ALGERIAN DEMOCRATIC AND POPULAR REPUBLIC
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
SETIF 1 UNIVERSITY - FERHAT ABBAS

FACULTY OF NATURE AND LIFE SCIENCES
DEPARTMENT OF ECOLOGY AND ENVIRONMENT

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Course Handout

For the use of first-year Master's students (M1 Level)

FIELD

NATURE AND LIFE SCIENCES (NLS)

FUNDAMENTAL TEACHING UNIT

BIODIVERSITY

Prepared by **Dr. Beldjazia Amina**

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Master's Title: Biodiversity and Environment

Semester: 1

Course Title: Fundamentals

Subject Title 2: Biodiversity

Credits: 06

Coefficients: 03

Teaching Objectives (Describe what the student is expected to have acquired in terms of skills after successfully completing this subject – maximum 3 lines).

This course enables students to understand biodiversity in its broad sense and the mechanisms for the sustainable use of diversity and specificity.

Recommended Prerequisites (Brief description of the knowledge required to follow this course – Maximum 2 lines).
Botany, Zoology, Microbiology, and Ecology.

Course Content:

1. History of the concept
2. Precise definitions of wild biodiversity and domestic biodiversity
3. Assessing biodiversity
   - 3.1 How to measure biodiversity?
   - 3.2 The different dimensions of biodiversity
   - 3.3 Inventorying and estimating the number of species
4. State of biodiversity in the world
   - 4.1 Examples of biodiversity-rich countries
   - 4.2 Examples of natural areas rich in biodiversity
   - 4.3 The state of biodiversity in Algeria
5. Services provided by biodiversity
6. What value should be placed on biodiversity?
7. Is biodiversity threatened?
8. Management, restoration, and protection actions for biodiversity

Assessment Method: Examination

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FOREWORD

Biodiversity is essential for the processes that support all life on Earth, including humans. Without a wide range of animals, plants and microorganisms, we cannot have the healthy ecosystems that we rely on to provide us with the air we breathe and the food we eat.

Biodiversity is one of the most precious and important things we have. We tend to think of it as something that's just nice to look at, and enjoy spending time in, but it's actually so much more. Without biodiversity, our entire support system for human, as well as animal life, would collapse. We rely on nature to provide us with food and clean water, for a lot of medicines, and to prevent flooding and other extreme weather effects. So much is provided by the natural ecosystems around us – they're truly vital to life on earth. We think we can just trash one bit, or remove a species, and it'll all be ok, but the different plants and animals are interconnected in vital ways that we don't even always understand.

A key objective of the course of Biodiversity is to provide student of Master 1 in Biodiversity and Environement with scientifically credible and independent up-to-date assessments of available knowledge for better understand the health state of biological diversity at the local, national, regional and global levels. The concept of biodiversity, which is discussed in detail in chapter 1, embraces a wide range of descriptions of history and interactions with environment, including through the concept of ecosystem other descriptions, which range from strongly utilitarian to strongly relational. Beside this several methods using in the meseare of biodiversity were discuss. We will also present the health state of biodiversity in Algeria and in all the world.

Introduction

Naturalists provided through many centuries a large amount of data on the ecology, behaviour, distribution and morphological diversity of animals. However, before Linnaeus published the *Systema Naturae* (Linnaeus, 1735), in which the modern species concept was introduced, this information, often extremely detailed, obviously lacked the assignation of the studied organisms to their modern specifc names, making these old studies a great source of hidden biodiversity data. studying ancient works is important for several reasons: (1) it may provide historical distribution information on organisms before Linnaeus, a period generally not covered in the analyses of communities' variation through time; (2) it may provide additions on species composition and species interactions in habitats and environments that may have been lost in the last century through human activity; (3) it may unveil information on behavioural ecology of species that could be compared with information on behavioural ecology retrieved from modern populations of the same species. All these points are directly linked with three of the main shortfalls of biodiversity knowledge: the Wallacean shortfall (the knowledge on the geographic distribution of most species is incomplete), the Raunkiæran shortfall (lack of knowledge on species' traits and their ecological functions) and the Eltonian shortfall (lack of enough knowledge on species' interactions and their effects on individual survival and fitness) (Hortal et *al*., 2015).

The concept of biodiversity is rather unquestionably associated with the idea of untamed forms of life, living entities, or parts of living entities, which developed on Earth independently of or prior to humans. Far more controversial, instead, is whether biodiversity measurements and interventions should take into account also forms of life and living entities that have been to some degree infuenced by human activities (Borghini, 2017).

Biodiversity helps regulate climate through carbon sequestration and control of local rainfall, filters air and water, and mitigates the impact of natural disasters such as landslides and coastal storms. Direct benefits include food and fibres from natural vegetation, wood and non-wood products from forests, fish from oceans and freshwater systems, pollination of crops, medicines from plants, and psychological health (Clark et *al.,* 2014; Harrison et *al.,* 2014; World Health Organization [WHO] and Secretariat of the Convention on Biological Diversity [SCBD] 2015; Pascual et *al.,* 2017).

Biological diversity or biodiversity is the variety of life, in all of its many manifestations. It is a broad unifying concept, encompassing all forms, levels and combinations of natural variation, at all levels of biological organization (Gaston and Spicer, 2004).

Biodiversity constitutes the most important working component of a natural ecosystem. It helps maintain ecological processes, creates soils, recycles nutrients, has a moderating effect on the climate, degrades waste, controls diseases and above all, provides an index of health of an ecosystem. Providing food, medicines and a wide range of useful products, it is the natural wealth that exists on land, in freshwater and in the marine environment. Plant diversity alone offers more than just food security and healthcare for the one-quarter of humanity who live their lives at or near subsistence levels; it provides them with a roof over their heads and fuel to cook, and, on average, meets 90 per cent of their material needs (Tuxill, 1999).

Chapter 1: Concepts and Definition

1. History of the concept

The concept of biodiversity has evolved significantly over time, reflecting changes in scientific understanding, environmental awareness, and societal values.

a. Early Understanding (Pre-20th Century)

- Natural History: Before the term "biodiversity" was coined, the study of living organisms was primarily focused on taxonomy and natural history. Naturalists like Carl Linnaeus in the 18th century classified species, laying the groundwork for understanding biological diversity (Muller-Wille, 2006).

- Ecology: In the late 19th and early 20th centuries, the field of ecology emerged, emphasizing the relationships between organisms and their environments. This laid the foundation for understanding the importance of species interactions and ecosystems (Odum, 1971).

b. Emergence of the Term (1980s)

Historically, the word 'biodiversity' was first referred to as 'biological diversity' by the wildlife scientist and conservationist called Dasmann (1968) in a book he authored titled 'A different kind of country' which campaigned for the conservation of nature's resources. Despite the contradiction regarding the creditor of the word, what is worth knowing is that there is a consensus with the year 1985 when the word came into existence.

The term ''biodiversity'' was first used in its long version (biological diversity) by Lovejoy (1980) and is most commonly used to describe the number of species (Swingland, 2001). The latter usage appears to have come into prominence around 1980, when Norse and Mc Manus (1980) first defined it. Its abbreviation into 'biodiversity' was apparently made by Walter G. Rosen in 1985 during the first planning meeting of the 'National Forum on Biodiversity' held at Washington D.C. in September 1986 (UNEP, 1995). The published proceedings of this meeting in a book entitled *Biodiversity* (Wilson and Peters, 1988) introduced the notion of biodiversity and popularized this word among the scientific community as well as the public. Since then, not only the numbers of publications on biodiversity, but also of people interested in the subject for one reason or the other has steadily increased.

c. International Focus (1990s)

The United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro (Rio Summit or Earth Summit) has also substantially elevated the status of Biodiversity (Krishnamurthy, 2004).

The concept of biodiversity hotspots was introduced in the 1980s and 1990s, identifying regions with high levels of endemic species that are also under significant threat from human activities (Myers N., 1988).

d. 21st Century Developments

- Biodiversity Assessments: The early 2000s saw comprehensive assessments of global biodiversity, such as the Millennium Ecosystem Assessment (2005), which highlighted the critical role of biodiversity in ecosystem services and human well-being. Biodiversity is one of the words in the area of ecological and environmental sciences that does not lend itself to a particularly unique meaning. Chadwick (1993) concurs that there is no agreed definition of the word. Owing to this, the word 'biodiversity', according to Science for Environment Policy (2015), is assigned different meanings in line with the context of its usage in ecosystem assessments and ecological services. Many conservationists and biological scientists normally adopt a working definition to suit their interests and the idea regarding the word they want to propagate.

- Biodiversity and Climate Change: As awareness of climate change grew, the interconnections between biodiversity and climate resilience became a focal point for conservation efforts.

- Biodiversity Crisis: The ongoing biodiversity crisis, characterized by accelerated species loss and habitat degradation, has led to increased advocacy for conservation and sustainable practices.

e. Current Trends and Future Directions

The word Biodiversity is now very widely used not only by the scientific community, but also the general public, environmental groups, conservationists, industrialists and economists. It has also gained a very high profile in the national and international political arena (Krishnamurthy, 2004).

- Integrative Approaches: Today, biodiversity is understood not just in terms of species counts but also in relation to ecosystem functions, cultural values, and human health. There is a growing emphasis on integrating biodiversity conservation with social and economic considerations.

- Global Initiatives: Recent global initiatives, such as the Post-2020 Global Biodiversity Framework, aim to set ambitious targets for biodiversity conservation and sustainable use, reflecting the urgency of addressing the biodiversity crisis.

In summary, the concept of biodiversity has transitioned from a focus on species classification to a comprehensive understanding of the intricate relationships within ecosystems and the importance of preserving biological diversity for the health of the planet and humanity.

2. Definition of biodiversity

The India's Biological Diversity Act 2002 defined it as, "the variability among living organisms from all sources and the ecological complexes of which they are part and includes diversity within species or between species and of ecosystems" (BDA, 2002).

Delong (1996) has defined biodiversity as "an attribute of an area and specially refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be measured in terms of gene, and the identity and the number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount of (*e.g.*, abundance, biomass, cover, and rate) and structure of each. It can be observed and measured at any spatial scale ranging from micro sites and habitat patches to the entire biosphere.

Biodiversity is generally considered an 'umbrella term' referring to organisms found within the living world, ***i.e.,*** the number, variety and variability of living organisms. It may thus be assumed to be a synonym for 'Life on Earth', variety of life and its processes' (Keystone Center, 1991), 'condition of being different' (Gove *et al.,* 1996), or what Darwin exclaimed as 'Life endless forms'. Taken in this general sense, biodiversity is indeed 'the essence of life' (Frankel, 1970). In reality, however, biodiversity is a very vast and complex concept and its ramifications extend deep into all spheres of human life and activity (Krishnamurthy, 2004).

Cho (2011) defines biodiversity as 'the variety of all living organisms including ecosystems, plants, animals, their habitats, and genes.' Takacs (1996), on the other hand, defines biodiversity as 'the full variety of life on earth'. The term concerns itself with the variety of individual species within populations and communities and the range of ecological roles within ecosystems (Science for Environment Policy, 2015). A generally loose definition for biodiversity implemented by biologists is the whole number of genes, species and of ecosystems of a region.

In technical parlance biodiversity is the variety and variability of life on the earth. It includes diversity of forms right from the molecular unit to the individual organism, and then on to the population, community, ecosystem, landscape and biosphere levels. *In the simplest sense, biodiversity may be defined as the sum total of species richness,* ***i.e.,*** *the number of species of plants, animals and microorganisms occurring in a given region, country, continent or the entire globe* (Agrawal, 2002).

All these definitions share one thing in common regarding biodiversity. It refers to the different kinds of all living organisms on earth and the different dwelling places. However, the most widely used explanation of the word 'biodiversity' is what the Convention of Biological Diversity gave. It defined biodiversity as 'the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystem' (CBD 1992). The International Union for the Conservation Nature (IUCN) also uses the term biological diversity to describe the variety of life on earth, including the number, variety and variability of living organisms like animals, plants, fungi, microbes etc. and the genetic differences among them and the ecosystems in which they occur.

3. Definition of domestic biodiversity and wild biodiversity

Domestic Biodiversity refers to the variety of living organisms that have been domesticated by humans for various purposes, such as agriculture, companionship, or utility. This includes cultivated plants (like crops and ornamental plants) and domesticated animals (such as livestock, pets, and working animals). Domestic biodiversity is characterized by selective breeding and genetic modification to enhance desirable traits, such as yield, disease resistance, or temperament.

Wild Biodiversity, on the other hand, encompasses the variety of living organisms that exist in their natural habitats without direct human influence or domestication. This includes all species of plants, animals, fungi, and microorganisms that thrive in ecosystems ranging from forests and grasslands to oceans and deserts. Wild biodiversity is crucial for maintaining ecological balance, supporting ecosystem services, and providing genetic resources that can be important for agriculture, medicine, and conservation efforts.

Chapter 2: Assess biodiversity

In the case of biodiversity, two main kinds of diagnostic challenges have to be addressed: on the one hand, the diffculties concerning data collection and systematisation; on the other hand, the choice of the appropriate measurement techniques and ways of monitoring.

Starting with the first challenge, probably the most striking aspect of the living world is its amazing variety, so immense that it eludes even our hardest systematisation attempts.

The second challenge addressed concerns the choice of the appropriate biodiversity measurements and the ways of monitoring the condition of the patient. Measuring biodiversity is a fundamental operation in biodiversity conservation, for instance because, when we need to choose and implement conservation actions, financial resources are usually limited; accordingly, ecologicals systems and/or places—i.e., specifc regions on Earth's surface "filled with the particular results of [their] individual story" (Sarkar 2002)—have to be prioritised and, to do so, biodiversity must be measured.

In a similar way as temperature can be measured by means of a substance, mercury, whose characteristics are particularly sensitive to heat fuctuations and easily measurable, a biodiversity surrogate is thought to be a sort of biological thermometer that would allow to measure biodiversity, even though indirectly.

1. How to measure biodiversity?

Assessing biodiversity involves evaluating the variety and variability of life forms within a given ecosystem, region, or the entire planet. This assessment is crucial for understanding ecological health, conservation needs, and the impacts of human activities. Assessing biodiversity involves various methods and approaches that can be categorized into several key areas.

1. 1. Field Surveys

- **Species Inventory**: is a comprehensive list or catalog of the various species present in a specific area or ecosystem. This inventory typically includes information about the species' names, characteristics, distribution, abundance, and ecological roles. Species inventories are crucial for biodiversity assessments, conservation planning, and ecological research, as they provide baseline data that can be used to monitor changes in ecosystems over time.

- **Quadrat Sampling**: Using fixed plots to assess species richness and abundance within a defined area. Plot size should be determined on the basis of the size and density of the plants being sampled. Plots should be large enough to contain significant numbers of individuals, but small enough that the individuals present can be separated, counted, and measured without confusion leading to duplication or omission of individuals. Suggested plot size are 1 square meter for herbaceous vegetation, 10-20 square meters for communities of shrubs or saplings up to about 3 meters in height, and 100 square meters for forest tree communities (Oosting, 1956) (fig. 1).

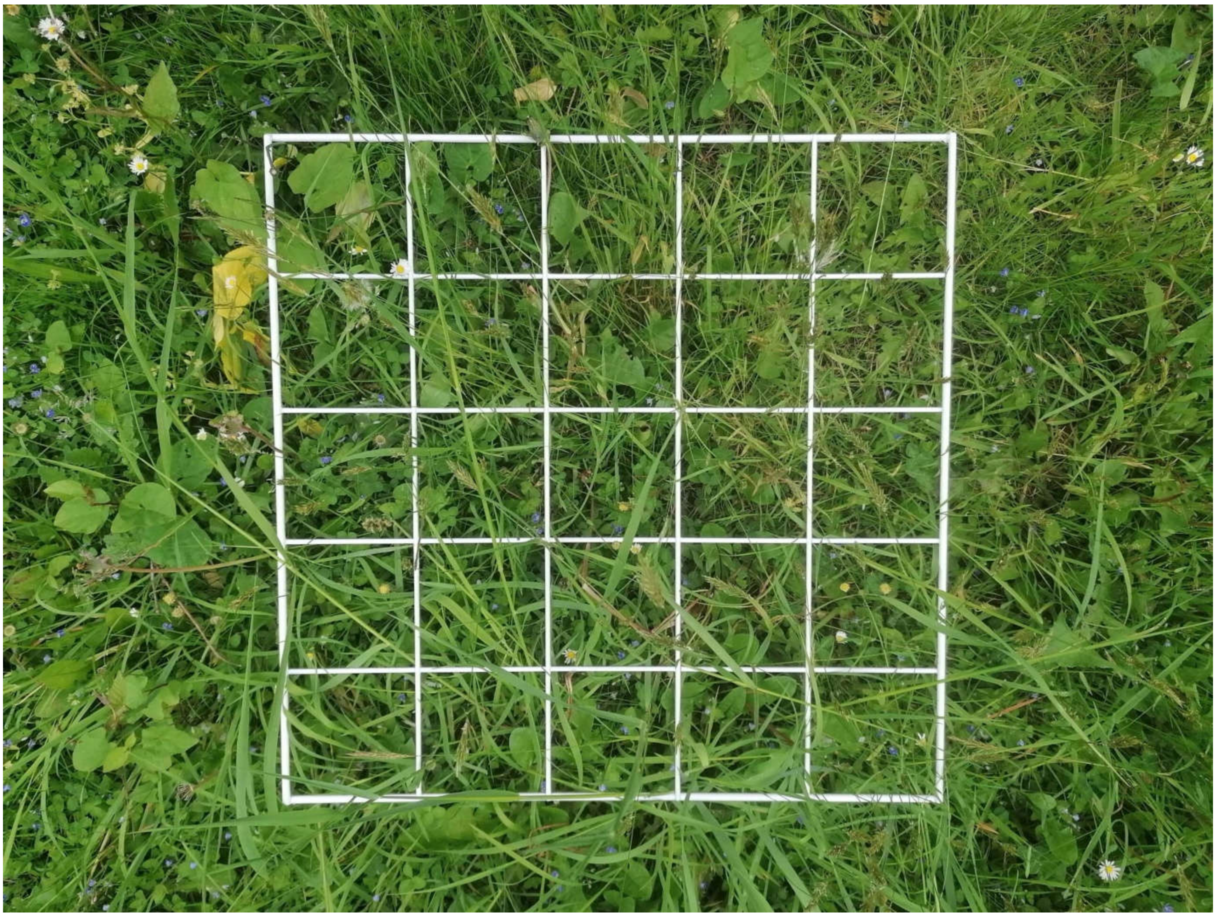

Figure 1. Quadrat Simpling

- **Transect Sampling**: Establishing linear paths across a habitat to record species presence and abundance (Fig. 2).

Figure 2. Line Transect

1. 2. Remote Sensing

- Satellite Imagery: Utilizing satellite data to assess land cover, habitat types, and changes in ecosystems over time (Fig. 3).

- Aerial Photography: Capturing images from aircraft or drones to analyze vegetation patterns and habitat distribution.

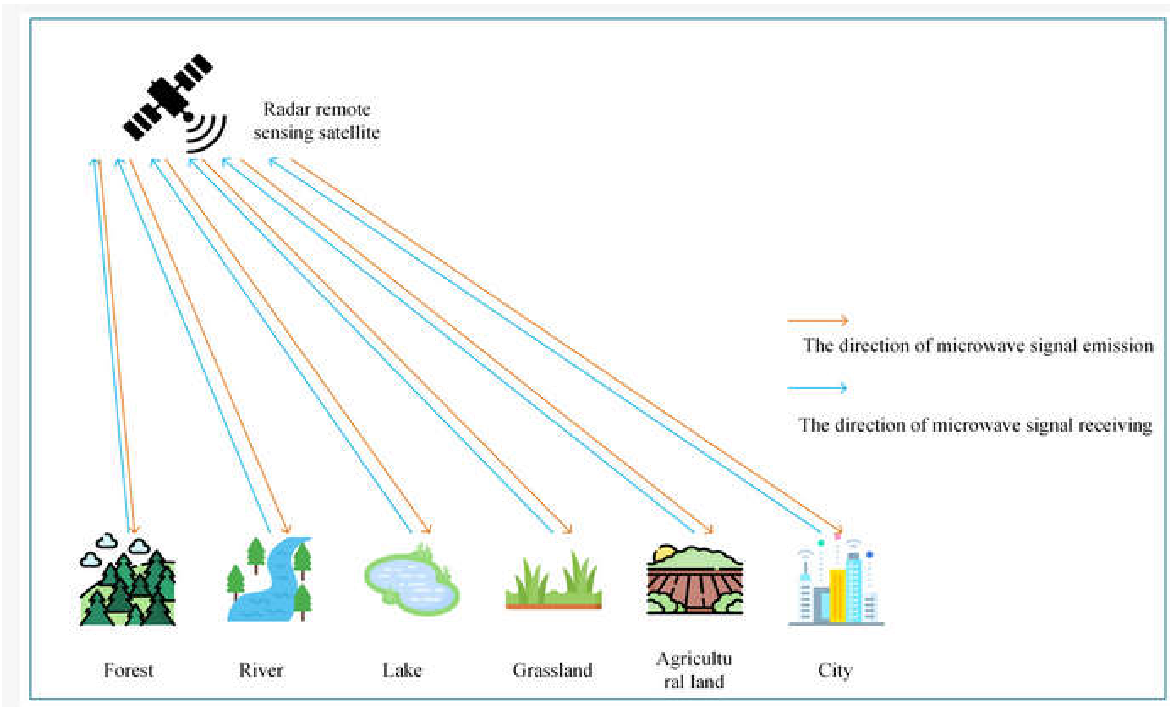

Figure 3. Remote sensing methods

1.3. Genetic Analysis

DNA barcoding is a new and exciting tool for the quick identification of any species of all life forms using a short nucleotide sequence. Paul D. N. Hebert et al. (2003) from the University of Guelph, Ontario, Canada, suggested current DNA barcoding as a method for identifying species in 2003. DNA barcoding has two basic steps, which is creating DNA barcode library of known species and identification of unknown samples against the barcode library using barcode sequence. Biodiversity monitoring (e.g., ecological, taxonomic, and conservation studies) and forensic science are examples of fields where DNA barcoding can be used. Furthermore, DNA barcoding could be used to track illegal wildlife trade, such as endangered or protected species (Shivji et al., 2002; Baker et al., 2000), or to DNA barcoding is a modern standard method to discover the unknown species. Some marker DNA are used to detect species. DNA barcoding is a DNA based technique where a small sequence of DNA is used to species identification. Marker DNA can be collected from nucleus, mitochondria and chloroplast. Cytochrome oxidase c subunit 1 is the ideal marker for eukaryotic species identification and 18S rDNA, 28S rDNA, and internal transcribed spacer are commonly used DNA barcodes (Powers et *al*., 2018; Montano et *al.*, 2015). Internal transcribed spacer (ITS) rRNA used for fungi and RuBisCO used for plants (Schoch et al., 2012; Hollingsworth et al., 2009).

Real-time DNA barcoding opens new chapter on biodiversity assessments and to understand the variation in genes, species, and ecosystems (Pomerantz et *al*., 2018). DNA barcoding provides an easy, simple and automatic qualitative method. Already this technique has been applied to different species (Fig. 4).

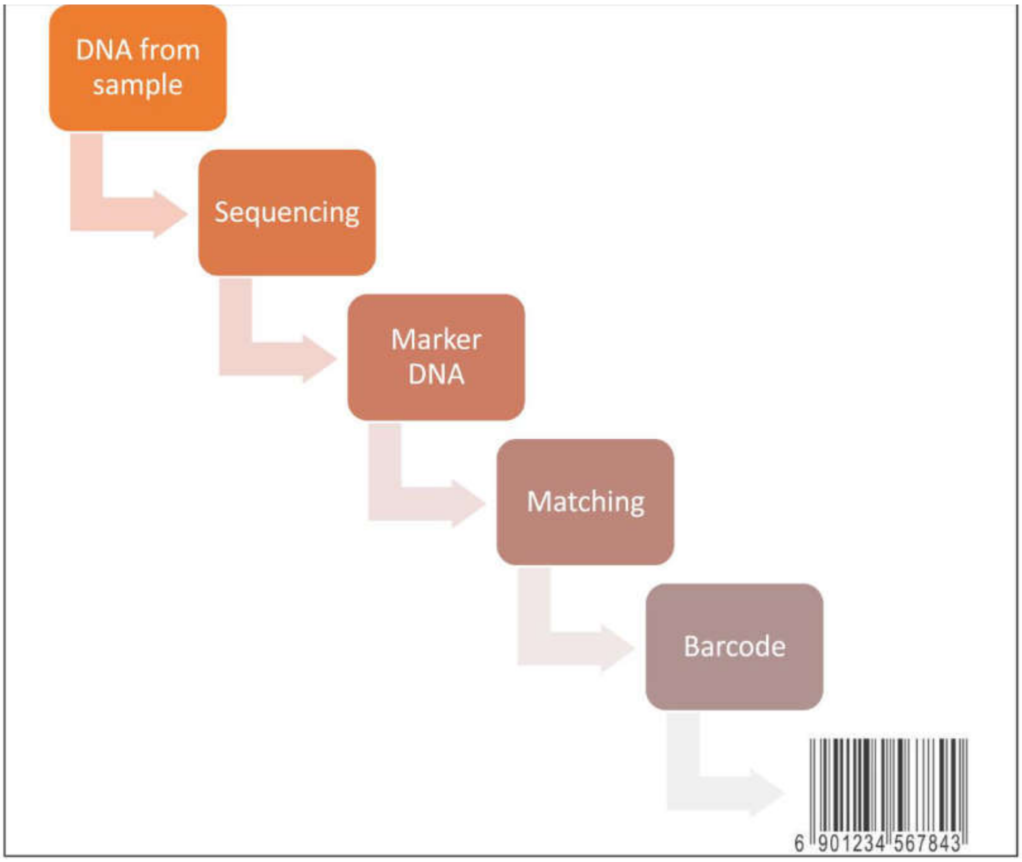

Figure 4.DNA Bar coding

DNA barcoding is the molecular technique for species identification. This technique is performed by few steps like

i). Sample collection

ii) Tissue sampling

iii) DNA processing

iv) PCR

v) DNA amplification and sequencing

vi) Bioinformatics (Blast)

vii) Sequence similarity and species identification (Ahmed et *al*., 2018; Chen et *al*., 2017)

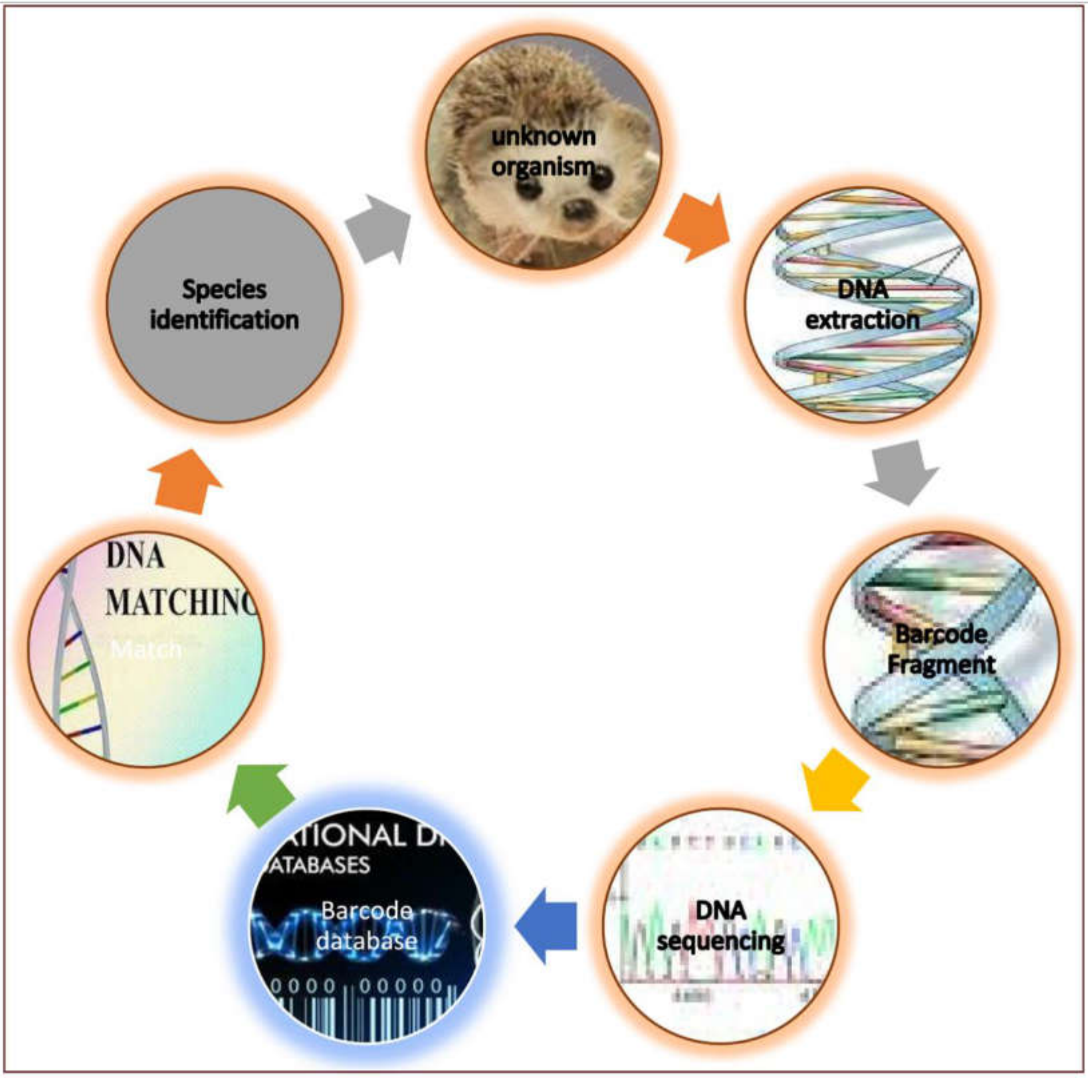

Figure 5: DNA barcoding workflow (Wilson et al., 2018)

DNA barcoding is the ideal tool for species discovery and identification. Which species are difficult to identify they also identified easily (Lopez-Vaamonde et *al.*, 2021). Barcoding and metabarcoding helps to increase number of world's species by discovering biodiversity (Li et *al.*, 2021). Fish, mollusk, algae, plant, animal species can easily identified by this molecular method (fig. 6).

