



Conservation And Sustainable Development

Intended for third year Bachelor's
students in Ecology and Environment

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Conservation and sustainable development

Credits: 2

Weighting: 1

Course Objectives

The knowledge gained in this module will enable students to understand in detail the causes of biodiversity loss (abiotic and biotic factors) and its consequences for ecosystems worldwide, particularly in North Africa, as well as the urgent measures that need to be taken (case study).

Recommended Prerequisites

Knowledge of the ecological factors governing species distribution is required (bioclimatic, phytogeographic, and topographic factors, etc.)

Course Content

1. The main causes of species extinction
2. Habitat fragmentation
3. The impact of species invasions on biodiversity
 - Intentional biological invasions
 - Unintentional biological invasions
 - The invasion process of exotic species
4. Consequences of species overexploitation on biodiversity
 - Organic pollution affecting animal and plant species
 - Chemical pollution
 - Species threatened by pollution (examples)
5. Sustainable development
 - Concept of sustainable development
 - Biodiversity conservation (in situ and ex situ)
 - Examples of protected areas worldwide, in the Mediterranean, and in Algeria
 - Combating biodiversity loss and desertification
6. Management of genetic resources in wild and domesticated populations
7. Socioeconomic aspects of the conservation and management of biological resources

Assessment method

Midterm exam

References

1. Akcakaya H., S. Butchart, G. Mace, S. Stuart, et C. Hilton-Taylor, 2006- Use and misuse of the IUCN Red List Criteria in projecting climate change impacts on biodiversity. *Global Change Biology*, 12: 2037-2043.
2. DAJOZ R., 1985- Précis d'écologie. Ed. Dunod, Paris, 505 p.
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Foreword

Biodiversity constitutes the foundation of life on Earth. It encompasses the immense variety of living organisms, their genetic diversity, and the ecosystems in which they interact. As the living fabric that sustains ecological processes, biodiversity provides essential ecosystem services, including food production, climate regulation, nutrient cycling, pollination, water purification, and cultural benefits. Human societies, economies, and well-being are deeply dependent on healthy and resilient ecosystems, making biodiversity conservation a critical component of sustainable development.

Despite its fundamental importance, biodiversity is experiencing an unprecedented decline worldwide. Species extinction rates are now far higher than natural background levels, largely as a consequence of human activities. Habitat destruction and fragmentation, biological invasions, overexploitation of natural resources, pollution, and climate change are among the major drivers of biodiversity loss. Understanding these threats, their underlying mechanisms, and their ecological consequences is essential for developing effective conservation and management strategies.

This document provides a comprehensive and accessible overview of biodiversity and the processes that influence its distribution, maintenance, and decline. It examines the historical context of extinction, from past mass extinction events that reshaped life on earth to the current biodiversity crisis often referred to as the “sixth mass extinction.” Particular attention is given to the role of invasive species, habitat fragmentation, resource overexploitation, environmental pollution, and other anthropogenic pressures that alter ecosystem structure and function.

In addition to exploring the causes and consequences of biodiversity loss, the document presents key conservation concepts, approaches, and tools used to protect biological diversity. These include protected areas, ecological restoration, species management programs, conservation genetics, environmental policies, and international agreements designed to promote sustainable use of natural resources. Through selected case studies and real-world examples, it illustrates both the challenges facing biodiversity conservation and the opportunities for successful intervention.

Designed for undergraduate students in ecology and environmental studies, researchers, educators, and environmental practitioners, this resource combines

scientific theory with practical applications and policy perspectives. By integrating ecological principles, contemporary research findings, and conservation experiences from around the world, it aims to foster a deeper understanding of biodiversity and its significance for both nature and society.

Ultimately, preserving biodiversity is not only a scientific and environmental imperative but also a social, economic, and ethical responsibility. The future of human well-being is inseparable from the health of the natural systems upon which all life depends. By enhancing awareness, encouraging critical thinking, and supporting informed decision-making, this document seeks to contribute to the collective effort to conserve biodiversity and promote a more sustainable future for present and future generations.

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Chapter I

The main causes of extinction of species

Introduction

Biodiversity, or biological diversity, refers to the total variability of life on Earth at the levels of genes, species, and ecosystems, as well as the ecological and evolutionary processes that sustain them. It represents the structural and functional basis of natural systems, ensuring ecosystem productivity, stability, resilience, and adaptability. Biodiversity is therefore not only a measure of the richness of living organisms, but also a key determinant of the functioning of the biosphere and the maintenance of life-supporting processes. At the genetic level, it enables adaptation and evolutionary potential; at the species level, it supports biological interactions and community organization; and at the ecosystem level, it regulates energy flow, nutrient cycling, and environmental equilibrium.

