution, treatment and disposal of waste and should compensate for the affected people. It may also suggest alternate sites for the project. EIA findings must be readily accessible and useful for policy makers and developers. The IAA shall prepare a set of recommendations based on the documents submitted by the profit planners, in addition to the data collected during their visits to sites. With the interaction of the local affected people, comments of the public will have to be solicited. The assessment should be completed within 90 days and construction related to setting should not be undertaken until the clearance is obtained. Finally, documentation is provided to the decision makers.

The scope of EIA ensures that the study should address all the issues regarding the magnitude of impact of the project on the environment, like depletion of natural resources, effects on social erosion, presence of any endangered flora and fauna near any historical sites. It should evaluate any significant change to warrant mitigation.

World conservation strategy has identified some criteria for identifying significant impact, that EIA will assess. The criteria are as follows:

- **(a)** The first criteria concern the time period and geographic area on which the effect of the developmental project will have, the number of people who would be affected, and the amount of the resources that would be degraded.
- **(b)** Rate of degradation of the natural system at the project site and the time taken for its resilience.
- **(c)** Finally, the extent of irreversible damage, the project might inflict on human health, natural resources and other natural systems. It is thus important to assess the cumulative changes, the bio-physical and socio-economic changes.

16.3.1 Environmental Guidelines for Industries in India

A. The project should be situated at least 25 km away from ecological or historically sensitive areas, depending on the geoclimatic conditions of the region.
B. Coastal areas (within 1/2 km from high tide time) are to be avoided.
C. Industries should be located at least 1/2 km away from the floodplain of lakes or the river system.
D. Transport and communication system at least 1/2 km away from highway/railway.
E. Industries should be 50 km away from the projected boundary of the major settlement area.

16.3.2 Siting criteria of projects

- No forest shall be converted for the setting up of projects (According to the Forest Conservation Act, 1980).
- No primary agricultural land shall be converted into industrial sites.
- Industry must locate itself at locations to remain as far as possible from the general site.
- A Green belt of 1/2 km wide should be present around the boundary limit of the industry.
- The layout and form of the industry must conform to the landscape, without affecting its scenic features.

16.4 APPLICATIONS OF EIA

- **Infrastructure Projects**: Roads, bridges, airports, and buildings.
- **Energy Projects**: Dams, power plants, and renewable energy developments.
- **Industrial Projects**: Manufacturing facilities, waste treatment plants, and mining operations.
- **Urban Development**: Housing, commercial areas, and urban expansion.

16.4.1 Projects Required for Detailed EIA

a) Developmental projects that alter landscapes and change lands-use patterns and lead to the concentration of working and service population.

b) Projects that need upstream developmental act like mineral and forest products supply or downstream industries process development.
c) Projects involving the manufacture, handling and use of hazardous materials.
d) Projects sited near ecologically sensitive areas, urban centres, hill resorts, places of scientific and religious importance.
e) Industrial estates with constituent units of various types which may incur significant environmental damage.

Important EIA extrapolates from scientific knowledge to assess the human intervention on nature and the chances of changes that may occur. Besides, measures taken to reduce environmental degradation has to be made before starting the project. For analysis, a number of professionals and disciplines are involved for decision-making.

The UNECE convention on EIA in a transboundary context that provide international legal framework for transboundary EIA.

16.4.2 List of Project Requiring Environmental Clearance

- Nuclear power and related projects
- River valley projects, mining and hydel power
- Ports, harbours, airports
- Petroleum refinery
- Chemical fertilizers, highway projects
- Pesticides, distilleries
- Petroleum complexes
- Pharmaceuticals
- Export of oil gas and their products
- Synthetic rubber, pulp, paper, cement
- Asbestos and its products, dyes
- Hydrocyanic acid, foundries
- Metal industry, electroplating
- Chlor-alkali industry

CBD has mandated EIA for infrastructure and other projects. According to the Article 14 of the Biodiversity Convention, each contracting party is required to "introduce appropriate procedures requiring environmental impact assessment of its proposed projects that are likely to have significant adverse impacts on biological diversity" and to identify processes and categories of activities that are or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity. The Convention further identifies in Article 11, "the need for incentive measures as a specific mechanism to help, guide national level actions and to promote conservation and sustainable use of resources, as expressed in the convention".

Ecologically Sensitive Area (ESA) or Environmental sensitive area is an area where the natural environment is easily harmed by natural or anthropogenic disturbances. These ecologically rich areas are biologically diverse, endowed with unique resource and are irreplaceable if destroyed. Thus, these ecologically significant zones are of immense economic, cultural and historical value. Their physiographical uniqueness lies in the rarity of species and their vulnerability to disturbances. Reserved forests, protected areas, sanctuaries, sacred groves, mangroves or coral ecosystem, breeding grounds of species or monuments of cultural significance besides flood prone areas, seismic zones are referred as ecologically sensitive areas, where industrial sitting is prohibited. These restrictions are for physiographic constraints, ecological fragileness and cultural considerations of the local's inhabitants.

16.5 SUMMARY

Environmental Impact Assessment (EIA) is a systematic process used to evaluate the potential environmental consequences of a proposed project or development before it is approved or implemented. The goal of EIA is to ensure that decision-makers consider environmental impacts along with economic or social benefits during the planning and approval stages of projects.

EIA involves several key steps, including screening (determining if a project needs EIA), scoping (identifying which impacts to assess), impact prediction and evaluation, public consultation, and finally the preparation of an Environmental Impact Statement (EIS). This statement outlines potential effects and proposes mitigation measures to minimize harm. Projects requiring EIA often include activities like mining, dam construction, industrial plants, infrastructure development, and tourism projects, especially when they affect ecologically sensitive areas.

EIA promotes sustainable development by identifying and reducing harmful environmental consequences before they occur. It also ensures transparency, public involvement, and regulatory compliance. However, EIA effectiveness depends on how thoroughly it is implemented and monitored, and whether political or economic pressures override environmental concerns.

16.6 TECHNICAL TERMS

EMP (Environmental Management Plan), Scoping, Impact Prediction, Mitigation Measures, Carrying Capacity, Cumulative Impact Assessment, Threshold Limits, Strategic Environmental Assessment (SEA).

16.7 SELF-ASSESSMENT QUESTIONS

Essay Questions:

1. Explain the steps involved in the Environmental Impact Assessment process.?
2. Explain the role of EIA in preventing ecological damage with examples.?
3. How does EIA contribute to sustainable development?

Short notes:

1. What is the difference between screening and scoping in EIA?
2. What is the purpose of an Environmental Management Plan (EMP)?

16.8 SUGGESTED READINGS

1. "Environmental Impact Assessment: Theory and Practice" by Peter Morris and Riki Therivel]
   – A well-balanced book covering both theory and real-world case studies.
2. "Environmental Management" by N.K. Uberoi

– Covers broader aspects of environmental planning and includes EIA chapters.
3. "Environmental Studies" by Erach Bharucha (UGC Recommended)
   – Introductory book for students with a section dedicated to EIA and conservation practices.
4. "Environmental Science" by G. Tyler Miller and Scott Spoolman
   – Includes sections on environmental planning, impact assessments, and sustainability.

Prof. P.V. Krishna