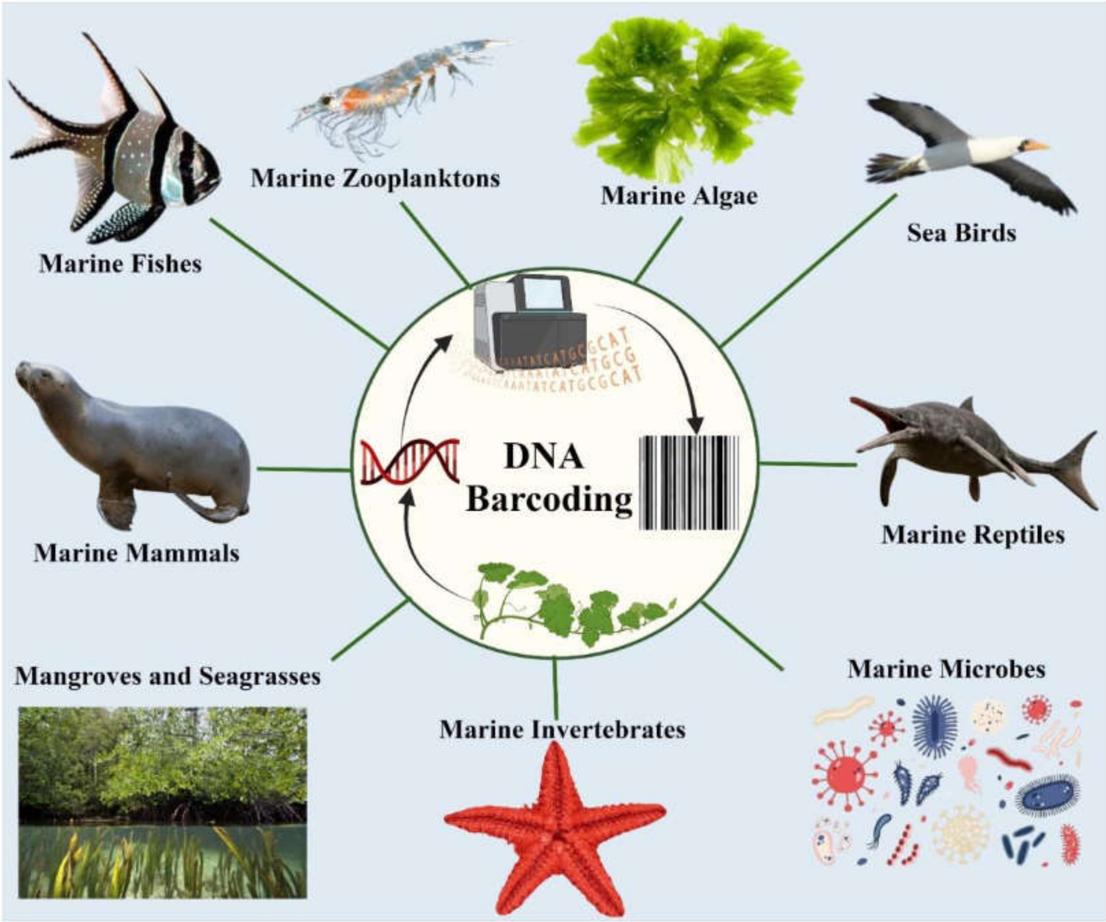

Figure 6. Application of DNA barcoding on Marine Ecosystem.

Metagenomics

Metagenomics refers to the application of sequencing techniques to analyse the totality of the genomic material present in a sample (Roumpeka et *al*., 2017). Currently, two main methods for studying microbial communities using high-throughput sequencing are used: marker gene studies and whole-genome shotgun (WGS) metagenomics. WGS metagenomics aims to sequence all genomes existing in an environmental sample to analyse the biodiversity and the functional capabilities of the microbial community studied. As the entire genetic material of a sample is recovered, it is possible to characterize the complete diversity of a habitat, including archaea, bacteria, eukaryotes, viruses and plasmids, as well as its gene content. In contrast, marker gene analyses are based on the sequencing of a gene-specific region to reveal the diversity and composition of specific taxonomic groups present in an environmental sample (Fig. 7).

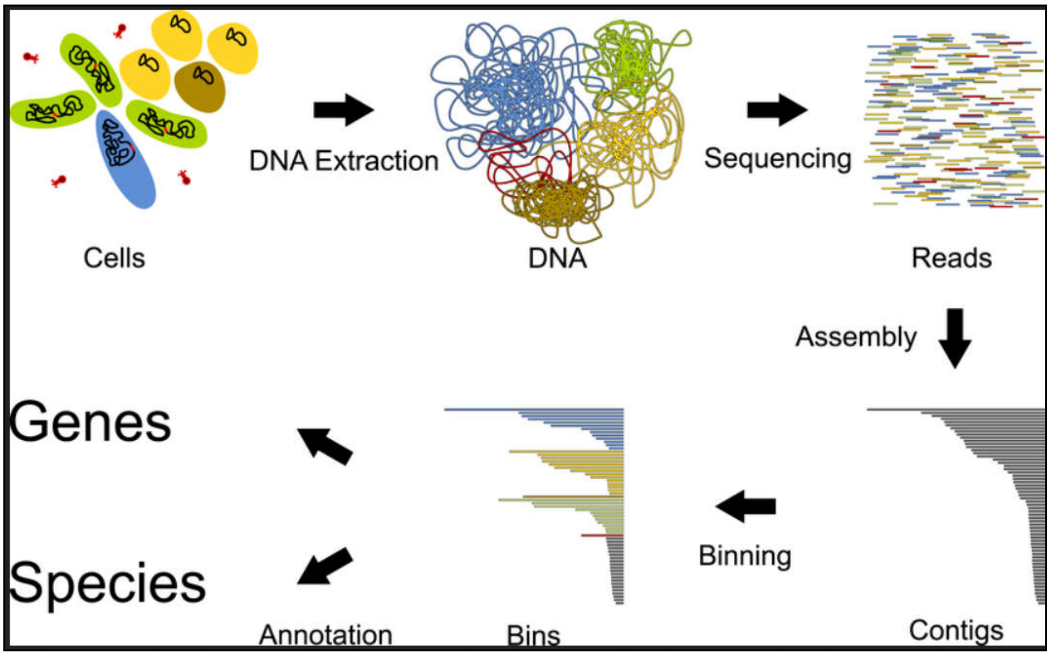

Figure 7. Metagenome analysis scheme (Goussarov et al., 2022)

First, DNA in the test sample is extracted. Then, reads are produced by sequencing, exposing the DNA's sequence as a series of fragments. After this, overlapping reads are assembled, producing "contigs." During these two steps, the source of each sequence is unknown; therefore, an additional separation step called binning is necessary. Finally, each sequence needs to be annotated, which is the process of assigning meaningful names to different subsequences.

The principal marker genes used in microbial ecology are the 16S rRNA gene (to analyse the presence of archaea and bacteria) (Case et *al*., 2007), the internal transcribed spacer (ITS) region (to characterize the composition of the fungal community) (Schoch et al., 2012) and the 18S rRNA (to report the occurrence of eukaryotes) (Nilsson et *al.*, 2013).

1.4. Ecological Modeling

Ecological modeling is a powerful tool used by ecologists and conservationists to understand and predict ecological phenomena. It involves the use of mathematical and computational techniques to simulate ecological processes and interactions. In assess of biodiversity, we have two important aspects of ecological modeling: Species Distribution Models (SDMs) and Biodiversity Indices.

A. Species Distribution Models (SDMs):

Species distribution modeling (SDM) is a methodology – a set of procedures, definitions, and techniques – built on a foundation of core ecological and biogeographical concepts about the relationship between species distributions (or other biotic response variables describing aspects of biodiversity) and the physical (abiotic) environment. SDMs are quantitative, empirical models of species–environment relationships typically developed using species location data (occurrence, abundance) and those environmental variables thought to influence species distributions. Sometimes biotic information (other species, vegetation types, etc.) is included as a predictor variable. Provided appropriate data are available, SDMs can be applied to any taxa, including marine, terrestrial, and freshwater species, and at any grain and extent. Although the models can provide insights into factors influencing patterns of biodiversity even without predicting to maps, often the models are extended to making spatial predictions using maps of the environmental predictors. The practice of SDM has flourished over the past four decades in part because geospatial species locality and environmental data have become so widely available. The spatial predictions as well as the models themselves can inform both basic and applied biodiversity research (Elith and Franklin, 2024).

Some of the earliest uses of SDMs focused on the insight and explanation that the models or their mapped predictions can provide, and this role continues to be important to this day. For instance, Leathwick and Austin (2001 in Elith and Franklin, 2024) explored competitive interactions between tree species in New Zealand's forests in a dataset in which geographic disjunctions provided the equivalent of a natural removal experiment. Regression models relating plot-based estimates of tree density to environmental and biotic covariates indicated substantial competitive displacement (e.g., Fig. 8). This was one of the first pieces of statistical evidence for competition effects under field conditions. A second example of this theory-oriented use of SDMs is the recent focus on examining evidence for, and methods for detecting, niche shifts or niche conservatism (Wiens *et al*., 2010 in Elith and Franklin, 2024) under processes of invasion or speciation (e.g., Broennimann *et al*., 2007 in Elith and Franklin, 2024)

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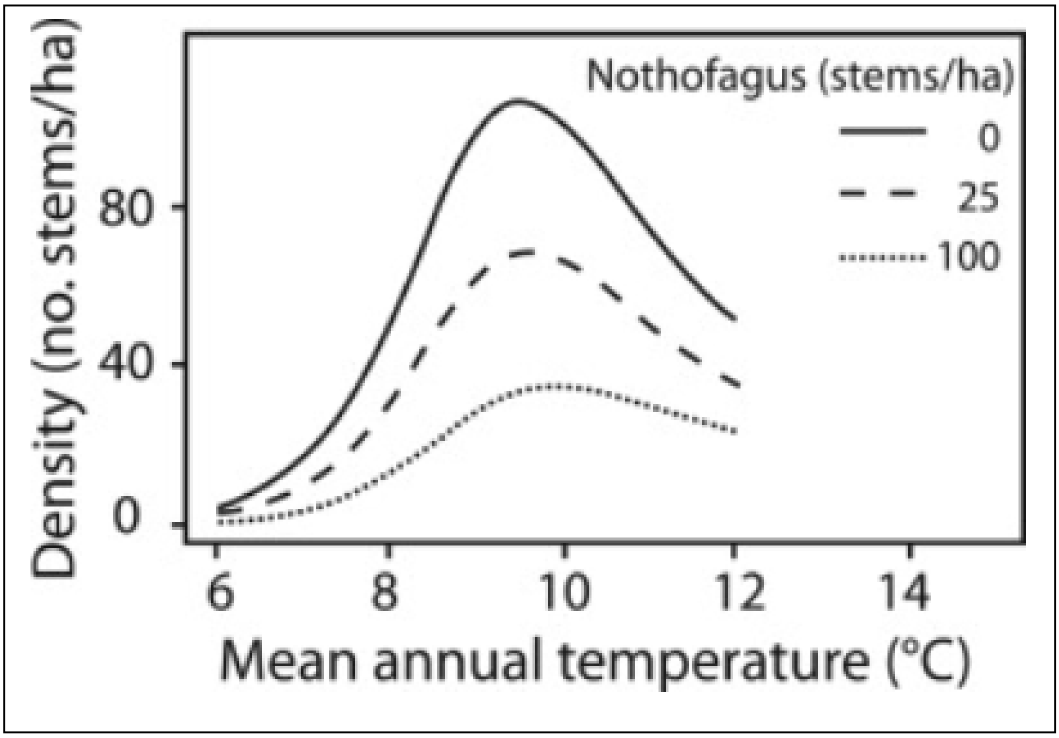


Figure 8. Density of the tree Weinmannia racemosa in relation to mean annual temperature, for 0, 25, and 100 stems per hectare of a competitor, Nothofagus (four species, combined) (Elith and Franklin, 2024)

These models help us understand where species are likely to be found and how they might respond to changes in their environment. The key Components of SDMs are:

- Environmental Variables: These can include climate data (temperature, precipitation), land use, elevation, and other ecological factors that influence species distribution.
- Species Occurrences: Data on where a species has been observed, often collected through field surveys or databases like the Global Biodiversity Information Facility (GBIF).
- Modeling Techniques: Common techniques used in SDMs include:Generalized Linear Models (GLMs), MaxEnt (Maximum Entropy), Random Forests and Machine Learning Approaches.

B. Biodiversity Indices:

A diversity index is a quantitative measure that reflects how many different types (such as species) there are in a dataset (a community). These indices are statistical representations of biodiversity in different aspects (richness, evenness, and dominance). When diversity indices are used in ecology, the types of interest are usually species, but they can also be other categories, such as genera, families, functional types, or haplotypes. The entities of interest are usually individual plants or animals, and the measure of abundance can be, for example, number of individuals, biomass or coverage.

Richness simply quantifies how many different types the dataset of interest contains. For example, species richness (usually noted *S*) of a dataset is the number of species in the corresponding species list. Richness is a simple measure, so it has been a popular diversity index in ecology, where abundance data are often not available for the datasets of interest.

Although species richness (denoted ***S***) is often used as a measure of biodiversity, of more interest to ecologists and conservation biologists are diversity indices that include both species richness *and* measures of abundance. This is because richness alone does not account for evenness across species. In Example below (Fig. 9), both lakes have the same richness, but Lake B is more diverse because abundance is spread more evenly across the species present.

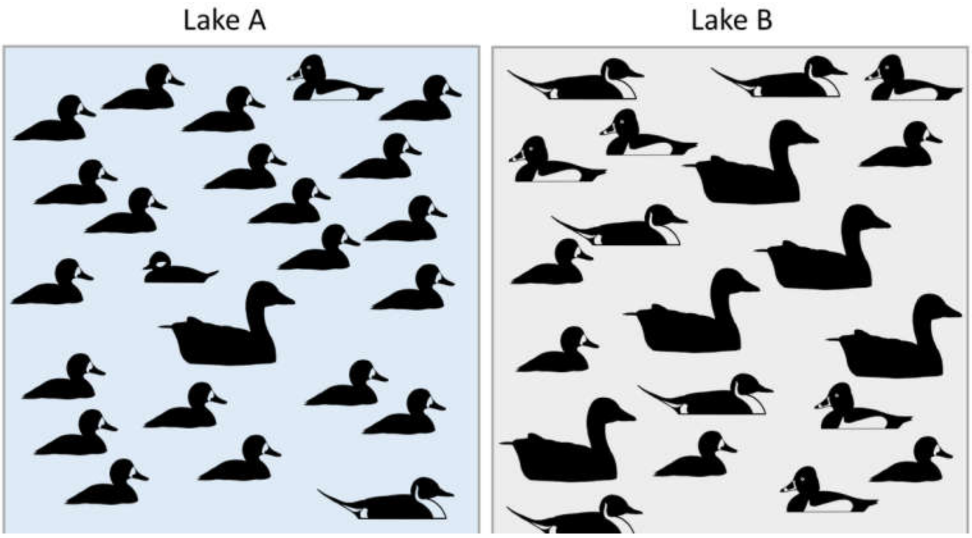


Figure 9. Though both Lakes A and B have the same amount of birds and the same number of different species, their diversity is different.

Many different indices of diversity are used by scientists, but below we cover the most widely used.

Simpson's Index

Simpson (1949) developed an index of diversity which is a measure of probability--the less diversity, the greater the probability that two randomly selected individuals will be the same species. In the absence of diversity (1 species), the probability that two individuals randomly selected will be the same is 1. Simpson's Index is calculated as follows:

$$D=\sum_{i=1}^{S}\left(\frac{n_i}{N}\right) \qquad Eq1$$

where n_i is the number of individuals in species *i,* N = total number of individuals of all species, and $n_i/N = p_i$ (proportion of individuals of species i), and S = species richness.

The value of Simpson's ***D*** ranges from 0 to 1, with 0 representing infinite diversity and 1 representing no diversity, so the larger the value of ***D***, the lower the diversity. For this reason, Simpson's index is often as its complement (1-***D***). **Simpson's Dominance Index** is the inverse of the Simpson's Index (1/***D***).

Shannon-Weiner Index

Another widely used index of diversity that also considers both species richness and evenness is the Shannon-Weiner Diversity Index, originally proposed by Claude Shannon in 1948. It is also known as **Shannon's Diversity Index.** The index is related to the concept of uncertainty. If for example, a community has very low diversity, we can be fairly certain of the identity of an organism we might choose by random (high certainty or low uncertainty). If a community is highly diverse and we choose an organism by random, we have a greater uncertainty of which species we will choose (low certainty or high uncertainty).

$$H=-\sum_{i=1}^{S}p_i*\ln p_i \qquad Eq2$$

where p_i = proportion of individuals of species *i*, and ln is the natural logarithm, and S = species richness.

The value of ***H*** ranges from 0 to H_{max}. H_{max} is different for each community and depends on species richness. (Note: Shannon-Weiner is often denoted H').

Evenness Index

Species evenness refers to how close in numbers each species in an environment is. So if there are 40 foxes and 1000 dogs, the community is not very even. But if there are 40 foxes and 42 dogs, the community is quite even. The evenness of a community can be represented by Pielou's evenness index (Pielou, 1966):

$$J=\frac{H}{H_{max}} \qquad Eq3$$

The value of J ranges from 0 to 1. Higher values indicate higher levels of evenness. At maximum evenness, ***J*** = 1.

J and ***D*** can be used as measures of **species dominance** (the opposite of diversity) in a community. Low J indicates that 1 or few species dominate the community.

Ecological modeling, through tools like Species Distribution Models and biodiversity indices, plays a crucial role in understanding and conserving our natural world. By predicting species distributions and quantifying biodiversity, we can make informed decisions that promote the sustainability of ecosystems. As we continue to face environmental challenges, these models will be essential in guiding conservation efforts and policy-making.

Estimation of the amount of carbon stored in a tree using biomass calculations:

This activity is related to the theoretical part of ecosystem services and requires mathematical skills. Carbon is a chemical element that is very present in all living beings. Every form of life is primarily composed of carbon, oxygen, and hydrogen. Trees are made up of 50% carbon because they store a large amount of it in the walls of their cells, in particular. All trees perform photosynthesis, which allows them to create new tissues and grow. In particular, they use atmospheric CO2 to store it in the form of organic or plant matter (wood/leaves/fruits/roots...).

The following activity allows you to estimate the amount of CO2 that a tree or a forest can store in its biomass. In this way, we know the amount of two ecosystem services that our forests generate, one being the amount of wood, as a provisioning service, and the other being the CO2 absorbed, as a regulating service.

To access the amount of carbon stored in a tree, we must first calculate the volume of a tree Vt, then we will calculate the total biomass of the tree Bt, and finally, we can estimate how much carbon is in all this biomass QCO2.

To perform these calculations, it is necessary to have measurements on the same tree: height measurement Ht, circumference measurement C1.3 (circumference taken at 1.3m from the ground). (We can use averages if we consider the scale of a forest.)

Measurement of the Height and Circumference of a Tree

The data collection carried out in the field is simply the circumference of the trunk and the height of the trunk.

- Height

Measure height application was used to measure the height of trees

- *Circumference*

To measure the circumference, a standard tape measure will be used to wrap around the trunk and measure its diameter. All the foresters in the world have decided that the circumference of a tree is measured at 1.3 meters above the ground. You then take your measuring tape to measure 1.3 meters from the ground, you go around the tree horizontally, holding the tape measure firmly, to know its circumference.

- Calculation of the aerial volume of a tree

We use the following formula to calculate the total volume of the tree.

$$V_t = 0{,}496 \times \frac{H_t \times {C_{1,3}}^2}{4\pi}$$

With :

V_t : Total volume of the tree (m3)

$C_{1,3}$: Circumference at a height of 1.3 m

H_t Total height of the tree (m)

f Form factor of the tree, which can be estimated at 0.496 for all species

- Calculation of the amount of CO2 in a tree

Another ecosystem service provided by the forest, in addition to the one calculated above, is CO2 absorption. The estimation of this CO2 absorption is given in tons, and it is increasingly important to know it, as this element is directly linked to climate change.

Forests store more carbon than they release, and are therefore considered carbon sinks. The carbon dioxide or inert CO2 they absorb from the atmosphere is directly stored in the form of biomass (living organic matter).

In order to access this amount of carbon stored in trees, it is necessary to first calculate the biomass of a tree.

- Calculation of aerial biomass

Next, from the total volume of aerial wood Vt and the infradensity of the wood di, it is possible to calculate the aerial biomass of dry matter. The infradensity is defined as the ratio between a mass of dry wood and its volume at saturation point. It is expressed in tons of dry matter per m³ (tDM/m³).

$$B_a = V_t \times d_i$$

With:

B_a Aerial biomass in tons of dry matter (tMS)

V_t Total volume of the tree (m3)

d_i Species infradensity (tMS/m3) which can be estimated at 0.546 tMS/m3 for hardwoods and 0.438 tMS/m3 for softwoods.

- Calculation of total biomass

Next, once the aerial biomass B_a has been obtained, the underground part of the trees must be integrated. It is estimated using root expansion factors or equations based on above-ground biomass . BEF_r

With:

$$B_t = B_a \times BEF_r$$

B_t Total biomass, aerial and root (tMS)

B_a Aerial biomass (tMS)

BEF_r The root expansion factor, which can be estimated at 1.28 for deciduous trees and 1.30 for conifers

- Calculation of the quantity of carbon

Finally, the quantity of carbon Q_{CO2} contained in a tree can be calculated from the total biomass (aboveground and belowground) and the carbon content in the dry matter. Finally, to convert a value in tons of carbon to a value in tons of CO2, simply multiply the mass of carbon by the molar mass of a CO2 molecule, which is $\frac{44}{12} \approx 3,67$

$$Q_{CO2} = \tau_c \times B_t \times \frac{44}{12}$$

With:

Q_{CO2} The amount of CO2 sequestered in a tree (t)

τ_C The carbon rate, which can be estimated at 0.475 tC/tMS

B_t Total biomass, aerial and root (tMS)

1. 5. Citizen Science

Citizen science projects cover a broad range of topics across diverse disciplines such as biology, art, history, climate, nature, social science, literature, and space. Sometimes referred to as 'crowd science', 'networked science', or 'massively-collaborative science' (Franzoni & Sauermann, 2014 in Hodgkinson et *al.*, 2021), the term 'citizen science' was first defined by sociologist Irwin (1995) as 'a science which assists the needs and concerns of citizens … a form of science developed and enacted by citizens themselves' (p. xi). More recently, the European Commission's white paper on citizen science defined it as 'general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources' (EC, 2014 in Hodgkinson et *al.*, 2021).

Based on the stages of the scientific process in which volunteer citizens are involved and their degree of control and participation, citizen science projects can be classified as either contributory, collaborative, or co-created (Bonney et *al.*, 2009 in Hodgkinson et *al.*, 2021). Contributory projects are those where scientists generally shape the project design and research questions, and members of the public mainly help to collect data; collaborative projects involve the public in project design, data analyses, or dissemination of findings; and co-created projects involve citizens throughout, where at least some members of the public are actively involved in most or all stages of the scientific process.

While the goals of citizen science projects are varied, there is consensus that 'citizen science holds the potential for developing new ways to *collectively solve big problems* and to fundamentally change the relationship between science and society' (Bonney et *al.*, 2016 in Hodgkinson et *al.*, 2021).

Citizen science projects are prevalent throughout the world, with millions of individuals participating in the process of scientific discovery (Bonney et *al.*, 2016 in Hodgkinson et *al.*, 2021). Consequently, professional associations are actively supporting and co-ordinating best practices for citizen science projects, such as the European Citizen Science Association (ECSA), the Citizen Science Association (CSA) in the USA, and the Australian Citizen Science Association (ACSA). Public bodies have followed this development. The US federal government, for instance, provides an e-toolkit to assist with designing and maintaining citizen science projects and, in 2021, UK Research and Innovation (UKRI, 2016 in Hodgkinson et *al.*, 2021) invested £1.46 million in funding a series of citizen science projects.