The importance of biodiversity extends far beyond its ecological dimensions. It underpins a wide range of ecosystem services essential to human well-being, including food production, pollination, soil fertility, water purification, climate regulation, and the supply of medicinal and genetic resources. Consequently, biodiversity constitutes a fundamental component of sustainable development and environmental security. Its conservation is increasingly recognized as a scientific, ethical, and socio-economic necessity, particularly in the context of rapid population growth, land-use change, and global environmental degradation.

Despite its importance, biodiversity is undergoing unprecedented decline worldwide. Biodiversity loss refers to the reduction in the number, abundance, and genetic variability of species, as well as the degradation and fragmentation of habitats and ecosystems. This decline is driven primarily by human activities, including habitat destruction, overexploitation of natural resources, pollution, invasive species, and climate change. These pressures alter ecological balance, disrupt species interactions, and reduce the capacity of ecosystems to recover from disturbance. In many regions, the rate of biodiversity loss now exceeds the natural background rate of extinction, raising serious concerns about the long-term integrity of ecological systems.

The consequences of biodiversity loss are profound and multidimensional. Ecologically, it weakens ecosystem functioning and resilience; economically, it threatens agriculture, fisheries, and natural resource availability; and socially, it compromises health, livelihoods, and quality of life. The continued erosion of biodiversity thus represents one of the most critical environmental challenges of the

twenty-first century. Addressing this crisis requires integrated strategies that combine conservation, restoration, sustainable resource management, and stronger environmental governance. In this context, biodiversity conservation is inseparable from the broader objective of preserving planetary sustainability and ensuring the continuity of human development.

I.1. Definition of biodiversity

Biodiversity is commonly defined, in accordance with Article 2 of the Convention on Biological Diversity (1992), as the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems, as well as the ecological complexes of which they are part; it encompasses diversity within species, between species, and among ecosystems. In a broader scientific sense, biodiversity represents the totality of life on Earth, including animals, plants, microorganisms, their genetic variability, and the ecosystems in which they interact. It constitutes a fundamental attribute of the biosphere and a critical determinant of ecosystem functioning, stability, and resilience.

From an ecological perspective, biodiversity is not limited to the enumeration of species, but reflects the dynamic interactions among organisms and between organisms and their environment. These interactions sustain key ecological processes such as nutrient cycling, energy flow, pollination, soil formation, and the regulation of hydrological and climatic systems. Consequently, biodiversity plays an essential role in maintaining ecosystem services that support both natural systems and human societies. As Edward O. Wilson emphasized, biodiversity is one of the greatest riches of the planet, although it remains among the least recognized and least appreciated forms of natural capital.

In the context of contemporary environmental change, biodiversity has become a central concern in ecological research and sustainable development policy. Its decline, driven by habitat destruction, overexploitation, pollution, invasive species, and climate change, threatens ecosystem integrity and the continuity of essential biological functions. For this reason, biodiversity conservation is increasingly regarded as a scientific, ethical, and strategic priority, particularly in relation to environmental protection, resource management, and the long-term resilience of socio-ecological systems.

I.2. Concept of species

In classical taxonomy, the species concept was formalized by Linnaeus through the designation of a reference individual, known as the type specimen or holotype. In this framework, a species is considered to comprise a set of individuals that share the same diagnostic morphological characteristics and correspond to the specimen selected as the taxonomic reference for its formal description. The holotype is preserved in a scientific collection or museum, where it serves as an authoritative

reference for subsequent identification and comparative studies. Within a species, subordinate taxonomic units such as subspecies may be recognized when populations exhibit stable morphological, ecological, or geographical differentiation.

I.3. Evolution of biodiversity through geological time

Since the emergence of the first living organisms on Earth approximately 3.8 billion years ago, life has undergone a long and continuous process of diversification. The fossil record, preserved primarily in sedimentary rocks, constitutes a fundamental source of evidence for reconstructing the history of biodiversity and for comparing past biotic assemblages with those existing today. Modern geochronological methods, particularly radiochronology based on the oldest known minerals such as zircon, together with astronomical data, indicate that the Earth formed approximately 4.567 billion years ago. These approaches also permit the absolute dating of geological epochs and provide a temporal framework for interpreting the evolution of life. The oldest known traces of life are dated between 3.5 and 3.7 billion years ago.