The potential role of citizen science to solve wicked problems is highlighted by Fraisl et *al*. (2020 in Hodgkinson et *al.*, 2021, who observe how such projects are proving critical to realizing the United Nations Sustainable Development Goals (SDGs). In Ecology, projects driving the discovery of new solutions include:

- *BioCollect*, developed by the Atlas of Living Australia (ALA), collects biodiversity data in collaboration with organizations and citizens. New biodiversity data is transferred to the ALA to enable access to big data for activity-based interventions (for example protection and restoration) (ala.org.au/biocollect/).

- *Air Quality Citizen Science* uses low-cost sensors deployed by citizen scientists to generate spatially and temporally resolved air quality data that complement NASA satellite observations. The overarching goal is to help overcome particulate air pollution, which is the cause of an estimated 6.5 million deaths every year from pollution-attributable diseases (aqcitizenscience.rti.org).

Technology has revolutionized the way citizen science projects are conducted. Various platforms and mobile applications have been developed to facilitate community involvement in data collection. Here are some popular examples:

1. **iNaturalist**: This platform allows users to record and share observations of plants and animals. Users can upload photos, and the community helps identify species. The data collected contributes to biodiversity research and conservation efforts.

2. **eBird**: Managed by the Cornell Lab of Ornithology, eBird is a citizen science project that allows birdwatchers to report their sightings. The data collected helps researchers track bird populations and migration patterns.

3. **Zooniverse**: This platform hosts a variety of citizen science projects across different fields, including astronomy, ecology, and history. Volunteers can participate in tasks such as classifying images or transcribing historical documents.

4. **Project Noah**: This app encourages users to document wildlife in their local areas. Participants can create "missions" to focus on specific species or habitats, fostering community engagement and education.

Citizen science represents a powerful tool for advancing scientific research while fostering community involvement and environmental stewardship. By leveraging technology and engaging the public in data collection, we can enhance our understanding of the natural world and address pressing environmental challenges. As we continue to explore the potential of citizen science, it is essential to prioritize community involvement, ensuring that everyone has a voice in the scientific process.

1. 6. Long-term Monitoring Programs

Long-term datasets are as old as ecology itself. In the same way that astronomy flourished once observers began to systematically document the positions of stars and planets, the development of ecology as a discipline is linked to the accumulation of data on the distribution and abundance of species in space and time. These data collections were often initiated to answer applied questions. For example, The Park Grass Experiment at Rothamsted in southern England, now the longest running (Anne E. Magurran et *al*., 2010).

Long-term datasets are an essential resource in biodiversity research and monitoring. However, we have it is not always as easy as it first appears to determine whether the underlying nature of a community is changing, and by how much.

Long-term monitoring programs focused on biodiversity are essential for understanding ecological changes, assessing the health of ecosystems, and informing conservation efforts. These programs typically involve systematic, repeated observations and data collection over extended periods. Here’s a breakdown of the methods and approaches used in these programs:

A. Study Design

- Objectives: Clearly define the goals of the monitoring program, such as tracking species populations, habitat changes, or ecosystem health.

-Spatial and Temporal Scale: Determine the geographic area and the time frame for monitoring. Long-term programs often span years or decades to capture trends and changes.

B. Baseline Data Collection

- Initial Surveys: Conduct comprehensive surveys to establish baseline data on species richness, abundance, and distribution.

- Habitat Assessment: Evaluate the physical and biological characteristics of the habitats being monitored.

C. Sampling Methods

- Site Selection: Use random or stratified sampling methods to select monitoring sites that represent the diversity of habitats and species.

- Standardized Protocols: Implement standardized methods for data collection to ensure consistency. This may include:

*Transects and Plots: Establish fixed transects or plots for vegetation and species surveys.

*Point Counts: Use point count methods for bird populations.

*Camera Traps: Employ camera traps for monitoring elusive or nocturnal species.

*Aquatic Surveys**: Utilize netting, electrofishing, or visual surveys for aquatic biodiversity.

D. Data Collection

- Quantitative Data: Collect numerical data on species counts, biomass, and other measurable parameters.

- Qualitative Data: Record observations on species behavior, habitat conditions, and ecological interactions.

- Citizen Science: Engage the public in data collection to expand monitoring efforts and increase community involvement.

E. Data Management and Analysis

- Database Development: Create a centralized database to store and manage collected data.

- Statistical Analysis: Use statistical methods to analyze trends, assess biodiversity indices, and evaluate the effects of environmental changes.

- Longitudinal Studies: Compare data over time to identify patterns, shifts in species distributions, and changes in ecosystem functions.

F. Reporting and Communication

- Regular Reporting: Produce periodic reports summarizing findings, trends, and implications for biodiversity conservation.

- Stakeholder Engagement: Communicate results to stakeholders, including policymakers, conservation organizations, and the public, to inform decision-making.

G. Adaptive Management

- Feedback Loop: Use monitoring results to adapt management strategies and conservation practices. This may involve modifying sampling methods, adjusting conservation priorities, or implementing new management actions based on observed trends.

- Continuous Improvement: Regularly review and refine monitoring protocols to enhance data quality and relevance.

H. Integration with Other Data Sources

- Remote Sensing: Incorporate satellite imagery and remote sensing data to assess habitat changes and landscape-level patterns.

- Climate Data: Integrate climate data to understand how changing environmental conditions affect biodiversity.

I. Collaboration and Partnerships

- Multi-Disciplinary Approaches: Collaborate with ecologists, statisticians, and other experts to enhance the robustness of the monitoring program.

- Networking: Partner with other organizations, research institutions, and governmental agencies to share data, resources, and expertise.

Long-term monitoring programs are vital for understanding biodiversity dynamics and informing conservation strategies. By employing systematic methods, engaging stakeholders, and adapting to new information, these programs can effectively contribute to the preservation of biodiversity and the health of ecosystems over time (Figure 10).

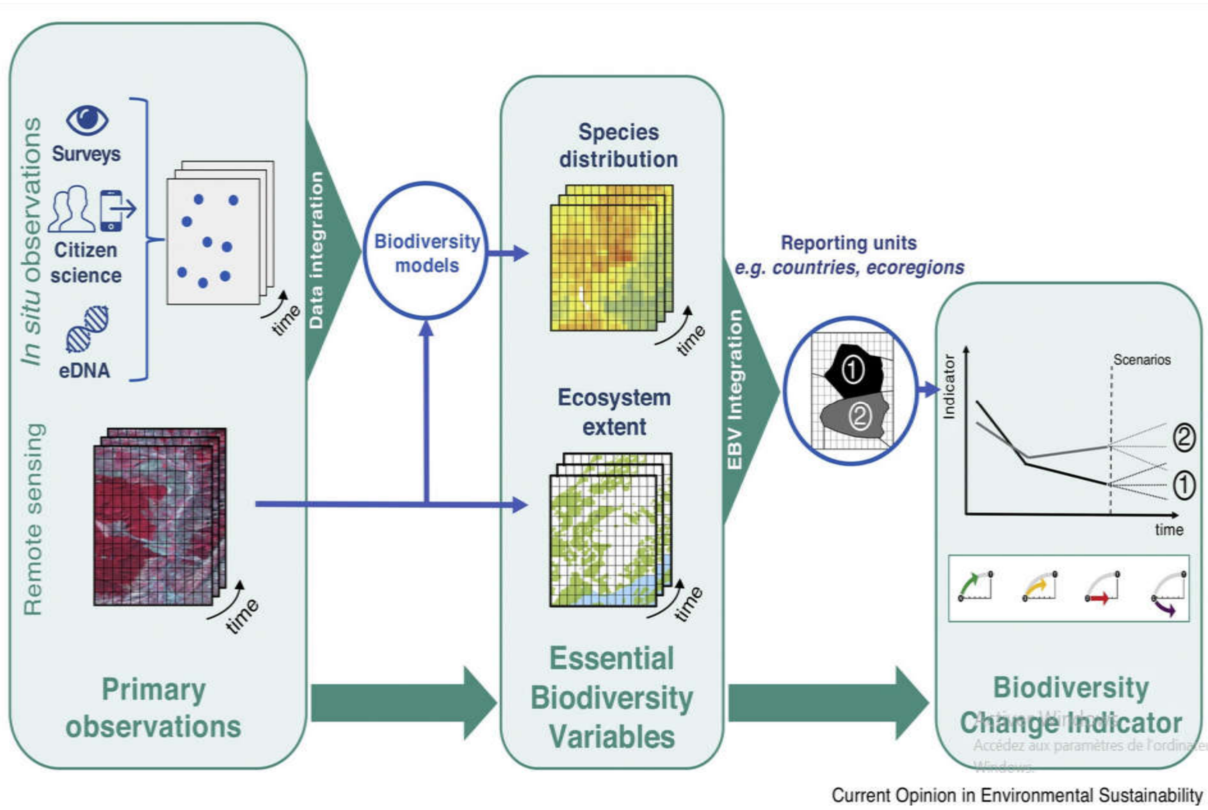


Figure 10. Long term monitoring program.

1.7. Habitat Assessment

Habitat quality refers to the ability of a species' living space to provide suitable living conditions for individuals or populations, that is, the ability of an ecosystem to provide sustainable development within a certain spatial and temporal range. Habitat quality is the basis of functional ecosystems and an important factor that influences biodiversity. Ecosystem fragmentation is increasing with the intensification of industrialization and accelerated urbanization. Habitat quality is significantly declining, and biodiversity is facing a significant threat (Liu et *al*., 2023).

Evaluating the condition of habitats based on factors like vegetation structure, water quality, and presence of invasive species.

1.8. Taxonomic Studies

Taxonomy (or systematics) is the fundamental discipline of biology dedicated to the description, naming, and cataloging of organisms and their relationships (Mayr and Ashlock, 1991; Knapp, 2000; Wheeler, 2004; Wheeler et *al*. 2004 cited in Kim and Byrne, 2006). Taxonomy provides identities and names for newly discovered organisms, which provides a central framework for the discipline of biology (i.e., organization of biological knowledge) and offers key tools for the identification of all known organisms, which other biologists, primarily taxonomists in practice, can use to facilitate dissemination of their study subject and better communicate about the organisms with which they work (Savage, 1995 cited in Kim and Byrne, 2006). In addition, taxonomists have also contributed to fundamental natural history knowledge of species, which facilitates studies by other biologists and environmental scientists. The Linnean revolution had an enormous positive impact on the description of local flora and fauna (Knapp, 2000 cited in Kim and Byrne, 2006).

Throughout the eighteenth, nineteenth, and most of the twentieth centuries, most biologists studied taxonomy and natural history [e.g., Brunfels 1530; Bauhin 1623; Linnaeus 1751, 1758; Fabricius (1745–1808), cited in Kim and Byrne, 2006). Throughout the immediate post-Linnean period, species discovery, description, and naming comprised the main focus of biological science, with the completion of comprehensive and detailed monographic works that described major groups of organisms (Tuxen 1973; Lindroth 1973 cited in Kim and Byrne, 2006).

Methods needed to guide the study of backyard biodiversity are currently lacking. The detailed protocols that must be developed for rigorous and repeatable biodiversity assessment should include recommended sampling designs, sampling methods for diverse types of organisms, ways of sorting, classifying, and identifying the collected specimens, as well as procedures for organizing, managing, and analyzing the resultant data (Kim, 1993; Danks, 1996; Mahan et *al*., 1998; Boone et *al*., 2005 cited in Kim and Byrne, 2006). The process between field sampling and species identification, involving alpha-taxonomy, referred to here as taxonomic service, is lengthy and laborious but important in maintaining quality control and data integrity (Grove 2003). Rigorous species identification, particularly for invertebrates, microbes, and less-well- known plants, is a taxonomic domain requiring the expertise of competent taxonomic specialists. Demand for taxonomic services is rapidly increasing concomitantly with increased adoption of practices associated with ecosystem management

(Kim, 1993; Botkin et *al*.,1997 cited in Kim and Byrne, 2006), community-based conservation (Berkes, 2004), integrated pest management (US Congress Office of Technology Assessment, 1995; NRC, 1996; Benbrooks et *al*., 1996 cited in Kim and Byrne, 2006) and for the prevention and control of invasive, non-indigenous species (Shigesata and Kawasaki, 1997; Mooney et *al*., 2004 cited in Kim and Byrne, 2006). Also, biodiversity-related research usually requires taxonomic services for measuring anthropogenic impacts on ecosystem health and to assess the state of community and ecosystem dynamics.

The dynamic nature and multiplicity of taxonomic frameworks is further compounded by the different types of data associated with names in biodiversity repositories, including spatial, functional, genetic, and physical data (Figure 11). The taxonomic backbone – connecting accepted names to synonyms in a taxonomic hierarchy – is often presented as a global species list. That list of names forms the key enabler of subsequent synthesis for linking different data sources and/or types that use different names for the same species in support of integrative science, interdisciplinary research, and conservation.

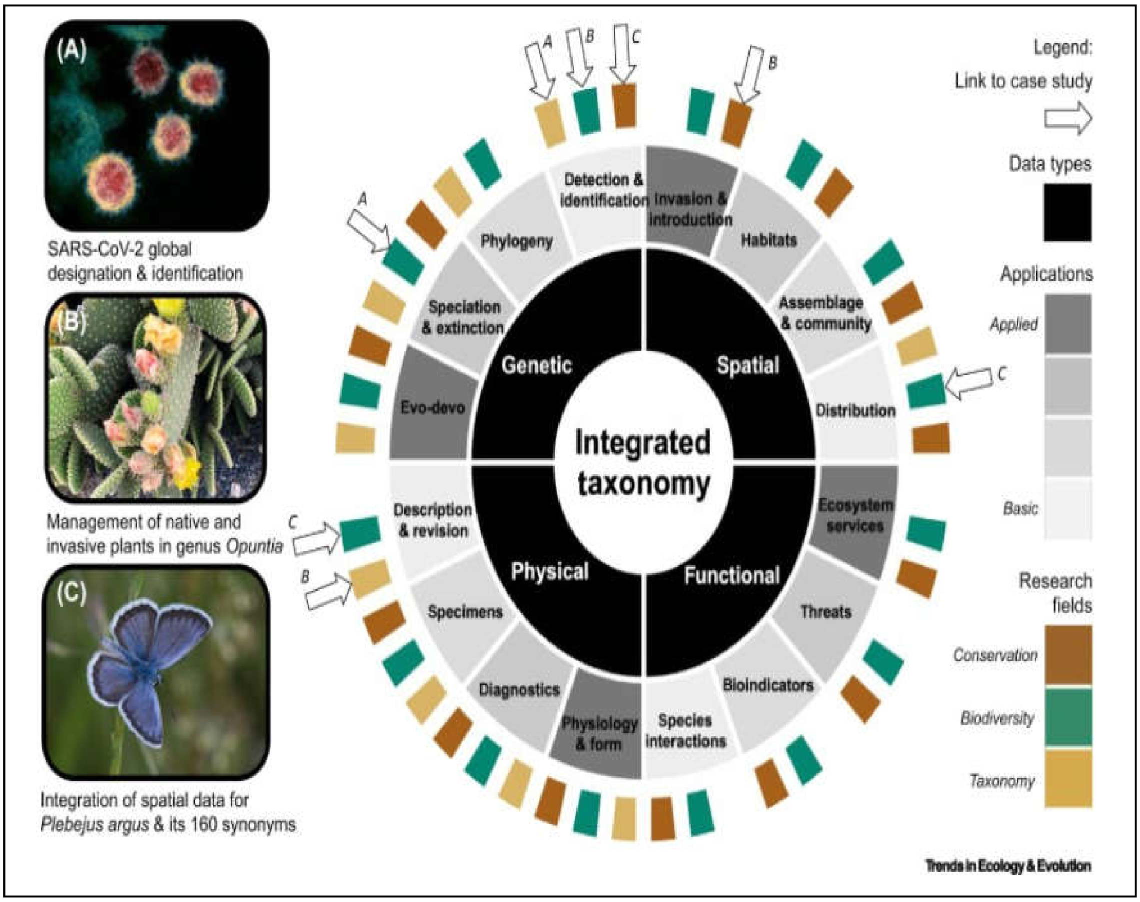


Figure 11. Research themes and examples with associated data types relying on taxonomic integration (Sigwart, et al., 2018; König et al., 2019).

Innermost ring (black): main data categories. Middle ring (gray gradient): data applications (foundational to applied) across the four data categories. Outer ring (color categories): example research questions and applications (from taxonomy, biodiversity, and conservation). Arrows on the outermost edge of the rings denote a linkage with one of three examples (A, B, and C), illustrating how integration facilitates a transparent connection between primary data, biodiversity analysis, and practice, and could avoid problems downstream. (A) severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), coronavirus 2 global designation and identification. (B) Management of invasive plants in Opuntia, a genus of cactus species. (C) Spatial range comparison of the butterfly Plebejus argus, characterized by 160 synonyms.

Although demand for taxonomic services is rapidly increasing for biodiversity and ecosystem research and management, it is increasingly difficult to obtain competent taxonomic services at the species level (or even at lower taxonomic—genus and family level) for biodiversity assessment and impact studies, for a reasonable fee. At the same time it is commonly presumed that there is a lack of funding for inventory and assessment and a shortage of qualified taxonomists who can identify known species and describe new ones. As a result, biodiversity inventory and assessment are scarcely undertaken for ecosystem management, although site-specific biodiversity information is fundamental to community/ecosystem ecology, conservation, and management of backyard biodiversity, which provide information on biodiversity structure, and the status of endangered and invasive species (Bu¨ chs, 2003 cited in Kim and Byrne, 2006).

In fields like public health and agriculture, taxonomic identification is vital for identifying pathogens, pests, and beneficial organisms, which can influence disease control and crop management strategies. In summary, taxonomic identification is a foundational aspect of biological sciences that plays a critical role in understanding and preserving biodiversity, guiding conservation efforts, and informing ecological and agricultural practices.

1. 9. Ecological Surveys

Understanding the spatial characteristics of ecosystems is one of the central challenges in ecology. Such knowledge forms a prerequisite for effective ecosystem management due to an increasing need for spatially explicit approaches in fisheries and wildlife management and for the establishment of terrestrial and marine protected areas.

Some surveys can be carried out throughout the year; however, as the timetable illustrates, certain species require surveys to be carried out at specific times to ensure the most reliable results are obtained. Surveys carried outside of these times may therefore be unreliable; i.e. a great crested newt survey carried out over the winter season would be unlikely to provide the required information.

• A negative result achieved from a survey outside the optimum period should not be interpreted as showing an absence of a particular species – further work may be required within the optimum surveying season. This is especiallyimportant on sites where existing surveys and records show that a particular species has been found either on the site previously, or in the surrounding area. An application may not be valid until this survey information is gatheredin the optimum time for that particular species.

• The absence of evidence of a species does not necessarily mean that the species is not active on a site, or that a particular site is not protected – for example, a bat roost is protected regardless of whether any bats are present.

• Species surveys can also be highly weather dependent, so surveys should be planned, or postponed, to fit in with weather forecasts; for example, heavy rain can mean that an otter survey can yield less accurate results, as can very cold or wet weather for bat surveys (Figure 12).

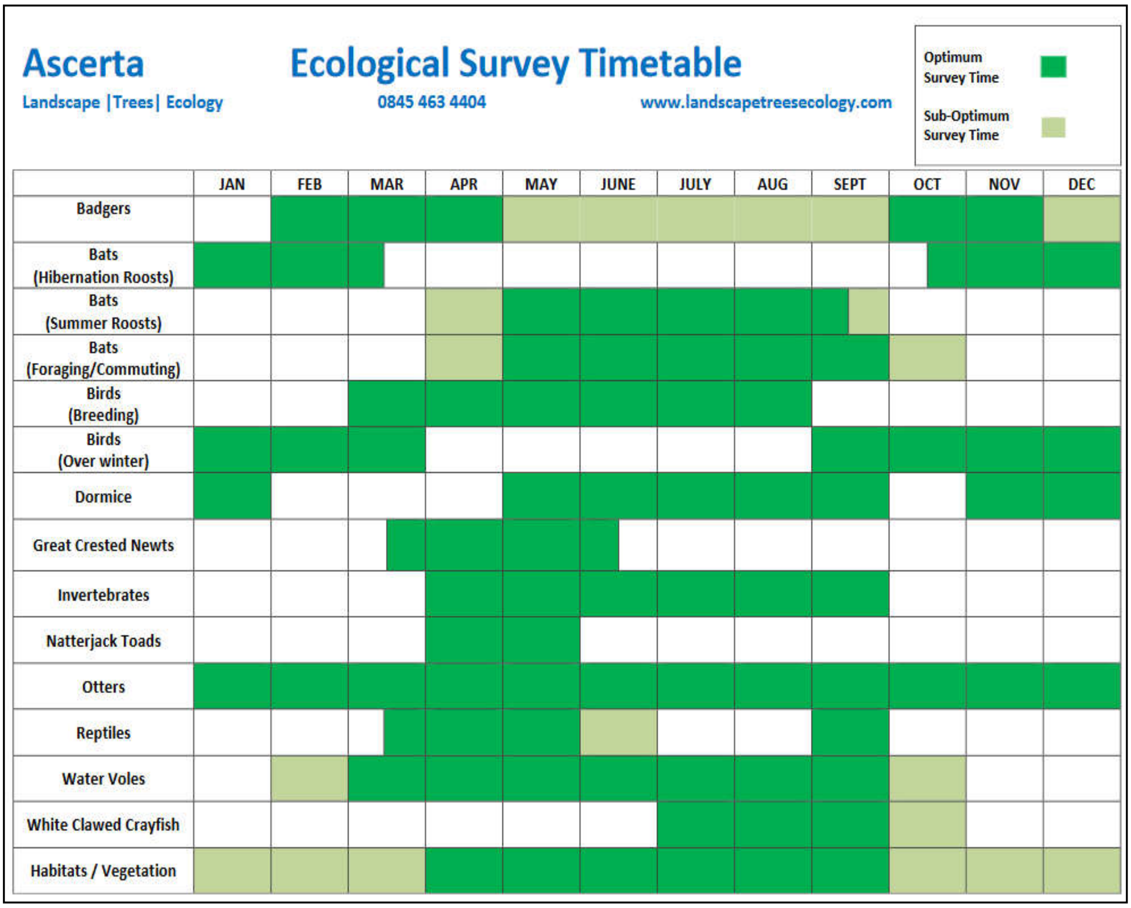


Figure 12.Ecological survey Timetable (Ascerta, 2020).

Functional diversity is a key aspect of biodiversity that encompasses the variety of functional traits exhibited by microorganisms within an ecosystem. It plays a crucial role in ecological processes, influencing factors such as ecosystem dynamics, stability, and nutrient availability. The functional diversity of a community can be assessed through two main metrics: functional richness and functional evenness. Functional richness indicates the number of species present in a specific niche, while functional evenness measures the uniformity of species distribution. Changes in functional richness and evenness directly affect functional diversity; a decline in either leads to reduced ecosystem productivity and stability, ultimately diminishing the functional diversity of that ecosystem. The relationship between functional diversity and ecosystem productivity can be explained through models such as the sampling effect and niche differentiation. Additionally, concepts like niche complementarity and species redundancy further connect functional diversity to ecosystem functioning. Models like the rivet and idiosyncratic approaches also explore the interplay between functional diversity, species richness, and ecosystem performance (Goswami *et al.,* 2017).

2. The different dimensions of biodiversity

Biodiversity can be understood through several dimensions, which include:

2.1. Phylo-temporal diversity

The first is phylo-temporal diversity, measuring the genetic distinctiveness of the species in an area. Although species richness is a commonly used measure of biodiversity, it fails to capture the reality that species without close relatives contribute more uniqueness than do species with many close relatives. Phylogenetic diversity is used as a general term for a range of measures that consider the total length of all the branches linking a set of species on their phylogeny ("evolutionary tree") and so reflect species' evolutionary uniqueness. One of the first such measures is simply the sum of the branch lengths (Faith, 1992).

2.2. Compositional diversity

The second is compositional diversity, measuring which species occur in an area. Species composition is a composite variable that is not measured in the field, but is calculated based on other plant attribute measurements. Species composition is defined as the proportion (or percent) of various plant species in relation to the total on a given area. Species composition is also known as "botanical composition", or simply "composition".

Why estimate species composition

- Species composition is an intuitive measurement. It is an expression of the relative contribution that each species makes as a percent of the total community, which people can easily visualize.
- Traditional guidelines used to set stocking rates for livestock on rangelands are based on the availability of forage, and consider the relative contribution of forage species to total biomass.
- Species composition has been used extensively to describe ecological sites and to evaluate rangeland condition, or similarity to a desired plant community.

- Measurements of composition over time can be used to characterize trend or changes in rangeland condition.
- Allows comparison of dominance of individual plants across plant communities. For example, two sites may be very different in terms of total biomass produced but they could both have about 50% mesquite by weight.
- Composition can be calculated based on individual species or groups, such as percent of noxious weeds, or percent forbs, grasses, and shrubs. Measurements of composition over time can be used to characterize trend or changes in

Value of Calculating and Comparing Composition

- Allows for "relative" comparison of individual species across sites, or times, that vary significantly.
- Composition reflects the relative contribution of a species to a community and the dominance of a specific species on a site.
- Many management objectives are focused on the assessment or manipulation of species composition. For example, a land manager may want to:

minimize the composition of noxious weeds in a community.

increase the relative abundance of desirable forage species in a pasture.

manipulate the relative abundance of warm-season or cool-season plants

alter the relative contribution of various species that provide shelter or food for wildlife.

Calculating species composition

Species composition is generally expressed as a percent, so all species components add up to 100%. Composition can be calculated with measures of density, biomass or cover. It is NOT appropriate to estimate composition based using frequency data (Web 1).

2.3. Trait diversity

And the third is trait diversity, measuring how the species in an area vary in place, food, time, and size niches. These aspects include:

- **Place**: The specific locations or habitats where different species are found.

- **Food**: The types of food that different species consume, which can vary widely among them.

- **Time**: The times when species are active or reproduce, indicating differences in their life cycles.

- **Size niches**: The physical sizes of the species, which can affect how they interact with their environment and other species

Understanding these dimensions is essential for conservation efforts and maintaining the health of our planet's ecosystems.

3. The inventory and estimation of the number of species

Inventory is a stocktake of what is present at a point in time. Monitoring establishes how the inventory changes with time and follows the processes that produce that change.

The key question with inventory is: How much do we really need to know? For a conservation agency there is also the question of what information it can safely leave to other agencies to collect.

Inventory mainly concerns the legal conservation status of the national estate, the extent of various vegetation and landform types, and the variety and abundance of the biota. The first two are relatively straightforward and have been immensely assisted by recent technological developments. However, regarding the variety and abundance of the biota, many difficult can found in order to estimate the number of species in the world.

There are a very large number of distinct living organisms, but the problems posed by these huge numbers of living things are:

• Many species have no scientific names

• The vast majority of those named have virtually no ecological information available beyond that which can be inferred from their relationships to those few species that do

• Nearly all are variable between individuals and populations

• Genetic information is lacking for nearly all species

• Each has a multitude of relationships with other species and with the abiotic environment.

International and national goals for conservation have declared that each and every native species is of intrinsic value. It is claimed that completion of a full inventory of the Earth's biota is one of the most urgent tasks facing nature conservation (Wilson, 2003). Species are the independently evolved key working parts of biodiversity, and solid advances will depend on a detailed knowledge of species and their natural history (Wilson, 2000). It is therefore argued that only by thoroughly documenting species so that those at risk can be identified and remedial action taken can we avert a species catastrophe. Even when much is already known about a biota, as is the case with North America and Western Europe, there is a constant refrain in the literature for more and better-focused information to achieve conservation goals. A name is of little value of itself; to be useful, a species inventory will have to include a minimum of distributional and ecological information.

There are initiatives under way in several nations, to obtain complete all-taxa biodiversity inventories. For example, the Instituto Nacional de Biodiversidad in Costa Rica is undertaking a national biodiversity inventory, in part through training parataxonomists to assist specialists. Perhaps the most ambitious and advanced national all-taxa inventory is The Swedish Taxonomy Initiative.

Biodiversity inventories are associated with universities, museums or specialist taxonomic centres, and are only performed by conservation agencies alone at local levels. The inventory process typically involves:

A. Field Surveys: Researchers conduct fieldwork to observe and collect specimens. This may involve trapping, photographing, or sampling organisms in their natural habitats.

B. Taxonomic Identification: Collected specimens are identified using taxonomic keys and expert knowledge. This often requires the expertise of taxonomists who specialize in particular groups of organisms.

C. Data Collection: Information about the species, such as their abundance, distribution, and ecological roles, is recorded.

Many undiscovered species are difficult to find because they are cryptic, small in size or have small geographic ranges. Shown in Figure 13 : (a) a recently discovered burrowing caecilian species from India, (b) a newly discovered chameleon (Brookesia micra) from Madagascar that is the smallest lizard in the world, and (c) a locallyendemic waterfall frog

(Barbourula kalimantanesnis) from Borneo. Photographs reproduced, with permission, from Biju Das (a), Frank Glaw (b), and David Bickford (c).

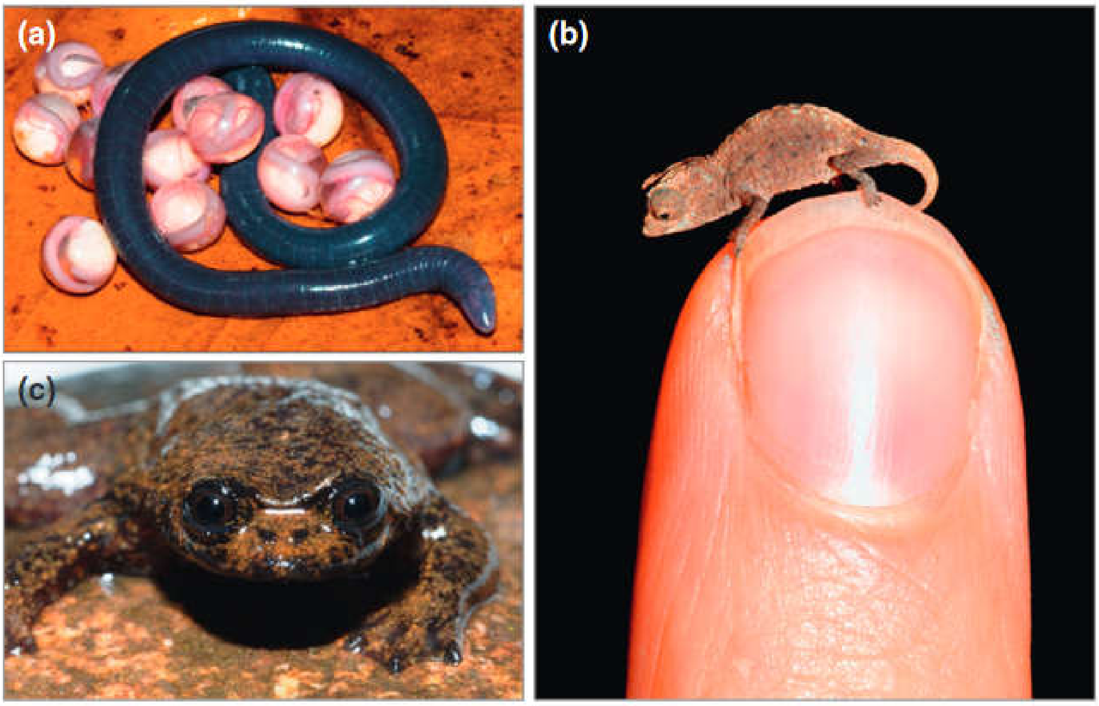


Figure 13. Species discovered. Photographs reproduced, with permission, from Biju Das (a), Frank Glaw (b), and David Bickford (c) (Scheffers et al., 2012).

Only a small fraction of the total number of species on Earth has been scientifically described due to a combination of factors. The difficulty of access to certain habitats, limited resources and time, and the constant discovery of new species all contribute to this phenomenon. Despite the challenges, researchers continue to make progress in documenting and understanding Earth's biodiversity (Audesirk et *al.*, 2016).

Also, it has found that some species are morphologically similar but genetically distinct, making them difficult to identify without advanced techniques like DNA barcoding. Human activities, such as habitat destruction and climate change, contribute to species extinction, complicating the estimation of current biodiversity.

Mora and colleague in 2011estimated that there are about 7.8 million animal species, 298,000 plants, 611,000 fungi, and 63,900 protists. They estimated relatively few prokaryotes (10,000 bacteria and 500 archaea). Overall, they projected that there are 8.75 million living species, of which only 1.2 million were described (including approximately 0.95 million animal species). Below, I review published diversity projections for several key groups that are dramatically larger than those from Mora and colleagues, with species revealed by molecular data largely driving these bigger estimates (Table 1) (Wiens, 2023).

Table 1. Contrasting estimates of species richness from Mora and colleagues with projections that incorporate molecular data.

Group	**Mora and Colleagues estimate of species richness (2011)**	**Alternative estimate of species richness**	**Source**
Bacteria	9,700	2-4 million to 3.2 trillion	Locey and Lennon, 2016; Louca et *al.*, 2019
Protists	63,900	1-10 million	Adl et *al.*, 2007
Fungi	644,000	6.3 million	Baldrian et *al.*, 2022
Insects	<5.6 million	21.1 million	Li and Wiens, 2023
Insect-associated taxa	<5.6 million	Aproximately 50-90 million each of animals, protists, and fungi; many more bacteria (hundred of millions)	Li and Wiens, 2023; Larsen et *al.*, 2017

Chapter 3: State of Global Biodiversity

1. Current Status of Global Biodiversity

The current state of global biodiversity is a cause for concern. The rapid decline in species diversity, destruction of habitats, and the looming threat of mass extinctions have raised alarms among scientists and environmentalists worldwide. In this section, we will delve into the current state of global biodiversity, examining different perspectives, providing in-depth information, and discussing potential solutions (Figure 14).

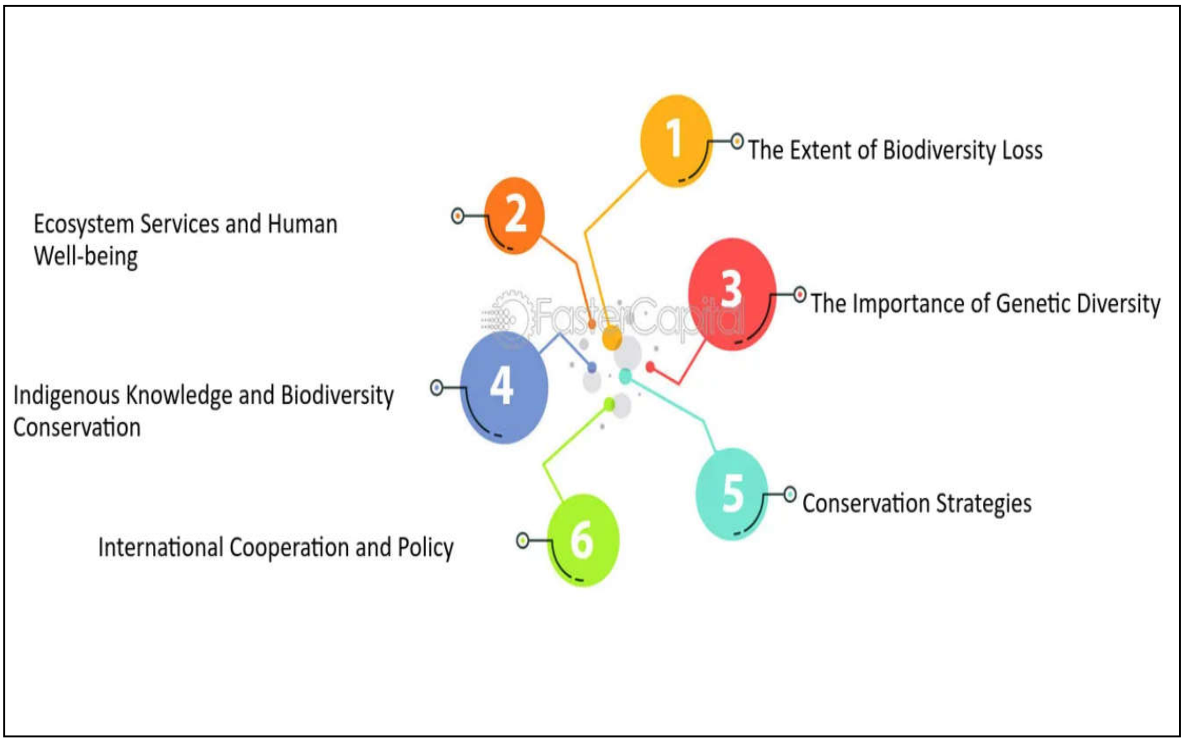


Figure 14. The current state of global biodiversity

1.1. The Extent of Biodiversity Loss:

- According to the Intergovernmental Science-Policy Platform on biodiversity and Ecosystem services (IPBES), one million species are at risk of extinction, many within decades (Figure 15).

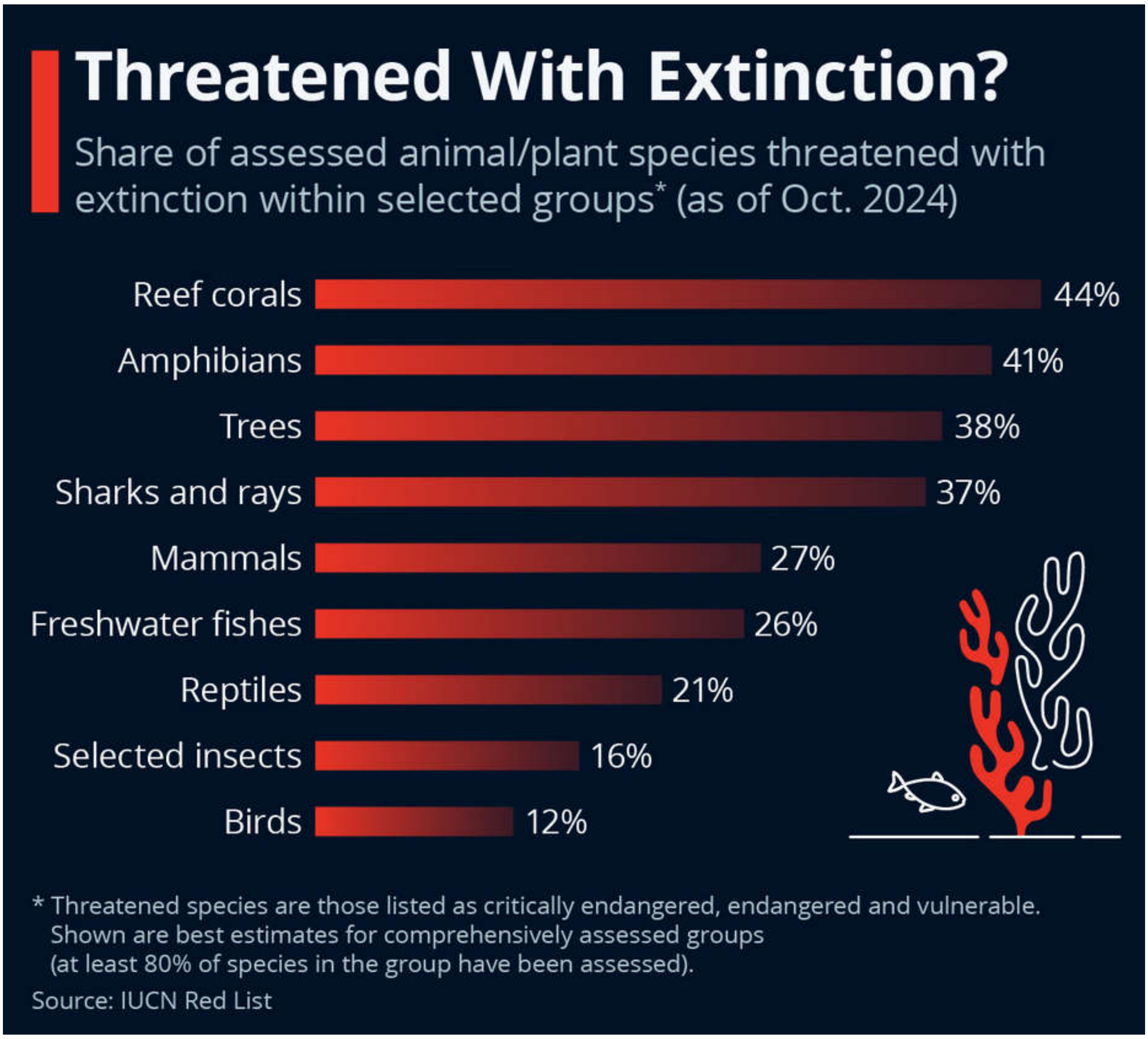


Figure 15. Species threatened with extinction

- Habitat loss, driven primarily by human activities such as deforestation, urbanization, and agriculture, is a significant contributor to biodiversity decline (Figure 16).

Figure 16. Habitat loss due to destruction, fragmentation or degradation

- Climate change further exacerbates the situation, altering ecosystems and disrupting the delicate balance of species interactions.

1.2. Ecosystem Services and Human Well-being:

- Biodiversity loss not only affects the natural world but also has profound implications for human well-being.

- Ecosystem services, such as pollination, carbon sequestration, and water purification, are provided by diverse ecosystems and are crucial for our survival.

- The decline in biodiversity jeopardizes these services, leading to negative impacts on agriculture, water availability, and overall human health.

1.3. The Importance of Genetic Diversity:

- Genetic diversity within species is crucial for their resilience and adaptation to changing environmental conditions.

- A lack of genetic diversity makes species more vulnerable to diseases, reduces their ability to withstand climate change, and limits their capacity for future evolution.

- The loss of genetic diversity also affects our ability to develop new medicines, as many pharmaceuticals are derived from plant and animal compounds.

1.4. Indigenous Knowledge and Biodiversity Conservation:

- Indigenous peoples have long been custodians of biodiversity-rich areas and possess valuable traditional knowledge about ecosystems and species.

- Recognizing and respecting indigenous rights and including their knowledge in conservation efforts can lead to more effective and sustainable biodiversity management.

- Collaborative partnerships between indigenous communities, scientists, and policymakers can help protect both biodiversity and cultural heritage.

1.5. Conservation Strategies:

- Protected areas, such as national parks and reserves, play a crucial role in safeguarding biodiversity.

- Implementing and enforcing stricter regulations against illegal wildlife trade and habitat destruction is essential.

- sustainable land-use practices, including agroforestry and organic farming, can help preserve biodiversity while ensuring food security.

- Promoting public awareness, education, and citizen science initiatives can engage communities in biodiversity conservation efforts.

1.6. International Cooperation and Policy:

- Addressing the global biodiversity crisis requires international collaboration and coordinated policy actions.

- The Convention on Biological Diversity (CBD) aims to conserve biodiversity, ensure its sustainable use, and promote equitable sharing of benefits.

- Strengthening and implementing international agreements, such as the CBD and the Paris Agreement, can provide a framework for effective action.

The current state of global biodiversity is a complex issue with far-reaching consequences. Recognizing the urgency and magnitude of the problem, it is crucial for individuals, communities, governments, and international organizations to come together and take decisive action. By understanding the importance of biodiversity, valuing indigenous knowledge, implementing conservation strategies, and fostering international cooperation, we can strive towards a more sustainable and biodiverse future (FasterCapital, 2024).

2. Examples of countries rich in biodiversity

Countries rich in biodiversity are often characterized by a wide variety of plant and animal species, many of which are endemic (found nowhere else in the world).

Magadiversity Countries is a term used to refer to the world's top biodiversity-rich countries in the world. This country-based method raises national awareness for biodiversity conservation in nations with high biological diversity, with many species unique to a specific country. This concept complements that of biodiversity hotspots and high-biodiversity wilderness areas to achieve significant coverage of the world's biological resources and was firest proposed in 1988. The Megadiversity country concept is based on four premises:

1. The biodiversity of each and every nation is critically important to that nation's survival, and must be a fundamental component of any national or regional development strategy;

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

3. Some of richest and most diverse nations also have ecosystems that are under the most severe threat;

4. To achieve maximum impact with limited resources, we must concentrate heavily (but not exclusively) on those countries richest in diversity and endemism and most severely threatened; investment in them should be roughly proportional to their overall contribution to global biodiversity (Mittermeier et *al*., 1997) (Figure 17).

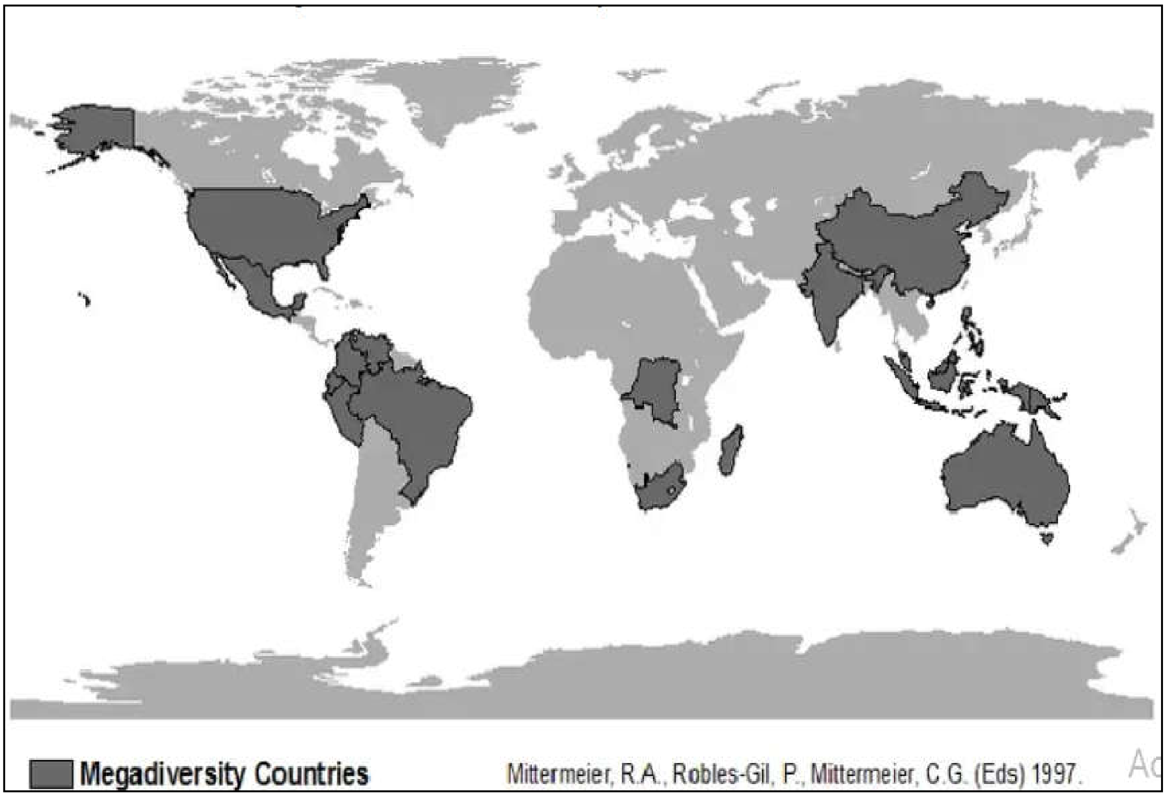


Figure 17. Countries of the world with the greatest levels of biodiversity ((Mittermeier et al., 1997).

2.1. Brazil

Brazil is the country with the greatest biological diversity in the world. It is one of seventeen countries regarded as megadiverse. Megadiverse countries have at least 5000 indigenous botanical species and a marine ecosystem on their coasts. According to Conservation International, 70% of the world's flora and fauna are found in these seventeen countries, which occupy only around 10% of the earth's surface. Brazil is the most megadiverse of the seventeen. It has the greatest land biological diversity (flora and fauna), while Indonesia has the greatest marine biological diversity. Recent estimates are that the animal and plant species currently known in the country (there is an incalculable number of species not yet discovered, mainly in the Amazon – on average, 700 new species are discovered every year) represent 15% to 20% of global biological diversity. Other natural resources contributing to Brazil's megadiversity include: 20% of the world's drinking water; the largest continuous area of mangroves (1.3 million hectares); and the only coral environment in the South Atlantic, stretching for 3000 km along the country's northeastern coast (Abranches, 2020).

2.2. Colombia

Colombia is one of the countries with the highest biological diversity in the world. With a land surface of 1,1400,000 km^2 (approximately 0.7% of the continental surface area of the globe), it is home to more than 40,000 plant species, over 1800 bird species, and over 580 amphibian species, close to 15% of the world's species for these groups.

This enormous richness can be attributed to the geological history and geographical location of the country. Colombia's location near the Equator, as a land bridge between North and South America, has allowed the migration of species between the continents. Many northern species have distributions that reach as far south as Colombia. Oaks of the genus Quercus, widespread in North America, are found in higher elevation forests throughout Central America, and in some forests in the Andes of Colombia as far south as the border with Ecuador. The geological history of Colombia has also played a significant role in speciation and diversification. The oldest rock formations in Colombia are parts of the Guyana shield, and are found as giants standing over the plains of the Orinoco and parts of the Amazonian region of Colombia. The Andes is more recent, and is split into three separate ranges, with the Eastern range stretching as far north as Venezuela. The Pacific coast of Colombia, known as the Chocó, is one of the places with the highest rainfall world-wide, with some locations getting more than 12,000 mm of rain annually (Samper, 1997).

2.3. Indonesia

Due to its tropical setting and geological complexity, Indonesia is one of the most biologically diverse nations in the world with very high levels of both terrestrial and marine diversity and a high level of endemism. Together with the Philippines, Indonesia has some of the most diverse marine environments in the world and lies in the centre of the triangle of marine diversity (Crame, 2000). Indonesia boasts a vast array of ecosystems, including rainforests, coral reefs, and volcanic landscapes, supporting numerous unique species. The country is also home to the largest tropical peatland in the world with approximately 15 million hectares of peatland (both forested and non-forested) spread across Sumatra, Kalimantan, Sulawesi, and Papua.

According to Indonesia's updated biodiversity profile in its Sixth National Report to the Convention on Biological Diversity (CBD), Indonesia is home to around 31,750 plant species, 732 mammal species (14% of the total species in the world), 1,711 bird species (17% of the total species in the world), 750 reptile species (8% of the total species), 403 amphibian species (6% of the total species), and 1,236 freshwater fish species (9% of the total species). In addition to being rich in species diversity, the level of endemism of Indonesian fauna is very high, this is mainly due to the country's unique geology. Some endemic species include the Komodo dragon (*Varanus komodoensis*), orangutan (*Pongo spp.*), bird-of-paradise (*Paradisaea ssp.*), and the Javan rhinoceros (*Rhinoceros sondaicus*). Further, Indonesia ranks as one of the world's centers for agrobiodiversity of plant cultivars and domesticated livestock (Republic of Indonesia, 2020).

2.4. Mexico

Mexico being the largest country in the region is very rich in species in itself. Lot of species occur even in the dry northern areas. In the Chihuahuan Desert 826 plant species are noted by Villarreal-Quintanilla et *al.* (2017), out of which 560 are endemic, 165 are quasi-endemic and és 176 are microendemic. 116 taxa can be originated from a non-arid habitat. The most species-rich are Cactaceae with 141, Asteraceae with 106, Boraginaceae with 34 and Brassicaceae with 31 species. On the California Peninsula 723 endemic species are noted by Riemann and Exequiel (Riemann and Exequiel, 2007), claiming that the great number of endemic species is due to the heterogenity of the environment. The flora and fauna are very interesting because the area of Mexico involves the border of Neotropis and Nearctis (Mexican Transition Zone), which is not exactly a border but rather a wide transition zone, its accurate definition is yet to be created. The determinaion is based on the distribution of the endemic genera characteristic to one or the other area. The several results obtained regarding this vary hugely. The determination of the location and width of the transition zone is different among authors without a consensus, which requires further floristic examinations (Villaseñor, 2020). Vegetation varies depending on the topography that has a great role in the fromation of the great number of endemic species as well.

2.5. Australia

Australia's biodiversity has developed largely in isolation over many millions of years, making this continent one of the most biologically diverse parts of the planet. It is estimated that Australia is home to as many as 560,000 species. Many of these species are found nowhere else on Earth – about 92% of higher plant species, 87% of mammal species, 93% of reptiles, 94% of frogs and 45% of bird species found in Australia occur only here (Chapman, 2009).

2.6. Madagascar

Madagascar is one of the world's top biodiversity hotspots (Myers et *al.*, 2000) and megadiversity countries (Mittermeier et *al.*, 1997), making it probably the most important global conservation priority on earth (Brooks et *al.*, 2006). Because of its geographic location in the tropics and subtropics, varied topography and long isolation, Madagascar has a very high level of species diversity and unparalleled rates of endemism – over 80 percent of Madagascar's species occur nowhere else on the planet. Endemism rates are particularly striking at higher taxonomic levels, with over 480 genera and at least 26 families entirely restricted to the island (Mittermeier et *al.*, 2013). The next richest hotspot for endemic families – New Zealand – has only eight. Madagascar's flora includes at least 11,220 species of vascular plant, divided within 1,730 genera in 243 families. There are more than 220 native, terrestrial mammal species surviving in Madagascar, of which there are 112 lemurs, 46 bats, 27 rodents, 31 tenrecs, and 10 carnivores in the endemic family Eupleridae.

2.7. Peru

Peru is indeed one of the most biodiverse countries in the world. Its rich biodiversity is attributed to its varied ecosystems, which range from the Amazon rainforest to the Andes mountains and coastal regions. Here are some key points about Peru's biodiversity:

* Amazon Rainforest: A significant portion of the Amazon rainforest lies within Peru, making it one of the most biodiverse areas on the planet. This region is home to an incredible variety of flora and fauna, including thousands of plant species, mammals, birds, reptiles, and amphibians.

*Andean Ecosystems: The Andes mountains run through Peru and create diverse habitats, from high-altitude grasslands (puna) to cloud forests. These ecosystems host unique species, including the Andean condor and various endemic plants.

*Coastal Regions: The coastal areas of Peru, particularly around the Humboldt Current, support rich marine biodiversity, including numerous fish species, marine mammals, and seabirds. The nutrient-rich waters are crucial for the fishing industry.

*Endemism: Peru is home to many endemic species, meaning they are found nowhere else in the world. This includes various species of orchids, birds, and amphibians.