I.3.1. Biological crises and the geological time scale

Earth's history, extending over 4.6 billion years, has been subdivided into a hierarchical geological time scale composed of eras and periods in order to facilitate analysis and chronological orientation. Throughout this immense span of time, species have continuously originated and disappeared. While extinction is an inherent component of evolutionary dynamics, the history of life has also been punctuated by exceptional episodes during which a large number of species, and sometimes entire taxonomic groups, became extinct within a relatively short geological interval. These events are referred to as biological crises or mass extinctions.

Such crises are generally associated with major geological and environmental perturbations, including intense volcanic activity, asteroid impacts, climatic instability, and profound habitat disruption at a global scale. Because of their magnitude, these events are used as stratigraphic markers for subdividing geological time into eras and periods of unequal duration. The major crises recorded in Earth's history caused abrupt and temporary reductions in biodiversity and profoundly restructured the composition of life on the planet.

I.3.2. Contribution of fossils to the reconstruction of biodiversity evolution

A. Fossil formation

Fossils result from the preservation of organisms or their traces under specific sedimentary conditions. Following death, a living organism may be rapidly buried by sediments, which slows decomposition and protects the remains from destruction. As sedimentation continues, the deposited layers compact and lithify, eventually transforming into rock and preserving the morphology, imprint, or structural trace of the organism. In some cases, tectonic movements and erosional processes later expose these fossil remains at the Earth's surface, sometimes millions of years after their burial.

B. Main fossil forms

Fossils occur in a wide variety of forms, including:

Internal or external molds of shelled organisms, such as ammonites.

Insects preserved in resin or amber.

Footprints, tracks, and other iconological traces left by animals and plants.

C. Reconstruction of past ecosystems

Fossils are a primary source of evidence for reconstructing past biodiversity and paleo ecosystems. Interpreting fossil remains relies on the principle of uniformitarianism the idea that the physical, chemical, and biological processes we observe today also operated in the past allowing paleontologists to use modern analogues to infer ancient conditions. From fossil morphology, taphonomic context, and associated sedimentary features, scientists can reconstruct habitats (for example, marine reefs, riverine floodplains, or forested wetlands), identify extinct species and community assemblages, and infer trophic relationships such as predator–prey links and herbivore diets. Microfossils and palynomorphs (pollen and spores) provide high-resolution records of past vegetation and climate, while geochemical proxies preserved in fossil shells, bones, and organic matter (stable isotopes, trace elements) reveal past temperatures, salinity, and nutrient cycles. Integrating multiple lines of evidence taxonomic, functional, sedimentological, and geochemical permits reconstruction of ecosystem structure, succession patterns, and resilience or vulnerability to disturbances such as climate shifts, sea-level change, and mass extinctions. As an indispensable archive of deep-time ecological dynamics, the fossil record illuminates the evolution of biodiversity, shows how communities reorganize following environmental change, and provides critical

analogues for predicting the long-term trajectories of modern ecosystems under ongoing anthropogenic pressures.

1.4. Types of diversity

In the vast biosphere, biodiversity is expressed not only at the species level but across all levels of biological organization, ranging from macromolecules within cells to entire biomes. It is conventionally described at three main levels: genetic diversity, species diversity, and ecosystem diversity.

1.4.1. Genetic diversity

Genetic diversity is a fundamental characteristic of species and populations. It refers to the variation in genetic information contained within and among populations of plants, animals, and microorganisms. Modern biological research has shown that genetic polymorphism is widespread across living organisms, from bacteria to higher plants and animals. This variability concerns not only the number of genes but also their structure and organization, and it constitutes a key biological resource. Genetic variation within individuals and populations arises mainly from two processes: mutations at the gene and chromosomal levels, and the recombination associated with sexual reproduction. Sexual reproduction promotes the continual reshuffling of genetic material, thereby ensuring gene mixing within populations and increasing their adaptive potential in changing environments.

1.4.2. Species diversity

Species diversity refers to the variety of species present within a given geographical area. It is commonly assessed through several parameters, including species richness, which represents one of the most basic and widely used indices in biodiversity studies. Since the work of Jaccard (1902), species richness has been defined as the number of taxa present in a given assemblage. However, this measure presents important limitations, since it is rarely possible to determine absolute species richness, except in the case of well-known or easily observable groups such as large mammals or trees.

In most ecological studies, species richness must therefore be estimated through inventories, which are often time-consuming, labor-intensive, and costly. Moreover, such estimates are frequently influenced by sampling effort, especially for species with irregular spatial distribution or cryptic behavior. Species diversity also includes taxonomic or phylogenetic diversity, which reflects the evolutionary relationships among species. These measures are based on hierarchical classifications that

represent the phylogenetic history of the taxa concerned.

1.4.3. Ecosystem diversity

Ecosystem diversity refers to the variety of ecosystems present within the biosphere. It includes the diversity of habitats, biotic communities, and ecological processes that operate at different spatial and temporal scales. This level of biodiversity reflects the complexity of interactions between living organisms and their physical environment, and it is essential for maintaining ecological balance and functional stability.

The present richness of life on Earth is the result of millions of years of evolutionary processes. However, this diversity remains highly vulnerable to anthropogenic pressures. If current rates of species loss continue, a substantial proportion of biodiversity could be lost within a relatively short geological time. For this reason, biodiversity conservation has become a major international environmental concern, as its preservation is directly linked to human survival, well-being, and sustainable development.

1.5. Taxonomy and extinction

Taxonomy is a branch of biology devoted to the description, identification, naming, and classification of living organisms into taxa, using standardized criteria and dichotomous identification keys. It plays a central role in biodiversity science by providing the conceptual and methodological framework for organizing biological diversity.

Throughout Earth's history, species have continuously emerged and disappeared. Extinction is a natural component of evolutionary dynamics and reflects the inability of a species to persist under changing environmental conditions. The history of life has been marked by periods of crisis during which numerous species vanished over relatively short intervals. As a result, the biodiversity observed today represents only a small fraction of all the species that have existed on Earth in the past.

1.6. Main episodes of mass extinction

1.6.1. End-Ordovician (≈ 440 Ma)

This event eliminated about 50% of animal families. It is chiefly attributed to a major glaciation that caused a significant drop in sea level and the loss of many continental-shelf habitats, leading to widespread marine extinctions (Fig. 1).

1.6.2. Late Devonian (≈ 367 Ma)

A series of crises during the middle–late Devonian led to the disappearance of an estimated

70–80% of species. Contributing factors include rapid cooling, changes in seawater chemistry, and possible meteorite impacts. Extinctions were concentrated in marine communities.

I.6.3. End-Permian (≈ 250 Ma)

Marking the close of the Paleozoic, this was the most severe extinction: roughly 95% of marine species, 83% of genera, and 57% of families vanished. Major victims included corals, brachiopods, bryozoans, and echinoderms; terrestrial insects lost about 63% of species. Sea levels fell by as much as ~250 m, eliminating rich coastal habitats. Large-scale volcanism, climate aridification, atmospheric pollution (including ozone depletion), and elevated ultraviolet radiation are implicated in driving this collapse.

I.6.4. End-Triassic (≈ 208 Ma)

This extinction removed about 20% of families. It is associated with climatic and environmental disturbances likely linked to massive volcanic activity that disrupted both marine and terrestrial ecosystems.

I.6.5. Cretaceous–Paleogene (K–Pg, ≈ 65 Ma)

This event famously caused the extinction of non-avian dinosaurs and eliminated about 45% of marine genera, notably many foraminifera and mollusks. Marine benthic communities and a substantial portion of terrestrial vegetation were greatly reduced. The K–Pg crisis is attributed to a large bolide impact combined with extensive volcanism and rapid environmental change.

Age (Ma)	Eon / Era (ÈRE)	System / Period (Système)
—	QUATERNARY	—
2	CENOZOIC or TERTIARY	Neogene
25		Paleogene
65	MESOZOIC or SECONDARY	Cretaceous
144		Jurassic
205		Triassic
245	PALEOZOIC or PRIMARY	Permian
290		Carboniferous
360		Devonian
400		Silurian
425		Ordovician
495		
530		Cambrian
2500	PRECAMBRIAN	Proterozoic
3800		Archean

Ma: millions of years.

Figure 1. The Geologic Time Scale (International Commission on Stratigraphy, 2024)

These major events in Earth's history allowed the living world to reorganize. The surviving organisms, subjected to less competitive pressure, were able to recolonize the environments that had become hospital-like again after the crisis and give rise to new diversifications.

Zircon crystals, in granular form, are the oldest known terrestrial mineral evidence. The oldest date back to 4.3 or 4.4 billion years ago (Ga), or 150 million years after the planet's formation. The zircon mineral forms during the genesis of common plutonic rocks, the main "granitoid" constituents of the Earth's crust, particularly granites and alkaline rocks such as pegmatite and syenite. It appears with the early products of the primary crystallization of igneous rocks.