3. Examples of natural areas rich in biodiversity

3.1. Amazon Rainforest

The Amazon rainforest is the largest remaining tropical rainforest in the world, blanketing the Earth's surface in approximately three billion trees. Spanning nine countries in South America, the Amazon is an expansive and incredibly diverse biome— almost twenty-five times the size of the United Kingdom. Through the region snakes the Amazon River, flowing for more than 4,100 miles.

● One fifth of world's flowing water runs through the Amazon.

● About 20% of the planet's oxygen is produced in the Amazon.

As of 2005, the Amazon is home to at least 10% of the entire planet's known species, including, at least:

● 437 mammal species

● 1,300 bird species

● 378 reptile species

● 400 amphibian species

● 3,000 fish species

● 40,000 to 53,000 tree species

These numbers don't include the new animal or plant species that are catalogued approximately every two days in the region. Nor do they take into account the significant losses in biodiversity caused by deforestation.

3.2. Coral Reefs

Coral reefs are a unique ecosystem in the tropical ocean that formed by massive deposits of calcium carbonate produced by hermatipic coral that live in symbiosis with zooxanthellae. Zooxanthellae can produce organic material through photosynthesis, which is then secreted in large part to its host (coral animal). There are four terms that sound same but their meanings are different, namely coral reefs, corals, hard coral, and rock coral. Coral reefs are large limestone structures formed and produced by coral animals and other calcareous organisms that forming a compact ecosystem as a habitat for marine organism. Corals are a group of organisms from the phylum Coelenterata, the class of Anthozoa, especially from the order Scleractinia which forms hard and soft corals.

Coral ecosystem is a habitat for many species of aquatic flora, such as algae, seaweed, coralin algae, calcareous green algae and seagrass. In coral reef ecosystems also live many species of aquatic fauna, such as:

1) Invertebrates, i.e. crustaceans, snails, shellfish, and echinoderm, such as sea urchins, sea anemones, sea cucumbers, sea stars and sea lilies

2) Fish, i.e. opportunistic carnivorous, herbivorous, omnivorous, and planktovorous fishes

3) Reptiles, i.e. sea snakes and sea turtles

Marine life diversity in the coral reef ecosystems are very high, around the world, there are about 33,000 to 60,000 species of flora and fauna. At least 30 animal and algae phyla are associated in coral reef ecosystems. The algae that are often found in coral reef ecosystems is seaweed. In the Eastern Indonesian waters are found about 765 species of seaweed, consisting of 179 species of green algae, 134 species of brown algae and 452 species of red algae. Molluscs are also very diverse. In the Raja Ampat Papua coral reef ecosystem, there are about 699 mollusc species. It is reported 3,000 species of sponge were found during the Sibolga expedition; and 1,500 species during the Snellius II expedition. About 736 species of reef fish of 254 genera were found in Komodo Island waters. There are about 970 species of reef fish found in the Raja Ampat Islands. This high biodiversity is the product of long evolutionary process that allows many species to coexist in limited apace and high density life in the coral reef ecosystems (Tuwo and Tresnat, 2020).

3.3. The Sundarbans mangrove forest

The Sundarbans mangrove forest, one of the largest such forests in the world (140,000 ha), lies on the delta of the Ganges, Brahmaputra and Meghna rivers on the Bay of Bengal. It is adjacent to the border of India’s Sundarbans World Heritage site inscribed in 1987. The site is intersected by a complex network of tidal waterways, mudflats and small islands of salt-tolerant mangrove forests, and presents an excellent example of ongoing ecological processes. The area is known for its wide range of fauna, including 260 bird species, the Bengal tiger and other threatened species such as the estuarine crocodile and the Indian python.

The property is the only remaining habitat in the lower Bengal Basin for a wide variety of faunal species. Its exceptional biodiversity is expressed in a wide range of flora; 334 plant species belonging to 245 genera and 75 families, 165 algae and 13 orchid species. It is also rich in fauna with 693 species of wildlife which includes; 49 mammals, 59 reptiles, 8 amphibians, 210 white fishes, 24 shrimps, 14 crabs and 43 mollusks species. The varied and colourful bird-life found along the waterways of the property is one of its greatest attractions, including 315 species of waterfowl, raptors and forest birds including nine species of kingfisher and the magnificent white-bellied sea eagle (Source Ramsar Sites Information Service).

4. The state of biodiversity in Algeria

Algeria, the largest country in Africa and the Mediterranean, covers an area of 2,381,741km² and has a coastline along the Mediterranean of 1,622 km. It stretches from north to south over more than 2,000 km. The country exhibits a great climatic diversity, as it encompasses all the Mediterranean bioclimatic zones, ranging from humid to Saharan. The orotopographic contrast accentuates the climatic one and gives this country a rich diversity of fauna and flora. However, it remains confined to a relatively small area, with the desert occupying most of the territory.

Two major mountain ranges, the Tell Atlas in the north and the Saharan Atlas in the south, divide the country into three types of environments distinguished by their relief and morphology, resulting in climatic diversity. From north to south, one can identify the Tellian system, the High Steppic Plains, and the Sahara.

Algerian biodiversity (natural and agricultural) is immensely rich, with approximately 16,000 known species overall. Known marine biodiversity amounts to 3,183 species and between 720 genera and 655 families. Marine flora is estimated to comprise 713 species, and up to 4,150 when littoral and island vegetation and marine and littoral ornithological fauna are considered. Mountain biodiversity is also very rich. Further, Algeria’s Sahara hosts a large diversity of ecosystems, most of which are still unknown.

Yet Algerian biodiversity is highly endangered. The country has a total of 121 species on the CITES list, of which 75 are endangered. They include 23 fish species, 14 mammals and 11 bird species. The most threatened plant species are the Tassili cypress, of which only 200 remain in the Tassili Biosphere Reserve, the black pine and thuriferous juniper. Among the most threatened animal species are the wild ungulates (gazelles, antelopes, barbary sheep, barbary deer), cheetah, monk seal and the barbary macaque. It is estimated that, within 20 years, fishery resources will have diminished by 30%, even if the country only fishes a third of the available authorized stock. Species affected include tuna, anchovies, sardines and langoustines. Coastal erosion, caused by sea level rise and the cumulative effects of storms, is undeniably the most significant form of degradation observed in the past 20 years. The province of Alger has been particularly hard hit having lost between 40-80% of its beaches in 50 years (1954-2003).

The Algerian forest is primarily of the Mediterranean type. Two centuries ago, it covered 5 million hectares according to old publications; today, it covers only 3.9 million hectares, of which 2 million consist of degraded forests (maquis and garrigues). From 1830 to 1955, the Algerian forest lost 1.815 million hectares, and from 1955 to 1997, it lost another 1.215 million hectares. This loss is partly due to the fragility of the forest and the causes of degradation such as the liberation war, deforestation, overgrazing, fires (which each year destroy 20,000 to 25,000 hectares), and pests (the processionary caterpillar has infested nearly 191,818 hectares of pine and cedar) (Rapport sur l’état et l’avenir de l’environnement, 2000).

Marine ecosystems constitute an important source of revenue for the Algerian population, with many people’s livelihoods dependent on small-scale fishery and trade (Source Convention on biological diversity).

Algeria's recognition of the importance of biodiversity is a crucial step towards ensuring the sustainability of its natural resources and the health of its ecosystems. Biodiversity, which encompasses the variety of life forms on Earth, plays a vital role in maintaining ecological balance, supporting food security, and providing essential services such as clean air and water. The loss of biodiversity can lead to detrimental effects on the environment and human well-being, making conservation efforts imperative.

One of the key measures Algeria has taken to protect its biodiversity is the establishment of national parks and protected areas. These designated regions serve as sanctuaries for various species and habitats, safeguarding them from threats such as urbanization, agriculture, and industrial development. By creating these protected areas, Algeria not only preserves critical ecosystems but also promotes ecotourism, which can provide economic benefits while fostering a greater appreciation for nature among its citizens and visitors.

Moreover, Algeria's commitment to international agreements, such as the Convention on Biological Diversity (CBD), underscores its dedication to global conservation efforts. The CBD aims to promote sustainable development through the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from genetic resources. By being a signatory to this convention, Algeria aligns itself with a broader international framework that encourages collaboration among nations to address biodiversity loss and implement sustainable practices.

In addition to these measures, Algeria's efforts can be further strengthened by enhancing public awareness and education regarding the importance of biodiversity. Engaging local communities in conservation initiatives can lead to more effective stewardship of natural resources, as people are more likely to protect what they understand and value. Furthermore, integrating traditional ecological knowledge with modern conservation strategies can yield innovative solutions tailored to the unique challenges faced by Algeria's diverse ecosystems.

Chapter 4: Services provided by biodiversity

1. Types of Ecosystem services

Ecosystem services are the links between ecosystems and human societies. In the broadest sense they are the benefits societies obtain from ecosystems (Millennium Ecosystem Assessment, 2005). More specifically, services are produced by living or nonliving components of ecosystems, through the conditions and processes in ecosystems. They contribute to human well-being in different ways: Services can be directly consumed, as in the case of water or food. Services can be experienced, as in the case of the scenic beauty or the sense of awe that a waterfall, a mountain covered by vegetation or a monarch butterfly can instill in us. Services also contribute to the fundamental environmental conditions for human life, such as the regulation of relatively stable climatic conditions and protection against extreme events.

Ecosystem services have also been defined as those components and processes of ecosystems that contribute directly to human well-being (Luck *et al*., 2009 in Quijas and Balvanera, 2013). By emphasizing the direct nature of such connections an effort is being made to distinguish ecosystem processes from ecosystem services.

There is a fine line between ecosystem processes and ecosystem services. Some authors have considered ecosystem processes as those ecosystem services that support the delivery of all other types of services. The advantage of this position is that it is possible to encompass both direct benefits to human societies as well as ecosystem functions and the origin and maintenance of biodiversity within the term ecosystem services. This approach can be very useful when communicating with decision makers.

Yet, in order to quantify the amount of services, a clear distinction between supply, service and value can be useful. Supply is the contribution of ecosystem processes and components to a service that can potentially benefit societies. Service is the actual benefit societies obtain from the service, which can include water consumption or the number of people that benefit from regulation of flooding. Value reflects how societies consider the relative importance of a service; it can be monetary, as an expression of markets or preferences or embedded into cultural perspectives (Chan *et al*., 2011 in Quijas and Balvanera, 2013).

The Millennium Ecosystem Assessment (2005) classifies services into four types: supporting, provisioning, regulating, and cultural services. The authors do not include supporting services, as they consider them to be ecosystem processes that indirectly benefit societies by supporting one of the other three types of services (Figure 18).

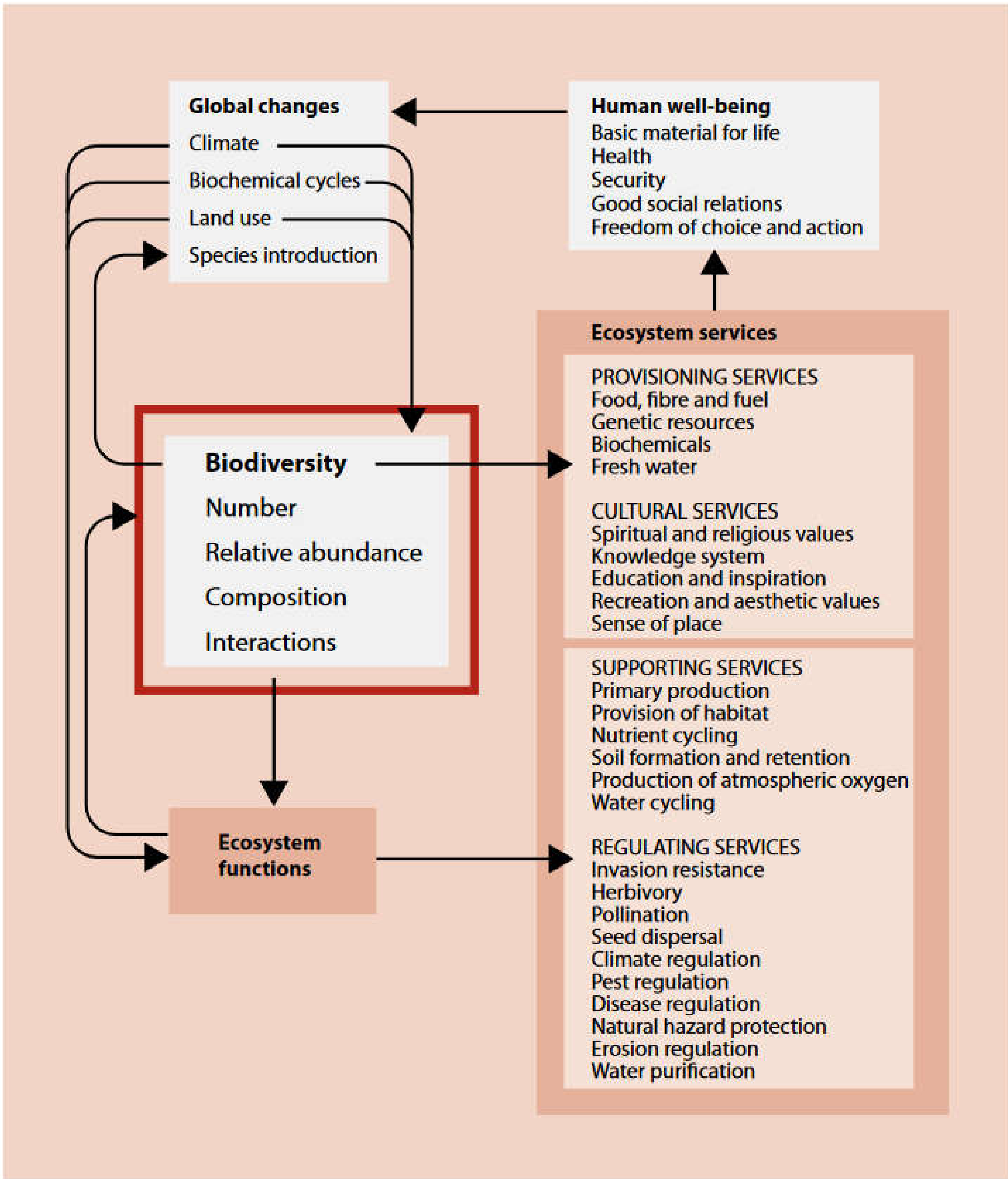


Figure 18. Ecosystems and Human Well-being: Biodiversity Synthesis (Source: Millennium Ecosystem Assessment, 2005).

1.1. Provisioning services

Provisioning services are products that can be harvested, consumed, or traded including food, clean water, fuel, and genetic resources. Provisioning services from marine environments include seafood, fuel wood from mangrove forests, sand for construction, and genetic resources for medicines.

Food is a particularly important provisioning service and much of the world depends on the ocean for sustenance. In 2019, aquatic foods (from marine and inland waters) provided 17% of global protein. However, in parts of the world (e.g., Bangladesh, Cambodia, Ghana, and small island states), aquatic foods can make up 50% or more of total animal protein intake. Such foods are an important source of protein, and also provide essential amino acids, vitamins, minerals, and heart-healthy omega-3 fatty acids (FAO, 2022a).

However, growing populations and environmental degradation could lead to *food insecurity* in many communities. Golden (2016) predicted that declining fish populations could lead to micronutrient and fatty-acid deficiencies in more than 10% of the global population in the coming decades. Rice and Garcia (2011) calculated that global fish production will need to increase by approximately 50% to keep up with projected food requirements for a growing population and expected trends in terrestrial production. Fishery managers and conservationists will need to work hand in hand to find a common solution (Figure 19).

Figure 19. Seafood is an important source of protein for much of the world (Photo by pdbreen).

Food is not the only provisioning service the ocean provides, fuel from mangrove trees, sand for building materials, and genetic resources for drugs are all also provisioning services. Indeed, the ocean could be a source of new drugs that improve human health. Marine sponges in particular have been found to have hundreds of unique compounds including antibacterial, antiviral, antiinflammatory, and immune suppressive compounds. For people to continue benefiting from these ecosystem services, the ecosystems and biodiversity within them need to be protected (Jungwiwattanaporn et *al.*, 2023)

1.2. Regulating services

Regulating services result from the contribution of multiple ecosystem processes to ecosystem functioning, specifically to the regulation of the conditions where humans live and make a living. Such regulation determines both the average and the variance in such conditions.

Regulating services include the regulation of local or global climate, of disease vectors and incidence, of pests, crop pollination, soil fertility, and soil erosion. They also regulate the amount, temporality, and quality of water provision, as well as the impact of severe weather conditions on ecosystems and people (Quijas and Balvanera, 2013).

Regulating services are believed to be the most valuable services that enable ecosystems to continue supplying different provisioning services such as food and water as well as safeguarding human well-being from a range of shocks and stressors; however, functions of these services are least understood (MEA 2005; Koch et *al.*, 2009). The Millennium Ecosystem Assessment (MEA 2005) extensively mapped regulating services and categorized those into eight major types: climate regulation, hazard regulation, disease and pest regulation, pollination, noise regulation, soil quality regulation, air quality regulation, and water quality regulation.

Each of these services functions as cogs that fit together as a whole and maintain the planet's capacity to support life as well as sustain human civilization (MEA 2005). Among these services, some act as "final" ecosystem services such as climate and hazard regulation, some others contribute significantly to final ecosystem services such as water detoxification and purification, while others are primary or intermediate ecosystem services such as the effect of pollination and disease on maintaining the provision of crops, plants, and livestock (Smith et *al.*, 2011 in Sinha and Baten, 2020).

Understanding the functionality of these regulating services is vital to understand the ecosystem's adaptive capacity against disturbances which is regarded as an essential function in ecosystem resilience. A healthy ecosystem generates a range of services required for securing human livelihood and well-being. Several attempts have been made for the valuation of these services in order to motivate the general public and politicians to promote environmental conservation and the protection of natural resources. Various ecosystem processes such as photosynthesis, nutrient cycling, and biomass production are directly linked to water cycle that only provides communities with provisioning services like drinking water, food, and fiber but also creates an ambient environment in which living organism and humanity thrives thus supporting regulating services like climate, hazard, and water quality regulation. Likewise, carbon sequestration is another crucial function played by the forest ecosystem and has drawn the attention of the policymakers with the rise of global attempts to counter climate change. Terrestrial biosphere sequesters one-fifth of the anthropogenic greenhouse gases emitted, where forest serves the most critical functions (Griscom et *al.*, 2017; Mukul and Saha 2016; Zhu et *al.*, 2019 in Sinha and Baten, 2020).

An example below in Figure 20: (a) A hilly stream in Bandarban, Bangladesh. These streams not only maintain water flow but also purify waters that are drinking water sources to many indigenous communities living there. (b) An artisanal fisher at the Jadukata River in Bangladesh. Nutrient cycling is an important ecosystem function that contributes to fish production. (c) Ratargul Swamp Forest in Bangladesh. Forest sequesters carbon and mitigates climate change impacts. (d) A coastal mangrove forest in Bangladesh. These mangroves protect the shoreline from erosion as well as stabilize the soil (Sinha and Baten, 2020).

Figure 20. Regulating Ecosystem Services: Enhancements Through Sustainable Management [Photo credit: Mohammed Abdul Baten].

1.3. Supporting services

Supporting ecosystem services are intermediate services generated through the internal functions of the ecosystem which neither deliver any products nor vary any environmental conditions that can be used instantaneously by people (Price, 2014 in Saiful and Khan, 2020) but patronize/buttress all other ecosystem services to be used for human well-being.

The term "supporting ecosystem services" was introduced through the Millennium Ecosystem Assessment program (MEA 2005a). MEA (2005a) recognized the fundamental services that are generated through the biophysical structure and functions of an ecosystem unit as a distinct category and named it "the supporting ecosystem services." The term "supporting" is used as these fundamental services support all other ecosystem services that directly benefit human society.

Characteristics of Supporting Ecosystem Services are:

- Used by the ecosystem units: Supporting ecosystem services are a integral part of the ecosystem functioning as the services support the fundamental processes of an ecosystem. It is the ecosystem itself which uses these supporting services. However, supporting ecosystem services may also be used by other interlinked ecosystem units. Supporting ecosystem services interplay with bio-physicochemical elements of ecosystem units. These are used as inputs for other ecosystem processes or regulate physicochemical elements used by other ecosystem components.

Supporting ecosystem services are different from the "regulating ecosystem services," which regulate the elements of physical systems that are directly consumed or enjoyed by people.

- Independent of anthropogenic input: The supporting ecosystem services are generated through natural processes without any external anthropogenic inputs.

However, the supporting services, indeed, can be affected by the exploitation as final services and can also be managed directly.

- Societal recognition: There are many natural processes that maintain ecosystem integrity. Only those processes for which people understand the linkage to become ultimately beneficial for society are recognized as supporting ecosystem services.

- Intermediate to producing final ecosystem ser vices: From the production point of view, the supporting ecosystem services are part of the production chain of the ecosystem services; these are interim goods and services that are used in the subsequent production phase.

- Indirect towards human use: From the human use perspective, the supporting ecosystem services are not used or enjoyed directly by the society.

- Not mutually exclusive from final ecosystem services: The supporting ecosystem services are not mutually exclusive from other ecosystem services. The same process/function can become a final ecosystem service if used, consumed, or enjoyed directly by people.

- Interrelated with each other: The supporting ecosystem services are part of the complex mix of ecosystem components and processes. Even though people try to identify them separately, supporting services are strongly interrelated to each other and underpinned by a wide range of physical, chemical, and biological interactions (Bardgett et *al*., 2011 in Saiful and Khan, 2020) (Figure 21 and 22).

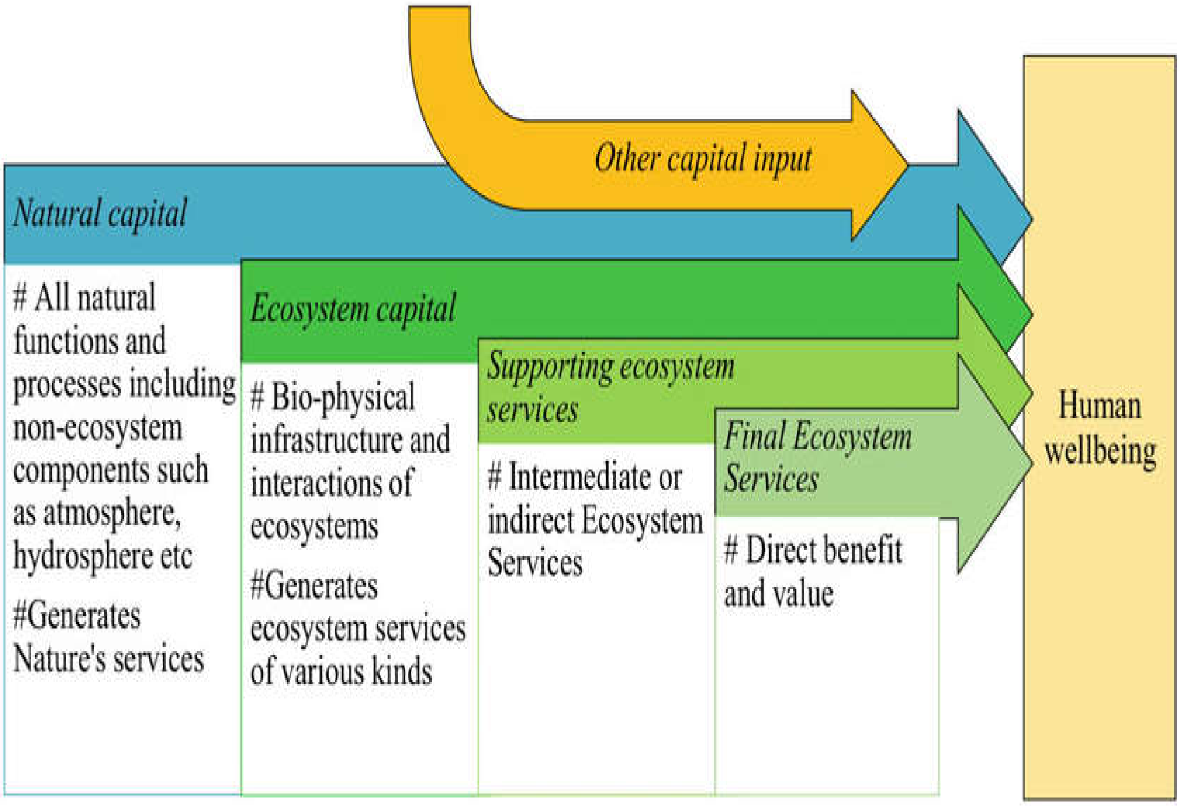


Figure 21. Linking nature's capital to human well-being via supporting and final ecosystem services (Saiful and Khan, 2020).

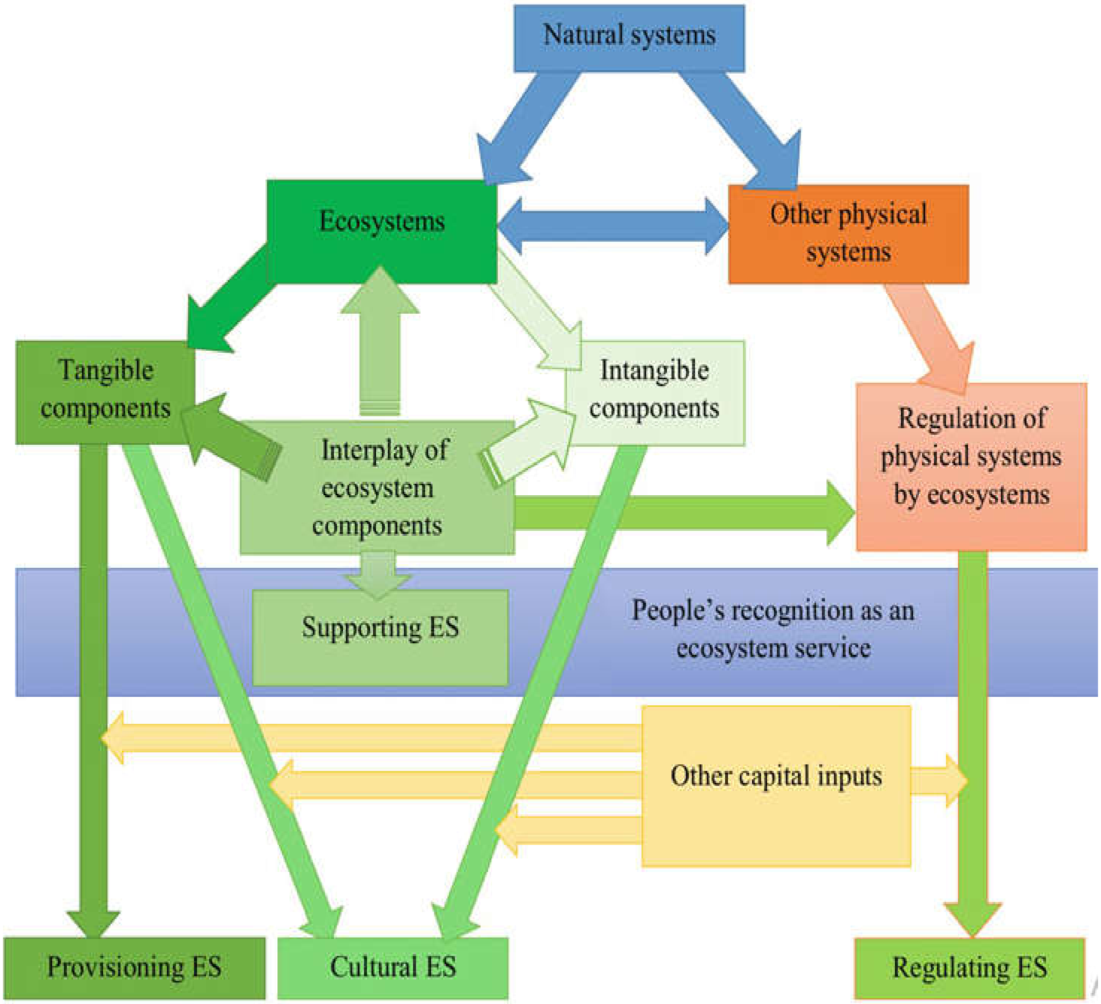


Figure 22. The complex interrelation of different types of ecosystem services in the perspective of their defining and distinguishing characteristics (Saiful and Khan, 2020).

Supporting services are the backbone of ecosystem functionality. Without them, other ecosystem services would be compromised, leading to a decline in biodiversity and the overall health of the environment. Understanding and protecting these services is crucial for sustainable development and conservation efforts.

1.4. Cultural services

The term "cultural ecosystem services" is defined within a wider framework of ecosystem services as "non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experience" (MA, 2005).

The concept of cultural ecosystem services is a simple one – natural amenities are essential for Cultural Ecosystem Services human existence through which people develop different relationships. As a "relational product" of natural processes and human experience which is gained through evolution, cultural ecosystem services are "results" of human thoughts, perception, and judgments. But, on the other hand, it is not easy to explain all dimensions of the "relational processes and entities that people actively create and express through interactions with ecosystems". Evolution of the relationships, which are readable within the concept of cultural ecosystem services, started with a human perception of nature as an essential source of spiritual and cognitive development and as an inspiration for art and science, research, and education. In the circumstances of modern life, when more than 70% of the population lives in towns and cities, isolated from nature, nature-based recreational activities are perceived as essential for urban life (Vasiljevic and Gavrilovic, 2019).

One of the main ideas of cultural ecosystem services is to recognize all dimensions of the specific relationship between men and nature. Some of those dimensions have produced characteristic ecologically, biologically, culturally, and scenically important natural values, tangible and intangible cultural heritage, as well as spaces with spiritual significance which is known under the wider concept of "cultural landscapes."

Cultural landscape is "amalgamation of physical and cultural forms, where culture is the agent, nature is the medium and the result is cultural landscape" (Sauer, 1925). As a way of their survival, many societies consider as very important the agricultural land maintenance within the framework of cultural landscapes (The Millennium Ecosystem Assessment). Ecosystem management, which is based on the indigenousknowledge and long-standing traditional maintenance, has designed specific elements of landscape composition throughout the world (e.g., rice and viticulture terraces; slagen – long stretched land parcels). At the same time, the value of its amalgamation is not always physically readable within ecosystems and elements of landscape structure. It is a construct of beliefs and ideologies, places of rituals, and myths. Anyway, the human perception is the only way to evaluate and define cultural landscape which plays a vital role in the conservation and sustainable use of the world's cultural and natural heritage (Vasiljevic and Gavrilovic, 2019).

2. Ecosystem services and economic frameworks

Economic frameworks are essential for understanding, valuing, and integrating ecosystem services into decision-making processes. They provide tools and methodologies to assess the economic value of ecosystem services, which can help inform policy, conservation efforts, and sustainable resource management.

This framework is useful for identifying and analysing the full suite of ecosystem services available within any given geographical area. It also helps us to understand the complexity of dependencies, feedbacks and trade-offs between services and human beneficiaries, and can provide useful information for decision making by:

■ explicitly identifying and classifying the benefits that people derive from ecosystems, including market and non-market, use and non-use, tangible and intangible benefits

■ describing and communicating these benefits in concepts and language that people can understand

■ asking, and trying to answer, ecological, economic and social questions to improve sustainable management of ecosystems and human wellbeing.

Although such analysis may be information intensive, taking an approach which looks for multiple benefits is likely to minimise the risks of compromising the structure, function and services of ecosystems and increase the options for retaining resilience. As outlined in Figure 23, a mix of ecosystem services is available from any area of natural or modified ecosystem or habitat. However, the potential for modified ecosystems to provide a full range of ecosystem services over the long term may be limited if ecological or other thresholds are reached (Department of the Environment, Water, Heritage and the Arts, 2009).

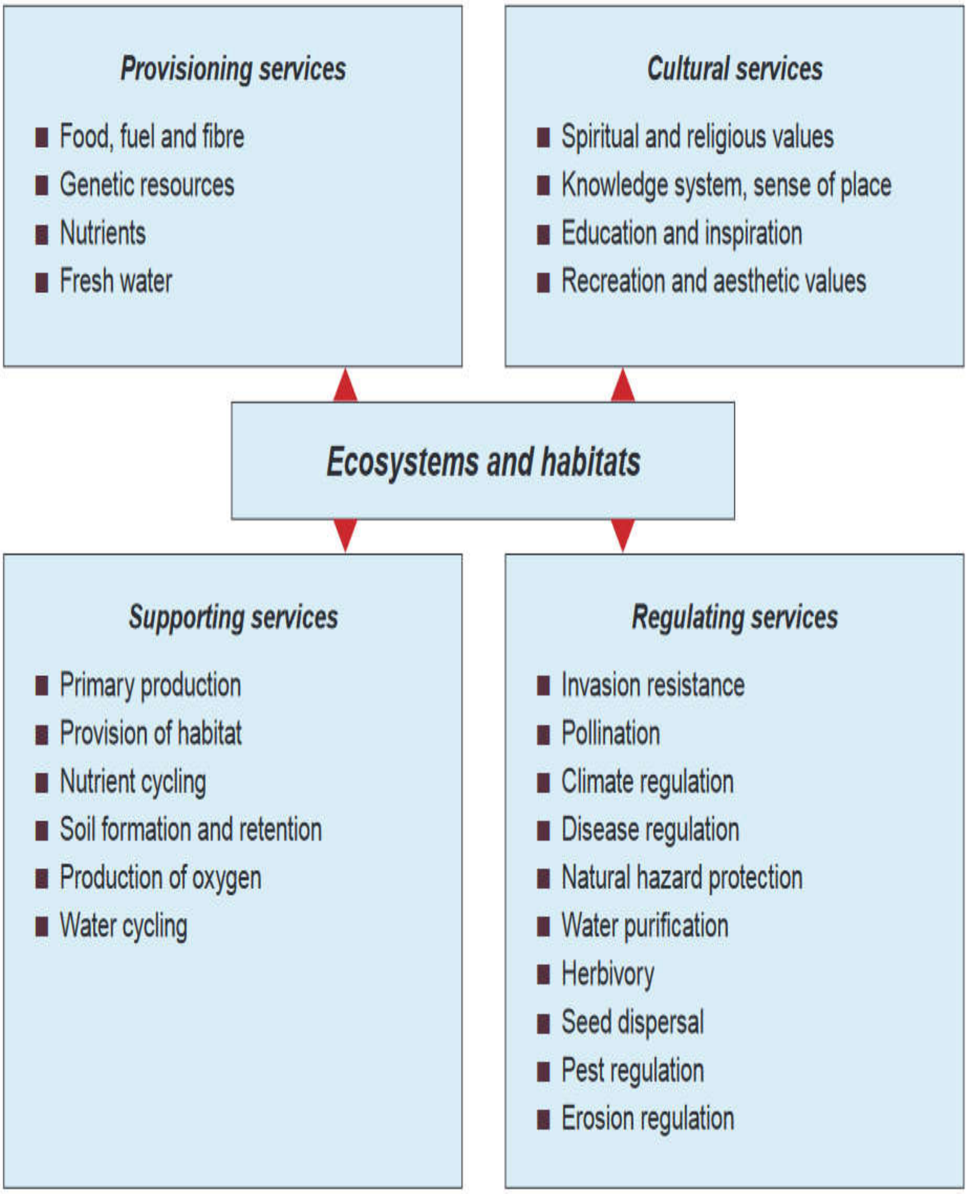


Figure 23. Biodiversity's contribution to ecosystem services.

The health of ecosystems and the services they provide are closely linked to biodiversity. A diverse ecosystem is generally more resilient and better able to provide essential services. Analyzing these benefits can serve as an indicator of biodiversity health, helping to identify areas that may be under threat or in decline. It informs decision-making, raises awareness, supports economic valuation, and guides restoration efforts, ultimately contributing to sustainable development and the well-being of both humans and the natural world.

Chapter 5: What value should be placed on biodiversity?

The conservation, sustainable use and restoration of biodiversity is vital to achieving a number of policy objectives beyond biodiversity, such as human health, food and water security, climate-change mitigation and adaptation, and disaster risk reduction. From the air we breathe to the food we eat, biodiversity plays a critical role in ecosystem services that are essential for survival. It contributes to climate regulation, pollination of crops, water purification, and disease regulation, among many other functions. However, human activities, such as deforestation, pollution, and climate change, have led to unprecedented rates of species extinction and habitat loss, raising alarms about the sustainability of our natural resources.

In this context, understanding the intrinsic and extrinsic values of biodiversity is crucial. Intrinsic value refers to the inherent worth of all living organisms, regardless of their utility to humans, while extrinsic value encompasses the tangible benefits that biodiversity provides to society, including economic, cultural, and recreational aspects.

1. Biodiversity and human health

Biodiversity provides services critical for human health and well-being. These services include the provision of basic needs (e.g. food and protection from environmental hazards) biomedical resources, air purification, and opportunities for recreational and therapeutic activities.

1.1. Biomedical resources and insights

Many of the drugs used today for health care and disease prevention were discovered from plant sources (e.g. digoxin), lizards (e.g. exenatide), cone snails (e.g. ziconotide), fungi (e.g. penicillin) and other wild species. More than 80% of the small-molecule anticancer drugs approved between 1981 and 2014 are either natural products, based on natural products or mimic natural products. The most profitable drug to date, atorvastatin (Lipitor), is a cardiovascular drug descended directly from a microbial natural product that posted annual sales of USD 12-14 billion between 2004 and 2014 (Newman and Cragg in OECD, 2019) . The untapped potential for future drug discovery and medical insights from biodiversity is vast, but is diminishing because of biodiversity loss. Although plants have been a major source of natural product drugs, only a fraction of the 400 000 plant species on Earth have been studied for their pharmacological potential. 7 Arthropods, microbes and fungi are even less studied. Given their diversity and the medicines already discovered from them, these taxa hold considerable potential for the development of new drugs (Neergheen-Bhujun et *al*., 2017 in OECD, 2019) (WHO and SCBD, 2015 in OECD, 2019).

1.2. Regulating air quality

Morbidity and mortality from air pollution is a major health challenge, particularly in urban areas. The OECD estimates the welfare cost from premature deaths stemming from exposure to outdoor fine particles and ozone at USD 5.3 trillion globally in 2017. Investing in nature can help reduce this burden. Trees and forests in the conterminous United States, for example, removed 17.4 million tones of air pollution in 2010, providing health benefits (avoidance of human mortality and incidences of acute respiratory symptoms) valued at USD 6.8 billion (Nowak et *al.*, 2014 in OECD, 2019).

1.3. Recreational and therapeutic activities

Access and proximity to nature and green spaces correlate with reductions in mortality, cardiovascular disease and depression, and increases in perceptions of well-being (WHO and SCBD, 2015 in OECD, 2019). The physical and mental-health benefits of natural environments (e.g. parks, woodlands and beaches) in the United Kingdom are estimated at GBP 2 billion (pounds sterling) a year (White et *al*., 2016 in OECD, 2019). With over half of the world's population living in urban areas today, and given current urbanisation trends, the savings in healthcare costs from integrating biodiversity conservation into urban planning and building design are likely only to increase

2. Biodiversity and food

Conserving and sustainably managing biodiversity is vital to meeting growing food demand and achieving Sustainable Development Goal 2: Zero Hunger. Biodiversity is the foundation of our food system. Biodiversity is the food we eat – domesticated and wild livestock and crops, aquatic species harvested from the wild or raised through aquaculture – as well as the myriad plants, animals and micro-organisms that underpin production processes such as maintaining healthy soils, regulating water and pollinating plants. Although food production has increased considerably to match growing demand, this increase has often come at the expense of the biodiversity and ecosystem services that underpin global food systems. The economic value of biodiversity's contribution to food systems is considerable. Pollination from bees, birds, bats and other species contributes directly to between 5% and 8% of current global crop production. The annual market value of these crops is USD 235- 577 billion (in 2015 USD) (IPBES, 2016 in OECD, 2019). Higher pollinator density and species diversity can lead to higher crop yields.The dramatic decline in the abundance of bees and other insects, therefore, poses a considerable economic risk. The loss of all animal pollinators would result in an estimated annual net loss in welfare of USD 160-191 billion globally to crop consumers, and an additional loss of USD 207-497 billion to producers and consumers in other markets (IPBES, 2016 in OECD, 2019). Biodiversity is also important to control pest outbreaks. Maintaining habitat within agroecosystems and surrounding landscapes for insectivorous birds and bats, and microbial pathogens that regulate populations of agricultural pest, can reduce the need for pesticides.

Reducing pesticide use and supporting biological control would help reduce one of the primary threats to bee and other insect populations, while also increasing the efficiency of farms (Lechenet et *al.*, 2017 in OECD, 2019).

Genetic and species diversity among crops and livestock (and the wild varieties of domestic species) is fundamental to ensuring agricultural systems' resilience to drought, flood, pests and disease. Maintaining genetic diversity allows farmers to adapt their livestock breeds and crop varieties to changing environmental conditions, reducing the vulnerability of farmers and the global food system. Nevertheless, the Food and Agriculture Organization of the United Nations (FAO) reports increasing extinction risk among wild varieties and livestock breeds; declining crop diversity; and widespread genetic erosion as a result of poor cross-breeding practices, the use of non-native breeds and the pursuit of more productive breeds at the expense of less productive ones (FAO, 2019 in OECD, 2019).

3. Biodiversity and water security

A major challenge facing governments across the globe is water security, which is projected to deteriorate in many regions owing to increasing water demand, water stress and water pollution. An estimated 40% of the global population is already affected by water scarcity (UN and WBG, 2018 in OECD, 2019), and around 30% lacks safely managed drinking water supplies (WWAP, 2019 in OECD, 2019).

The mismanagement and degradation of ecosystems is a root cause of water insecurity. To tackle water insecurity, governments must tackle biodiversity loss. Healthy soils, forests, wetlands, grasslands and other ecosystems provide vital hydrological services that can reduce water-related disaster risks, and improve water availability and quality. For example, nearly one-third of the world's 105 largest cities – including Los Angeles, New York, Rome and Tokyo – depend on protected forests for a significant share of their drinking water (Duley and Stolton, 2003 in OECD, 2019).

Conserving or restoring natural ecosystems, or enhancing the creation of natural processes in modified or artificial ecosystems, can be a sustainable solution to water insecurity and may be more cost-effective than grey-infrastructure alternatives, as shown in the examples below:

- *United States:* a cost-benefit analysis conducted for Philadelphia estimated the net present value of low-impact "green" infrastructure for storm-water control (e.g. tree planting, permeable pavement, green roofs) at USD 1.94-4.45 billion over a 40-year period. The net benefits for the grey-infrastructure alternative (e.g. storage tunnels) were much lower at USD 0.06-0.14 billion (Stratus Consulting Inc, 2009 in OECD, 2019). An analysis of options for improving water quality in Portland found that green infrastructure would be 51-76% cheaper (USD 68-72 million cheaper) than water-filtration plant upgrades (Talberth et *al.*, 2012 in OECD, 2019) and would bring ancillary benefits (i.e. salmon habitat and carbon sequestration) estimated conservatively at USD 72-125 million.
- *Kenya:* Tana River provides 80% of Nairobi's drinking water and 70% of Kenya's hydropower. However, ecosystem degradation from unsustainable agricultural practices has led to higher levels of erosion and sedimentation. As a result, the cost of water treatment for Nairobi has increased, and the hydropower reservoir capacity has declined. Planned investment of USD 10 million in sustainable land-management measures in the Tana River Delta is expected to deliver a return of USD 21.5 million over 30 years as a result of increased power generation and agricultural crop yields, and savings in water and wastewater treatment (TNC, 2015 in OECD, 2019).

4. Biodiversity, climate change and disaster risk

Countries need to decrease greenhouse gas emissions by 25% by 2030 compared to 1990 levels to achieve the 2 degrees Celsius (°C) target of the Paris Agreement and 55% to reach the 1.5°C target (IPCC, 2018 in OECD, 2019). Conserving, sustainably managing and restoring ecosystems can provide a substantial and cost-effective contribution to these efforts. Plants and soils in terrestrial ecosystems absorb an estimated 9.5 billion tonnes of carbon dioxide equivalent every year (Le Quéré et *al.*, 2015 in OECD, 2019). However, land-use change and poor management have depleted carbon stocks in terrestrial ecosystems, resulting in large emissions of carbon into the atmosphere. For example, deforestation and forest degradation account for around 12% of global emissions of carbon dioxide (CO_2). The destruction of marshes, mangroves and seagrasses releases an estimated 0.15- 1.02 gigatonnes of carbon dioxide ($GtCO_2$) per year, resulting in annual economic damages of USD 6-42 billion (Pendleton et *al.*, 2012 in OECD, 2019). Griscom et *al.* (2017 in OECD, 2019) estimate that conservation, restoration and improved management of forests, grasslands, wetlands and agricultural lands could deliver 23.8 $GtCO_2$ of cumulative emission reductions by 2030. About half of this mitigation potential represents cost-effective climate mitigation, defined as a marginal abatement cost of less than or equal to 100 USD per tonne of CO_2 by 2030. Deploying these approaches could deliver up to 37% of the emission reductions needed by 2030 in order to have a greater than 66% likelihood of holding warming below 2°C, and up to 20% of the emission reductions needed between now and 2050.

In addition to mitigation, biodiversity and ecosystem services play an important role in adapting to the impacts of climate change, and reducing the risk of climate-related and nonclimate-related disasters. For example, floodplains and wetlands can protect communities from floods. Coral reefs, seagrass and mangroves buffer coastlines from waves and storms. Forested slopes stabilise sediments, protecting people and their assets from landslides. Healthy, connected and biodiverse ecosystems also tend to be more resilient to the effects of climate change than degraded ecosystems (Oliver et al., 2015 in OECD, 2019). Hence, conserving, sustainably using and restoring biodiversity is critical to ensuring ongoing ecosystem function and service provision in a changing climate. In some cases, the speed and scale of climate change will make it difficult – if not impossible – for some species and ecosystems to adapt.

5. Cultural values

Cultural values, sense of place, cultural identity, knowledge systems, religions, social interactions and other amenity services (e.g. aesthetic enjoyment, recreation, artistic and spiritual fulfilment, and intellectual development) all contribute to an individual's quality of life and general wellbeing (Millenium Ecosystem Assessment, 2005). Therefore, fulfilment of cultural values is seen as an essential component of multidimensional wellbeing. The application of a wellbeing framework provides a more holistic evaluation of the human condition, reflecting the importance of social, psychological and cultural needs required to thrive. It not only considers the traditional material components of wellbeing (e.g. income and basic necessities) but also the relational and subjective components which emphasise the importance of social interactions, collective identities, cultural values, norms and belief systems that people require to live a good life.

Biodiversity change can directly affect human health, such as through the regulation of the emergence and transmission of diseases, or via pollution control. Biodiversity change can also indirectly impact upon human health via cultural pathways; biodiversity loss affects the provision of cultural goods, which reduces our opportunity to realise the cultural value placed upon those goods and, consequently, negatively impacts upon human well-being and, therefore, health (Figure 24).

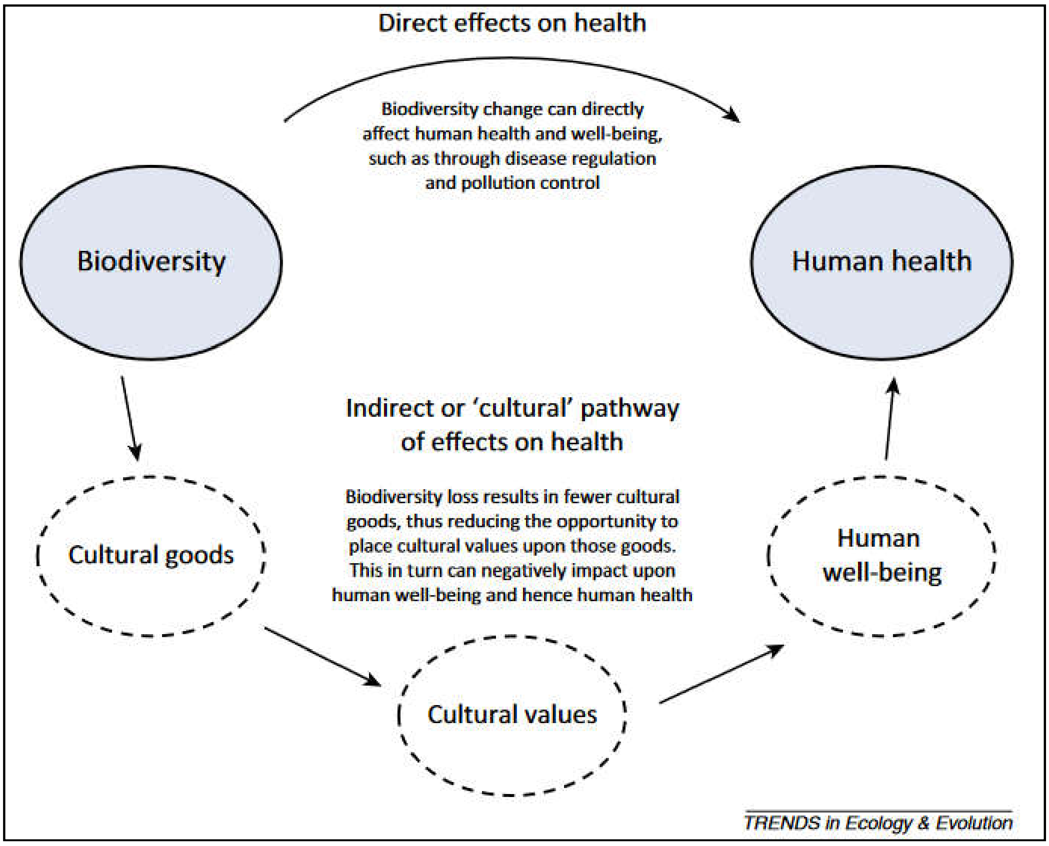
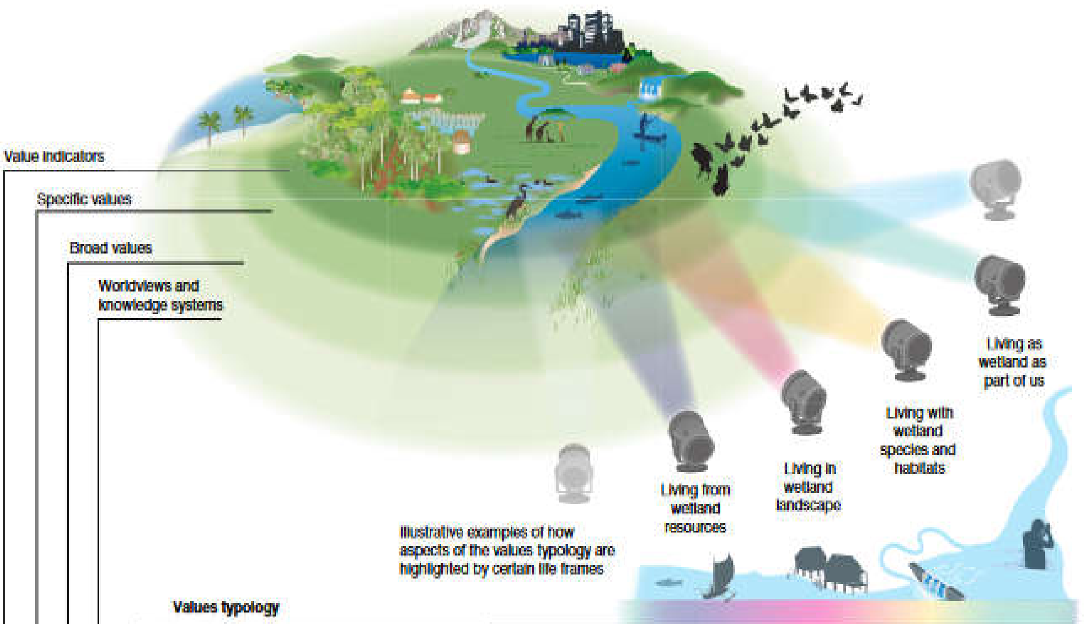


Figure 24. The direct and indirect (cultural) pathways from biodiversity to human health

6. Integrating Diverse Perspectives on Biodiversity Values into Policy and Practice

Over the world, people have developed myriad ways of understanding and relating to nature and its many values. Although acknowledged in some policy realms, a lot of work remains to consider this diversity in practice (for example, GBF Target 14 regarding "full integration of biodiversity and its multiple values into policies, regulations, planning and development processes … across all levels of government and … sectors").

To clarify and identify different values and their interrelationships, the typology distinguishes four flexible and interconnected layers of what value means: worldviews and knowledge systems, broad values, specific values and value indicators. Life frames (metaphorically shown as light beams) illustrate how some sets of values might be given prominence in the different ways people relate to nature (here an watershed feeding into an estuarine wetland) (Figure 25).



Values typology					
Worldviews	Ways through which people conceive and interact with the world	Anthropocentric	Anthropocentric	Bio/ecocentric	Pluricentric
Knowledge systems	Bodies of knowledge, practices and beliefs • Academic, indigenous, local				
Broad values	Guiding principles and life goals	Prosperity, livelihood	Belonging, health	Stewardship, responsibility	Oneness, harmony with nature
Specific values	Judgements regarding the importance of nature in particular situations				
	• Instrumental: means to an end, nature as a resource or asset, satisfaction of needs and preferences, usefulness for people	Fish to sell at market	Health benefits of recreation on the river	Fish as regulators of food web structure and function	Fish to eat
	• Intrinsic: agency of other-than-humans, inherent worth of biodiversity as ends in and of themselves			The right of fish to exist	Fish as co-inhabitants
	• Relational: importance of desirable, meaningful and often reciprocal human relationships	Cultural meanings of fishing	Sense of place of a fishing community	Awe inspired by spawning fish	Fish as part of kinship or clan relationships
Value indicators	Quantitative measures and qualitative descriptors				
	• Biophysical	Tonnes of fish	Physiological effects of being in nature	Number of fish species	Fish as nutrition
	• Monetary	Price premium of eco-certified fish	Willingness to pay (WTP) for recreational fishing	Non-use (that is, existence and bequest) WTP of a river feature	
	• Socio-cultural	Gender-specific participation in fishing	Ratings of special places	Legal standing of biodiversity	Narratives of sacred places

Figure 25. An inclusive typology of the many values of nature (Pascual et al., 2023).

Chapter 6: Is biodiversity threatened?

1. Biodiversity decline

Biodiversity loss and habitat decline continues to accelerate, potentially beyond planetary boundaries. Current rates of species loss are estimated to be 1,000-fold greater than background rates, sparking debate among scientists over whether we have already entered into a sixth mass extinction event. For many species, populations are in decline globally, and genetic diversity – vital for future adaptation to global change – is eroding (Food and Agriculture Organization of the United Nations FAO, 2015). Natural communities of plants and animals are being reshaped through climate change and human-mediated movement of species; some displaced species are invasive, posing risks to human health, genetic diversity, and food and water security. These changes seem likely to reduce the effciency by which ecosystems are able to capture essential resources, produce biomass, decompose and recycle nutrients, and decrease the resilience of ecosystems. The restoration and maintenance of biodiversity will enhance adaptive potential, and help sustain nature's contributions to people's livelihoods, health and well-being (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). Figure 26 show a schematic from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services describing the main elements and relationships linking nature, biodiversity and ecosystem services, human well-being and sustainable development. (In this diagram, anthropogenic drivers equate to the pressures (IPBS, 2013 in GEO, 2019).

So we can say that biodiversity is currently threatened by a variety of factors, leading to significant declines in species populations and the degradation of ecosystems.

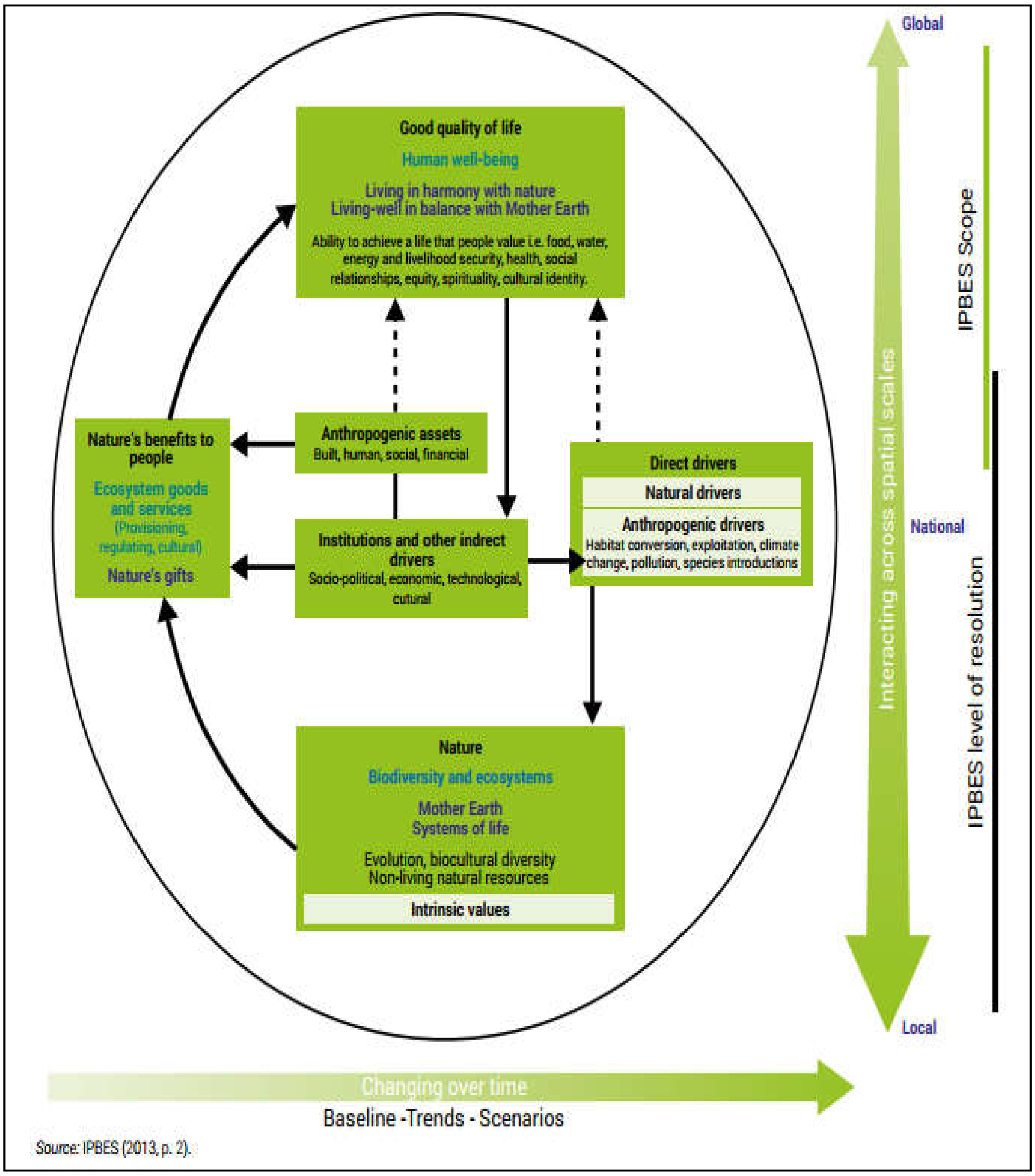


Figure 26. Schematic from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (in GEO, 2016).

1.2. Pressures

The main direct pressures on global biodiversity are habitat stress and land-use change, invasive species, pollution, unsustainable use/overexploitation and climate change (mainly as a consequence of higher temperatures, changes in precipitation patterns and increasing frequency and severity of extreme weather events and wildfres) (UNEP, 2012 in GEO, 2019). The spatial distribution and combination of these pressures varies across the globe (Figure 27) and affects species groups in different ways (Figure 28), although detailed data for invertebrates, which comprise most of the diversity of life, are lacking (Collen *et al.,* 2012 in GEO, 2019).

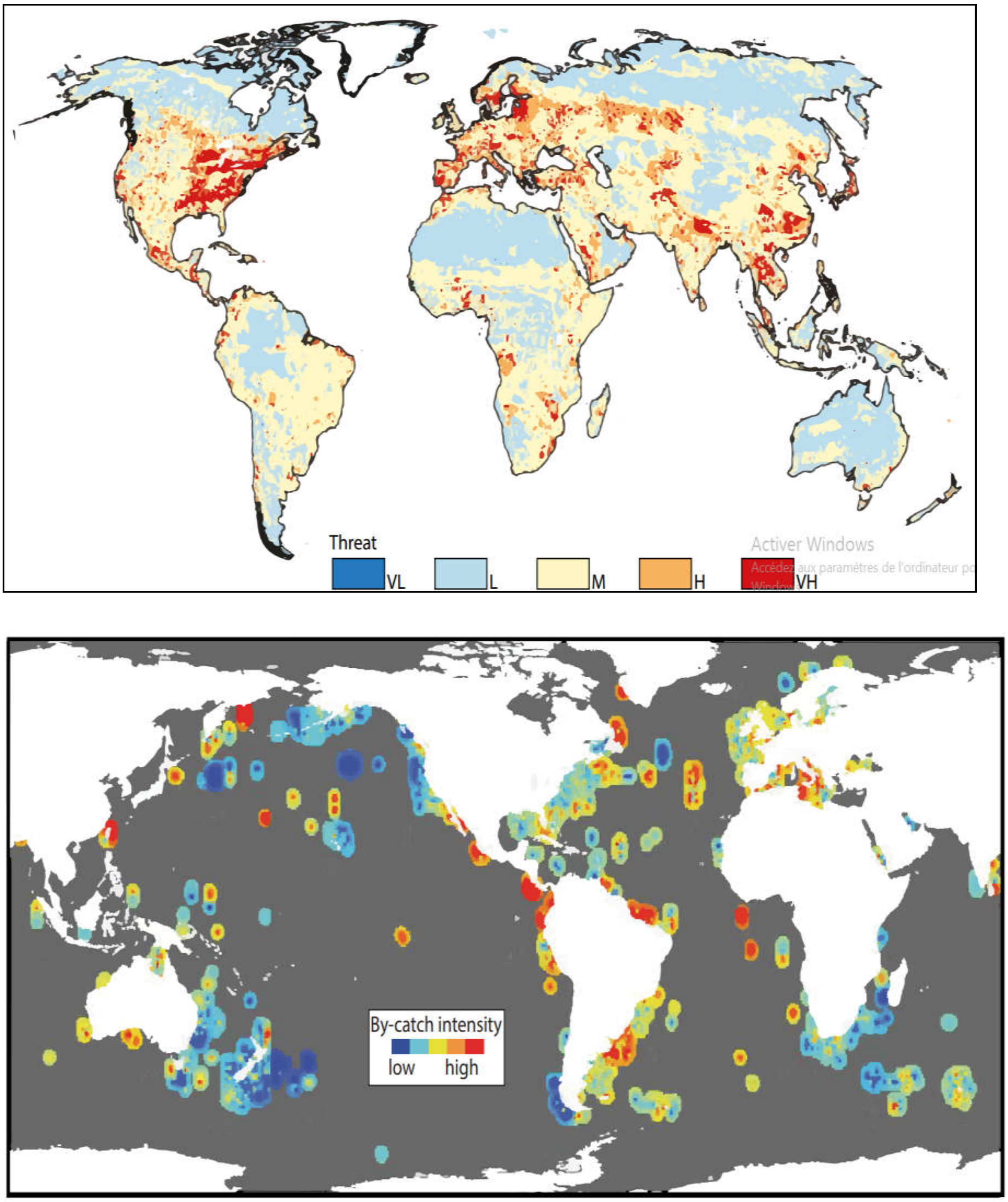


Figure 27. Examples of global distribution of pressures on (a) threat intensity (H: high; L: low; M: medium; VH: very high; VL: very low) from terrestrial invasive alien species and (b) cumulative fsheries by-catch intensity for seabirds, sea mammals and sea turtles, by all gear types (gillnet, longline and trawl) (Sources (a) Early et al., 2016 (b) Lewison et al., 2014 in GEO, 2019) .

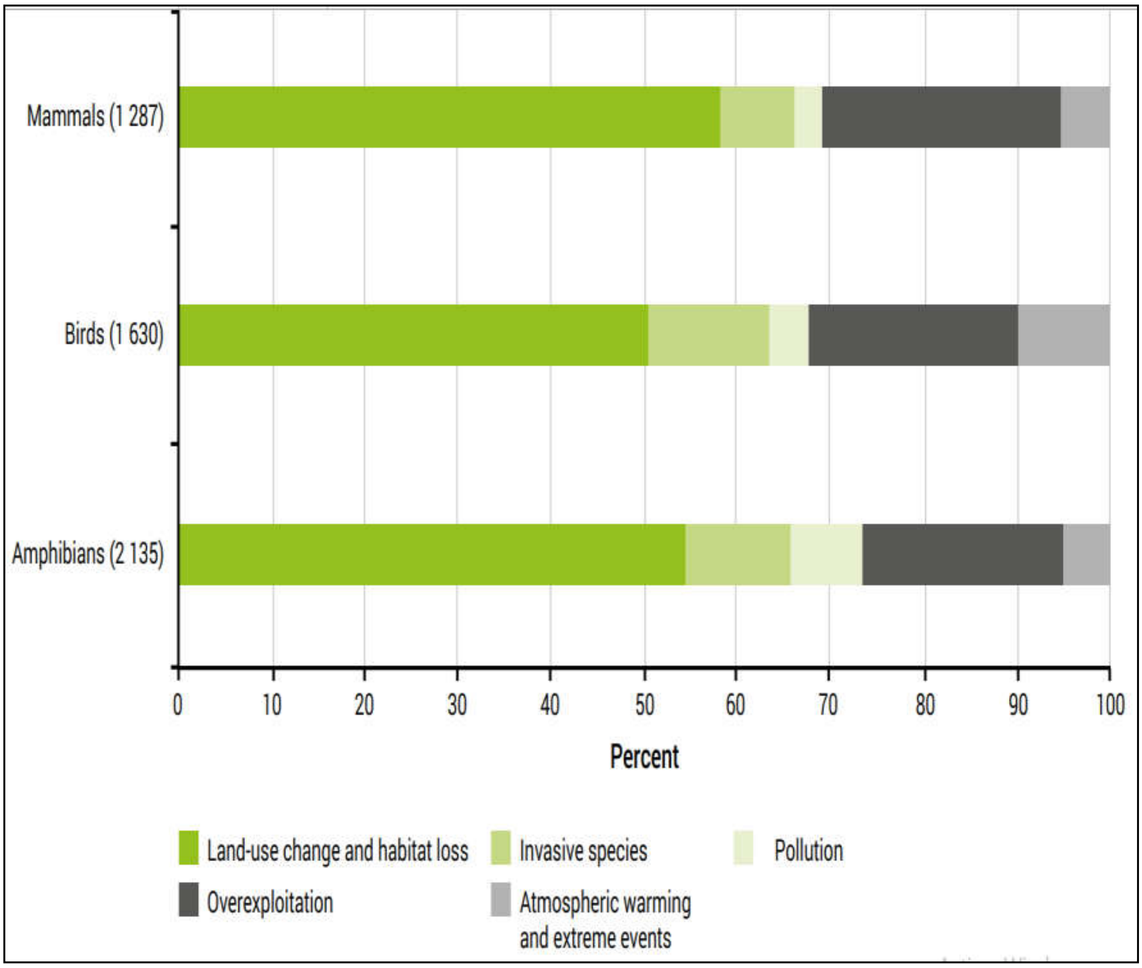


Figure 28. Percentage of threatened (critically endangered, endangered and vulnerable) and near threatened amphibian, bird and mammal species by major threat class (Maxwell et al., 2016 in GEO, 2019).

Number of threatened species in each taxonomic class in parentheses. Threat classes were aggregated as follows: 1 = Residential and commercial development, Agriculture and aquaculture, Energy production and mining, Transportation and service corridors, Human intrusions and disturbance, Natural system modifcations; 2 = Invasive and other problematic species, genes and disease; 3 = Pollution; 4 = Biological resource use; 5 = Geological events, Climate change and severe weather.

2.1 Land-use change and habitat loss

The global human footprint – infrastructure, land cover and human access into natural areas – is expanding (Figure 29) (Venter *et al.,* 2016 in GEO, 2019). Economic drivers and demographic pressures are the primary sources of accelerating land-use change. These drive agricultural expansion – the largest contributor to land-use change – for food, commodities, fodder and biofuels (Alexander *et al.,* 2015 in GEO, 2019), demand for extraction of mineral, metal and energy resources (Mudd and Jowitt 2017 in GEO, 2019), urbanization, road building, land-take and deforestation, land degradation, desertifcation and habitat fragmentation.

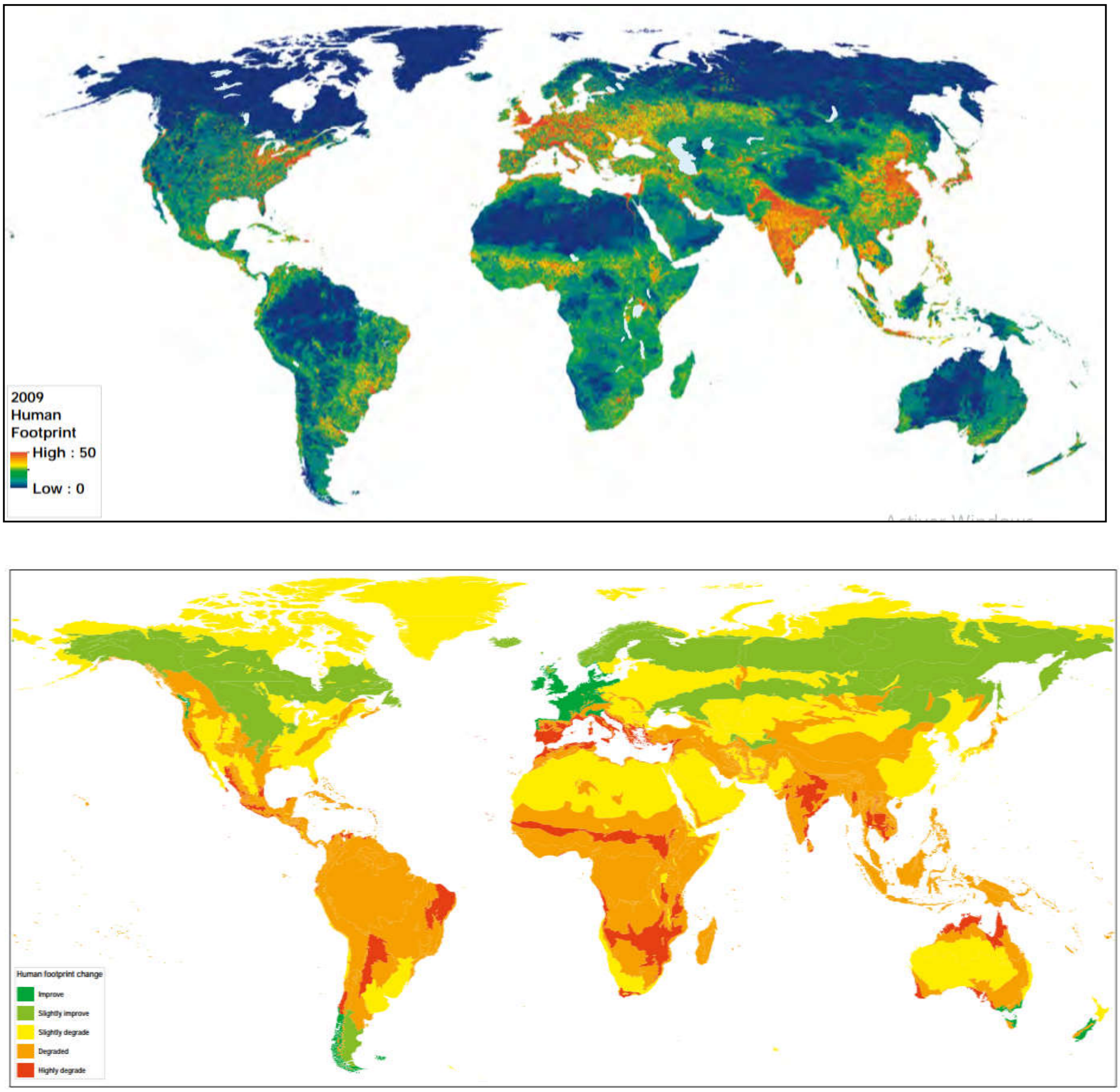


Figure 29. Map of the global human footprint for 2009 (combined pressures of infrastructure, land cover and human access into natural areas, using a 0-50 on a cool to hot colour scales) (a), and absolute change in average human footprint from 1993 to 2009 at the ecoregion scale (b) (Source: Venter et al., 2016 in GEO, 2019).

Global food production is forecast to rise by between 60 and 100 per cent by 2050 as a result of population growth and economic development, with an accompanying minimum net increase in land under crop production of 70 million ha.

Urban growth is a major driver of land-use change and habitat loss through deforestation. In developing countries, the establishment and expansion of urban areas (many of which lack adequate planning) and the growth of infrastructure can coincide with biodiversity hotspots (UNEP, 2016d). Road construction facilitates the spread of invasive species, and allows for easier access into previously intact habitats, exposing them to threats from hunting and resource exploitation (Alamgir *et al.,* 2017 in GEO, 2019).

Rapid development-induced impacts result from the construction of dams, mines and other hard infrastructure developments, including those associated with energy production.

Land-use change, which may impact both aquatic and terrestrial environments, can result in:

- exposure to pollutants, exotic pathogens and emerging infectious diseases harmful to humans, livestock and wildlife;
- increased human conflict;
- loss of habitat for wild species and the ecosystem services they provide, such as pollinators and predators of agricultural pests;
- and loss of human access to nature, with disproportionate impacts on vulnerable and indigenous communities.

2.2. Invasive species

Invasive species threaten ecosystems, habitats and other species. They are usually non-native (invasive alien species) but can also include expanding native populations (Nackley *et al.,* 2017 in GEO, 2019). The annual rate of frst records of non-native species has increased during the last 200 years and the increase in numbers does not show any sign of saturation, meaning that efforts to mitigate invasions have not been effective (Seebens *et al.,* 2017 in GEO, 2019). The ecological impacts of invasive species are felt through direct and indirect competition, predation, habitat degradation, hybridization, and their role as disease agents and vectors – also a threat to human health and food security (Figure 30).

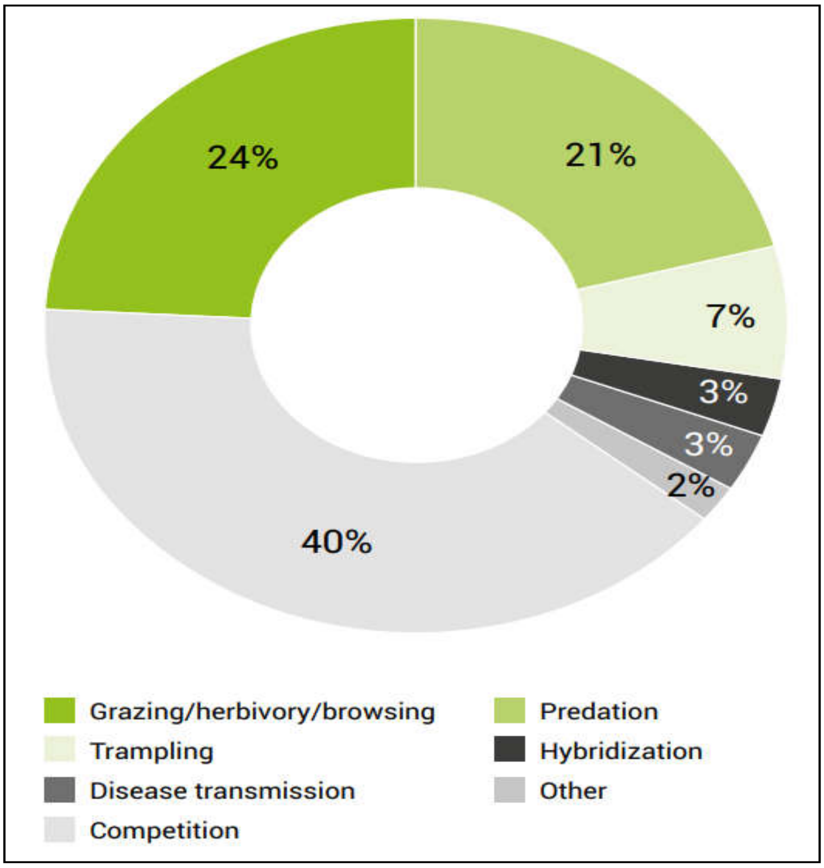


Figure 30. Impact mechanism of invasive alien species on threatened species in Europe. (Source: Genovesi, Carnevali and Scalera, 2015 in GEO, 2019).

Invasive plants can impact the provisioning of key ecosystem services, such as access to clean water, by the congestion and eutrophication of waterways, degradation of catchment areas, and viability of pasture and rangeland.

2.3 Pollution

Pollution can take many forms (e.g. waste and chemical products deliberately or accidentally released into the environment, but also light, noise, heat and microbes); major emitters include transport, industry, agriculture (Landrigan *et al.,* 2017 in GEO, 2019) and aquaculture Emerging pollutants include a wide range of synthetic chemicals, pesticides, cosmetics, personal and household care products, and pharmaceuticals.

On land, open waste dumps have local impacts on plants and animals, and soil pollution can affect the microbial population and reduce important ecosystem functioning (Wall, Nielson and Six, 2015). Pesticides, fertilizers and other chemicals used in agricultural processes can harm pollinators and natural predators of pests (Woodcock *et al.* 2016 in GEO, 2019), with surface run-off also impacting freshwater and coastal biodiversity.

Bioaccumulation of toxins, including heavy metals may have cascading impacts across the entire food chain, including humans.

Air pollution contributes to the acidifcation and eutrophication of terrestrial ecosystems, lakes, estuaries and coastal water, and to mercury bioaccumulation in aquatic food webs.

2.4 Overexploitation

Overexploitation includes illegal, unreported and unregulated fshing, illegal and unsustainable logging, overgrazing, unregulated bushmeat consumption, wildlife poaching and illegal killing (often for foreign markets). It also includes legal but ecologically unsustainable harvesting as a consequence of poorly designed quotas, lack of knowledge of the resource base or new advances in technology that allow more efficient resource exploitation. Direct exploitation has resulted in threats to iconic land and marine species alike, such as the beluga sturgeon prized for caviar (He *et al.,* 2017 in GEO, 2019), rhinoceros species targeted by poachers for their horns (Figure 31), African elephants hunted for their ivory, the Andean condor of South America hunted for feathers and bones, and agarwood (*Thymelaeaceae*) harvested for perfume and incense.

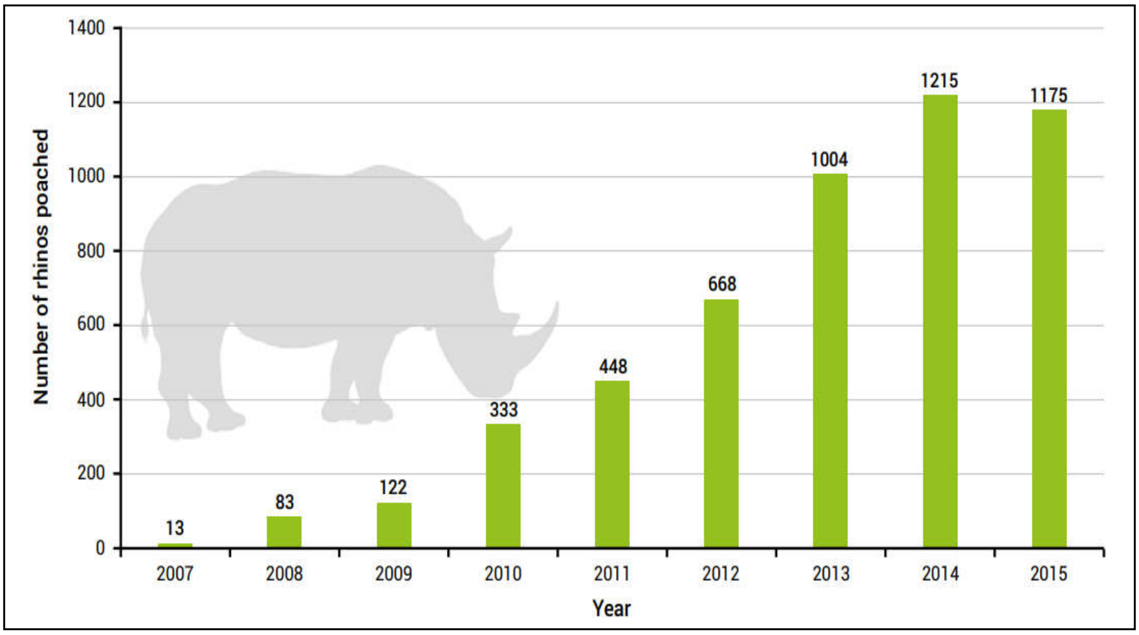


Figure 31. Recorded number of rhinoceros poached in South Africa, 2007-2015. In 2011, the rhino population in South Africa numbered just over 20,000. Source: South Africa Department of Environmental Affairs, 2016 in GEO, 2019).

2.5 Climatic warming and extreme events

The impacts of anthropogenic climate change on biodiversity are most evident in natural systems, and manifest as changes in both average climate and frequency of extreme weather events. One estimate suggests that up to one in six species could be threatened with extinction by 2050 if current warming trends continue. However, known impacts are not distributed evenly and our knowledge of impacts remains incomplete (Figure 31). Terrestrial areas with high numbers of vulnerable species were identifed on the basis of the number of species assessed and the taxonomic ranks higher than species considered.

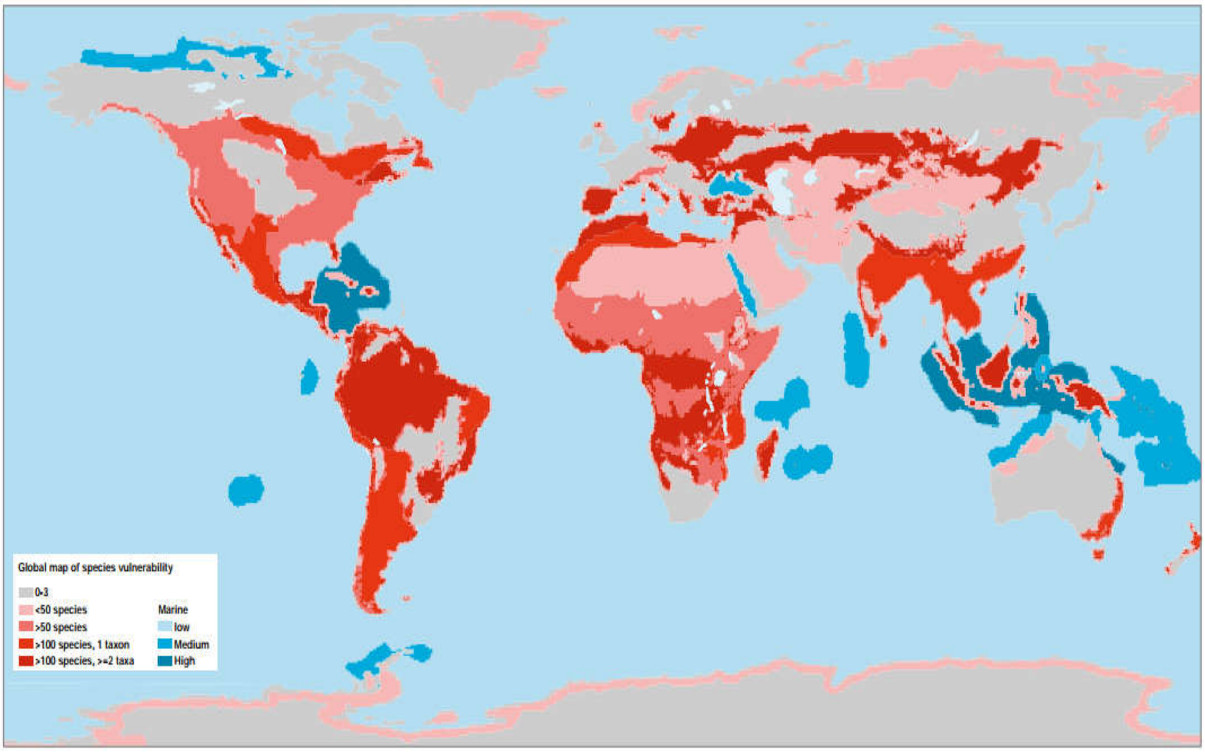


Figure 32. Global map showing species vulnerable to climate change. Source: Pacifci et al. (2015 in GEO, 2019).

In response to rising temperatures, species may move to cooler locations or alter their phenology to flower, breed or migrate sooner (Parmesan 2006; Scheffers *et al.,* 2016 in GEO, 2019). Evidence suggests they are doing both: species are moving, on average, 16.9 km per decade to higher latitudes or 11 m per decade upward in elevation (Chen *et al.,* 2011 in GEO, 2019), and advances in flowering phenology are suggested to be between 2.3 and 5.1 days per decade (Wolkovich *et al.,* 2012; IPCC, 2014 in GEO, 2019). There is increasing speculation that such climate-induced shifts in distributions and phenologies might cascade through trophic interactions, resulting in species asynchronies, such as between flowers and their pollinators. An analysis of over 10,000 time series suggests climate sensitivity (i.e. phenological shift in response to climate change) differs among trophic groups, but data on interacting species remains. In the marine environment, warming and acidifying oceans are associated with coral bleaching events, with unprecedented pan-tropical bleaching recorded during 2015-2016 (Hughes *et al.* 2017 in GEO, 2019). Ocean acidifcation may also have negative impacts on other marine systems, including mussel beds and some macroalgal habitats (Sunday *et al.,* 2017). Warmer waters additionally impose direct metabolic costs on reef fish, reducing swimming capacity and increasing mortality rates (Johansen and Jones, 2011 in GEO, 2019). In polar regions, decrease in sea ice and greater surface run-off may increase primary and secondary productivity, altering food-web dynamics (Post *et al.,* 2013 in GEO, 2019), and increase the probability of the establishment of invasive species.

2.5. Drought and Desertification

Drought is a phenomenon known since the dawn of humanity. However, it is increasingly becoming a significant issue as it is related to climate change, which largely stems from the greenhouse effect caused by various types of pollution. Drought disrupts the balance among living beings, promoting the collapse of habitats, which leads to the gradual disappearance of vegetation, followed by animals, ultimately resulting in the establishment of deserts. Indeed, "Various factors contribute to the diffuse degradation of natural resources in dry regions: climate change, inappropriate land use and poor agricultural practices, increasing population density, economic pressures, and changes in land tenure systems. Thus, the degradation of tree and shrub formations and the overexploitation of forests are among the main causes of soil deterioration." (FAO, 1997).

It becomes clear that the relationship between drought and desertification is more than evident. The repercussions of these two phenomena directly impact biodiversity, including for humans and the social relationships that bind them. Indeed, according to the FAO, "Dry regions account for about 30 percent of the Earth's surface and are home to 900 million inhabitants. Arid, semi-arid, and dry subhumid, these regions are among the most fragile ecosystems on the planet." Algeria is indeed one of the countries most affected by drought phenomena (increasingly scarce rainfall) and desertification (more than 3/4 of the country is desert).

Chapter 7: Management, restoration, and protection actions for biodiversity

Management, restoration, and protection actions for biodiversity are critical components of conservation efforts aimed at preserving the variety of life on Earth, including ecosystems, species, and genetic diversity.

1. Management Actions

1.1. Sustainable Resource Management

Natural Resource Management (NRM) refers to the sustainable management of natural resources such as land, water, soil, plants, and animals. It involves practices that aim at conserving these crucial elements of the ecosystem while also ensuring that they can continue to support various human activities and biodiversity. With the right management strategies, natural resources can be used responsibly to meet current needs without compromising the ability of future generations to meet theirs.

Sustainable practices in Natural Resource Management aim to minimise environmental impact while maximising the efficiency of resource use. These practices vary widely across different sectors and ecosystems but share common goals of preservation and sustainability. They include:

- Integrated Water Resources Management (IWRM) to ensure water availability and quality for all uses.
- Sustainable Forestry, which includes selective logging, replanting, and maintaining ecosystem balance.
- Conservation Agriculture, focusing on soil conservation, crop rotation, and reduced chemical use.
- Protection of Biodiversity through the establishment of protected areas and wildlife corridors.
- Climate Smart Practices, aimed at reducing carbon footprints and enhancing resilience to climate change.

1.2. Invasive Species Management

Invasive species management programs help minimize the harm of invasive species on natural lands and encourage the health of native plants and wildlife.

Invasive species can harm the values for which land is conserved. Natural lands are not fully protected unless they also are managed for the features that first motivated preservation. Invasive species can change community structure, composition, and ecosystem processes on these lands in ways that may not be anticipated or desirable. Careful management can minimize these negative impacts.

Implementation of an invasive species management plan requires a long-term commitment to ongoing stewardship. Expertise is needed to identify resources and the threats to them, and the ability to prioritize by threat, by geographic site or resource being threatened, and by individual plants. Assessment and interpretation of the scale and type of work required are key factors in ensuring a successful species management plan. Plan implementation involves the following steps:

- Monitor invasions and natural resources
    - Inventory, survey, and map invasive species and management efforts
    - Document in a written Invasive Plant Management Plan
- Prevent new invasions
    - Identify species known to be invasive in the region but not yet found on your land; these will be candidates for Early Detection–Rapid Response (EDRR) efforts.
    - Minimize unintended mechanical disturbance
        - Minimize seed movement and species introductions
        - Control deer population
- Reduce the impact of invasive plants on the preserve
    - Prioritize management efforts
        - by geographic location, including resources present

        - by species, including its ecological impact
        - by individual
    - Research best management practices for control methods
    - Apply best management practices to priority sites and species using integrated vegetation management (IVM)
    - Evaluate the effect of ongoing control efforts (adaptive management)
- Restore sites or promote natural succession as needed
    - Fill niches with a diversity of native vegetation
- Capacity - labor (volunteer and/or paid professional staff) and equipment
    - Labor – identify, train, coordinate, and mobi-lize personnel appropriate to the tasks required. If entirely or partially a volunteer labor force, then a volunteer coordinator position will be necessary to ensure focused and appropriate invasive species management.
    - Equipment – Secure such tools and equipment that will ensure safe and simplest accomplishment of the scale of the tasks at hand. Purchase is preferable (Web 1).

1.3. Land Use Planning

Integrating biodiversity considerations into land use planning to balance development needs with conservation goals. This includes zoning laws that protect critical habitats.

The systematic assessment of land and water potential, alternatives for land use and economic and social conditions, in order to select and adopt the best land use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. For exemple of application can be: Extensive application for rural, regional, local land use planning in developing and developed countries (Giasson et *al.*, 2005).

Integrating biodiversity considerations into land use planning is essential for creating sustainable communities that respect both development needs and conservation goals. By implementing thoughtful zoning laws, engaging with local communities, and prioritizing ecosystem health, planners can foster environments that support both human and ecological well-being. This holistic approach not only protects critical habitats but also enhances the resilience of communities in the face of environmental challenges.

1.4. Wildlife Management:

Wildlife management is a crucial field that focuses on the conservation and sustainable use of wildlife populations and their habitats. It involves a variety of strategies and practices aimed at maintaining healthy ecosystems and ensuring that wildlife populations thrive while also considering human interests. Here are some key components of wildlife management:

A. Management Plans

- Development: Wildlife management plans are developed based on scientific research, ecological assessments, and stakeholder input. These plans outline specific goals for wildlife populations, habitat conservation, and human-wildlife interactions.

- Implementation: Effective implementation of these plans requires collaboration among various stakeholders, including government agencies, conservation organizations, local communities, and hunters.

B. Hunting Regulations

- Sustainable Practices: Hunting can be a tool for wildlife management when regulated properly. Establishing hunting seasons, bag limits, and licensing requirements helps ensure that hunting is sustainable and does not negatively impact wildlife populations.

- Education and Outreach: Educating hunters about ethical practices, species identification, and the importance of conservation can foster a culture of responsible hunting.

C. Habitat Protection

- Conservation Areas: Protecting critical habitats through the establishment of national parks, wildlife reserves, and conservation easements is essential for maintaining biodiversity and supporting wildlife populations.

- Restoration Projects: In some cases, habitat restoration projects may be necessary to rehabilitate degraded ecosystems, such as reforestation efforts or wetland restoration.

D.Monitoring Programs

- Population Surveys:Regular monitoring of wildlife populations through surveys, tracking, and telemetry helps assess the health and status of species.This data is crucial for making informed management decisions.

- Ecosystem Health Assessments: Monitoring not only focuses on individual species but also on the overall health of ecosystems, including the presence of invasive species, habitat quality, and the impacts of climate change.

E.Research and Data Collection

- Scientific Research: Ongoing research is vital for understanding wildlife behavior, genetics, and ecology. This knowledge informs management practices and helps predict how populations may respond to various pressures.

- Citizen Science: Engaging the public in data collection through citizen science initiatives can enhance monitoring efforts and foster a sense of stewardship among community members.

F.Conflict Resolution

- Human-Wildlife Interactions: Wildlife management also involves addressing conflicts that arise between humans and wildlife, such as crop damage by deer or predation on livestock by carnivores. Strategies may include non-lethal deterrents, compensation programs, and community education.

2. Strategy for biodiversity conservation

2.1. Why conserve biodiversity?

According to Wilson, "It will take millions of years to remedy the erosion of genetic diversity and the loss of species due to the destruction of natural habitats during the 1990s. This aberration is what our descendants will have the hardest time forgiving us for. For biodiversity conservation to be effective, it must address all the causes of its current erosion and take into account the opportunities that genes, species, and ecosystems provide for sustainable development." The main goal of biodiversity conservation is therefore sustainable development. To achieve this goal, Wilson proposes three fundamental elements:

- Safeguarding biodiversity (genes, species, habitats, and ecosystems)

- Studying biodiversity (documentation, distribution, structure, and functioning)

- Sustainable use of biodiversity: this involves using biodiversity in a way that does not hinder its perpetuation.

Biodiversity can be conserved by various methods including in situ and ex situ conservation methods that include establishing national parks, wildlife sanctuaries, etc. Biodiversity should be conserved as it provides us with both economic and aesthetic benefits. In this article we will study the definition of biodiversity conservation, methods of conservation, and why it should be conserved (Figure 32).

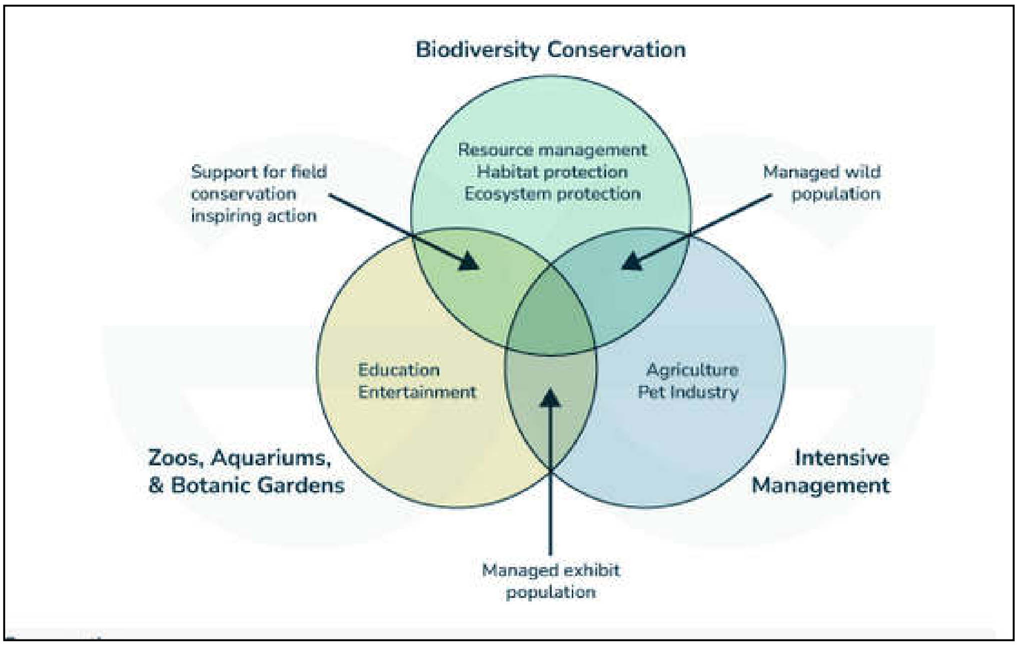


Figure 33. Biodiversity conservation.

2.2. General Principles for Biodiversity Conservation

According to WRI, IUCN, and UNEP, ten fundamental principles can guide us in establishing a strategy for biodiversity conservation:

- Every form of life is unique and deserves to be respected by humanity.

- The conservation of biodiversity is synonymous with significant benefits for humanity.

- The costs of biodiversity conservation must be shared fairly among nations.

- Biodiversity conservation for sustainable development requires changes in global economic development practices.

- Reform of policies and institutions is needed to increase financial resources in order to create favorable conditions for optimal use.

- All levels (local, national, and global) of biodiversity conservation are legitimate and must be taken into account. Each level has an interest in conserving its biodiversity.

- There can be no biodiversity conservation without raising public awareness and vigilance, as well as providing decision-makers with reliable information for sound political choices.

- Biodiversity conservation actions must be planned and implemented at determined scales (ecological and social criteria), meaning actions should be taken where populations are located as well as in wild areas.

- Cultural and religious diversity is closely linked to biodiversity. It is important to consider humanity's knowledge about biodiversity (ancestral knowledge).

- Public participation, respect for human rights, access to education and information, and accountability of institutions are all essential elements for biodiversity conservation.

2.3. Biodiversity conservation methods

For a more stable environment, a balanced diversity among different species plays an important role. We humans significantly depend on various species in one form or another to satisfy our needs. Considering this fact and the associated ethical and economic benefits, it is necessary to conserve biodiversity. There are two different ways that are considered for biodiversity conservation. These are explained below:

In-situ Conservation

t involves the conservation and protection of species in their natural habitat, i.e., in the area where they are found. For example, to save tigers from extinction, we save the entire forest. Such an approach has the following benefits:

- Economical and cost-effective and preserves both natural habitat and species.

- Protects a large count of the population simultaneously.
- Species can easily adjust to the environment as they are in a natural ecosystem.

Ex-situ Conservation

It involves the protection of endangered species in artificial ecosystems including zoological parks, botanical gardens, and nurseries. As a result, a less competitive environment is created in terms of food, space and water availability. The several advantages of this method are as follows:

- Genetic strategies like preserving seeds of important plants for long periods can be easily adopted.
- Cryopreservation techniques to preserve gametes of endangered species can be practised.
- Propagation of plants can be done using tissue culture techniques.

2.4. Strategy for Biodiversity Conservation

According to Tolba, the best way to conserve biodiversity is to prevent the destruction or degradation of habitats. To conserve species, populations, or genes, habitat protection must be complemented by other techniques. Options range from in situ conservation through the protection of the relevant habitats to ex situ conservation (botanical gardens, zoos, seed banks, aquariums, tissue banks, gene banks, etc.). According to the same author, "an integrated approach to conservation, utilizing all these techniques, is the cornerstone of biodiversity conservation." The importance of ex situ collections has been well understood by developed countries.

Among the most notable examples of this understanding is the case of botanical gardens. Indeed, the distribution of botanical gardens around the world is uneven, "thus reflecting the history and distribution of plant diversity. Europe has 540 botanical gardens, the USA and Canada have 290 botanical gardens, while these regions contain only 28,000 species. Latin America, which has 90,000 species, has just under 100 botanical gardens."

a- Establishment of a national political framework for biodiversity conservation.

"Biodiversity is such an important national cause that our country must develop a policy recognizing its importance in economic development. Biodiversity could become a leading sector around which other developments could be organized. It is also a renewable resource; if treated as such, it is much more reliable than oil and diamonds" (Juma, 1994).

The main objectives of this political framework are threefold:

**** Reform all public policies that encourage waste and misuse of biodiversity by**:*

- Abandoning any policy that promotes the degradation of genetic resources and the transformation of existing ecosystems into other forms of lesser value.

- Strengthening existing legislation based on a broad societal debate.

- Integrating the duty to conserve biodiversity into the constitution and establishing it as a sine qua non condition for our sustainability as well as that of future generations.

- Abandoning the scorched earth policy in the context of counter-terrorism efforts.

- Prohibiting any deforestation actions to expand agricultural activities.

- Imposing impact studies on biodiversity for all urban expansion projects and infrastructure works, by practicing the policy of the lesser evil.

- Reforming policies that accelerate the erosion of biodiversity in natural ecosystems, either through overexploitation, pollution, or any other means.

- Encouraging the emergence of NGOs and associations for the promotion of biodiversity.

****Adopting policies and accounting methods that encourage the conservation and equitable use of biodiversity***:

- Upholding national sovereignty over biological resources and regulating their collection.

- Establishing an open and interactive information, education, and awareness system based on the exchange of information, accompanied by a centralized database concerning all our biological diversity.

- Regulating cross-border transfers and uncontrolled dissemination of biological resources in nature.

- Promoting the development of a plant improvement sector using local genetic resources by launching training programs and research projects in this field.

- Involve the value of biological resources in the calculation of national income to account for the economic assessments of losses due to the degradation of biological resources and biodiversity (cultural, tourism value, etc.).

- Encourage local biodiversity enhancement actions, as well as mixed activities (partnerships) for its promotion.

- Strengthen border control measures accompanied by the establishment of an effective monitoring system and reliable alert mechanisms in case of bio-invasion threats, erosion, and genetic pollution.

- Establish and/or encourage sustainable development programs based on the rational use of biodiversity.

- Introduce an individual well-being tax, which will be paid directly into the national environmental fund and will be genuinely used to improve environmental quality at all levels: urban, suburban, and rural.

- Adopt the polluter-pays principle for all companies and apply it rigorously, and/or impose the treatment of all industrial, agricultural, or other waste before it is discharged into nature.

**** Reduce the demand and waste of biological resources by:***

- Family planning to promote balanced demographic growth.

- Involving the peasant and rural communities in programs aimed at promoting biodiversity.

- Strengthening literacy programs in rural areas and civic education to raise awareness of the value of biodiversity.

- Reducing the consumption of natural resources through the creation of production areas (e.g., strongholds) and recycling (e.g., paper).

- Analyzing the consumption of biological resources to improve awareness of the balance between local consumption and production.

b- Contribution to the creation of an international political environment capable of preserving national biodiversity.

All countries should put their rhetoric into practice and seriously review their own contradictions regarding biodiversity. They must also contribute, each in their own way, to establishing international laws and assisting in their implementation. The solution to global environmental and biodiversity issues should be based on a genuine partnership aimed at a common goal (rational use and sustainable development of biodiversity for its promotion) rather than on a donor-recipient relationship (Dourojeanni, 1994).

c- Establishing favorable conditions as well as incentive measures for biodiversity conservation at the local level.

"In general, the areas richest in biological diversity are also home to the poorest communities in the world. These communities, particularly tribal populations, have never received their share of wealth, both during the colonial era and in the current neocolonial period. The best way to break the vicious cycle of poverty is to empower these communities to control their natural resources and access information and technology. Supporting this type of advocacy is equivalent to supporting the cause of biodiversity conservation" (Roque, 1994).

d- Integration of biodiversity management into all human activities for sustainable development.

"This land is the place where we know we can find everything that is useful to us: the food we obtain through hunting, fishing, and farming, the materials for our buildings and tools, and the remedies. This land keeps us together within its mountains: we are beginning to understand that we are not just a few separate populations or villages, but a people belonging to one single part" (Akawaio, 1994).

e- Strengthening protected areas as well as creating new ones.

"We must make every possible effort to preserve, conserve, and manage biodiversity. This process encompasses all forms of protected areas, ranging from large wildlife and flora reserves to small sites for the conservation of particular species and reserves where certain activities are permitted. These systems of protected areas must be managed to account for a wide range of ecological and human-induced changes. This is no small task; however, humanity must rise to this challenge, or else these risks will become insurmountable" (Bridgewater , 1994).

f- Conservation of ecosystems (habitats), species, populations, and genes.

Two main objectives are assigned to this point:

- Strengthening the capacity to conserve species, populations, and genetic diversity in natural environments by:
  - o Integrating the conservation of species, populations, and genetic resources into regional management and protected area assessments.
  - o Using flagship species to increase support for conservation.
  - o Improving and extending legal protections for species.
  - o Eliminating privileges granted, particularly to foreigners, that cause enormous damage to the biological diversity of our country, especially wildlife (poaching in plain sight).
- Strengthening the capacity of ex situ conservation facilities to preserve biodiversity, raise public awareness, and contribute to sustainable development.
  - o Enhancing the conservation of genetic resources of cultivated plants and domesticated animals: seed banks, gene banks, DNA banks, etc.
  - o Developing collections of cultivated plants, livestock, forest species, fish species, microorganisms, etc., as part of an ex situ conservation network.
  - o Contributing to the development of new botanical gardens.

3. Protected areas

Protected areas are designated regions that are established to conserve biodiversity, protect ecosystems, and preserve natural and cultural resources. These areas play a crucial role in safeguarding critical habitats and species from the impacts of human activities, such as urban development, agriculture, and resource extraction. Here's an overview of the establishment and management of protected areas, including national parks, wildlife reserves, and marine protected areas:

- National Parks: National parks are large natural areas set aside for the enjoyment of the public and the protection of wildlife and natural resources. They often feature diverse ecosystems, scenic landscapes, and recreational opportunities. Examples include Yellowstone National Park in the USA and Banff National Park in Canada and El Kala National Park in Algeria (Figure 33)

Figure 34. El Kala National Park in Algeria.

- Wildlife Reserves: Wildlife reserves are areas specifically designated for the conservation of wildlife and their habitats. These areas may allow limited human activity, such as regulated hunting or ecotourism, to support conservation efforts. Examples include the Maasai Mara National Reserve in Kenya (Figure 34) and the Sundarbans Reserve Forest in India and Bangladesh (Figure 35).

Figure 35. Maasai Mara National Reserve in Kenya

Figure 36. Sundarbans Reserve Forest in India and Bangladesh.

- Marine Protected Areas (MPAs): MPAs are regions of the ocean where human activities are regulated to protect marine ecosystems and biodiversity. They can include various zones with different levels of protection, from no-take zones to areas allowing sustainable fishing. Examples include the Great Barrier Reef Marine Park in Australia (Figure 36) and the Papahānaumokuākea Marine National Monument in Hawaii (Figure 37) and Iles Habibas Marine Protected Area in Algeria (Figure 38).

Figure 37. Great Barrier Reef Marine Park in Australia

Figure 38. Papahānaumokuākea Marine National Monument in Hawaii

Figure 39. Iles Habibas Marine Protected Area in Algeria

Protected areas play a vital role in conserving biodiversity and maintaining ecological balance. In Algeria, the establishment and management of national parks and reserves are essential for safeguarding the country's unique natural heritage and ensuring the sustainability of its ecosystems. Through effective management, community involvement, and legal protection, these areas can thrive and continue to provide ecological, social, and economic benefits.

Conclusion

The course on Biodiversity is a crucial component for students pursuing a Master's in Ecology and Environment, as it provides a comprehensive understanding of the intricate web of life on Earth. Biodiversity encompasses the variety of species, genetic diversity, and ecosystems, all of which are vital for maintaining ecological balance. By studying biodiversity, students gain insights into the roles different organisms play in their environments, the importance of ecosystem services, and the impacts of human activities on natural habitats.

Understanding biodiversity is essential for addressing pressing environmental issues such as climate change, habitat destruction, and species extinction. The course equips students with the knowledge to assess biodiversity loss and develop strategies for conservation and sustainable management. Furthermore, it fosters critical thinking and analytical skills, enabling students to engage in research and policy-making effectively.

In a world increasingly affected by environmental degradation, the role of ecologists and environmental scientists is more important than ever. This course prepares students to become advocates for biodiversity conservation, emphasizing the ethical responsibility to protect our planet's natural heritage. By integrating theoretical knowledge with practical applications, students are empowered to contribute to global efforts aimed at preserving biodiversity for future generations.

In conclusion, the Biodiversity course is not just an academic requirement; it is a vital foundation for aspiring ecologists and environmental professionals. It cultivates a deep appreciation for the complexity of life and underscores the interconnectedness of all living organisms, ultimately shaping informed, responsible leaders in the field of ecology and environmental science.

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