I.7. The main causes of mass extinctions

All species persist only within particular ranges of environmental conditions (temperature, dissolved oxygen, light, salinity, etc.); when these limiting factors move outside a species' tolerance in a given locality, that species can no longer survive their mass extinctions occur

when environmental changes become widespread, rapid, or severe enough to push many taxa beyond their physiological or ecological tolerances. Several major causal categories have been proposed; these often act in combination and at different temporal and spatial scales:

Rapid and extreme climate change Large, abrupt shifts in global or regional climate including episodes of intense cooling (glaciations) or greenhouse warming—can eliminate habitats, alter ocean circulation and chemistry, and disrupt food webs. For example, glaciation at the end-Ordovician caused a dramatic sea-level fall that removed shallow continental-shelf habitats rich in marine life. Climate shifts may arise from internal Earth processes or external forcing such as changes in solar output.

I.7.1. Large-scale volcanism and associated environmental effects

Massive volcanic episodes (large igneous provinces, LIPs) release vast volumes of lava, greenhouse gases (CO₂), and aerosols (SO₂). These emissions can trigger rapid warming, ocean acidification, deoxygenation, acid rain, and prolonged climatic instability. The Deccan Traps in India and the Columbia River Basalts in the northwestern USA are examples of LIPs linked in time to major biotic crises. The cumulative climatic and geochemical disturbances from prolonged volcanism are strong candidates for driving several mass extinctions.

I.7.2. Extra-terrestrial impacts

Large asteroid or comet impacts inject dust, soot, and sulfur gases into the stratosphere, producing short-term global darkness and cooling (“impact winter”), followed by longer-term greenhouse warming from CO₂ release. The Alvarez et al. (1980) hypothesis linked a global iridium anomaly and a thin clay layer at the Cretaceous–Paleogene (K–Pg) boundary to an extraterrestrial impact. The Chicxulub structure on the Yucatán Peninsula (~180 km diameter) has been identified as the K–Pg impact crater. Effects of such an impact include immediate blast and firestorms, collapse of primary productivity from reduced sunlight, and cascading extinctions of photosynthesis-dependent organisms and their consumers.

I.7.3. Synergistic interactions and secondary effects

Extinctions commonly reflect multiple interacting causes rather than a single agent. For instance, an impact could trigger widespread fires and inject aerosols that cool climate, while contemporaneous volcanism elevates CO₂ and later drives warming together producing severe, prolonged environmental stress. Ocean anoxia and acidification can follow warming and nutrient redistribution, compounding marine extinctions. Ecosystem fragmentation, loss of keystone species, and disruption of evolutionary refugia further amplify biotic loss.

I.8. Debates over the K–Pg extinction: Chicxulub timing and the role of volcanism

1.8.1. Evidence for the impact hypothesis

The K–Pg boundary is marked by a global layer enriched in iridium (a siderophile element rare in Earth's crust but common in meteorites), shocked quartz, and spherules—signatures consistent with a large bolide. High-precision radiometric dating places the Chicxulub impact at about 66.038 ± 0.032 million years ago, essentially coincident (within dating uncertainty) with the mass extinction horizon. The size of the crater and the worldwide stratigraphic signals support a causal role for the impact in triggering rapid, global environmental perturbation that contributed to the extinction of non-avian dinosaurs and many marine taxa.

1.8.2. Alternative or complementary views

Some researchers (notably Gerta Keller and collaborators) have argued that the Chicxulub impact predates the main extinction interval by up to hundreds of thousands of years, and that biotic turnover across the K–Pg may have been more complex and diachronous than a single catastrophic pulse. These claims rely on stratigraphic evidence from specific localities and interpretations of fossil continuity across the boundary. However, the preponderance of geochronological, geochemical, and stratigraphic data supports near-synchronous impact and extinction events. Many paleontologists now favor a model in which the Chicxulub impact acted together with the Deccan Traps volcanism either by delivering the immediate, catastrophic perturbation (impact winter, wildfires) or by exacerbating longer-term environmental stress from volcanism—producing the observed global extinction patterns.

1.8.3. Current consensus and remaining uncertainties

The majority of evidence supports a major role for the Chicxulub impact in producing the rapid environmental disturbances that caused the K–Pg biotic crisis, while also recognizing that Deccan volcanism and other Earth-system processes likely modulated extinction severity and recovery. Open questions remain about the precise timing and relative contributions of impact versus massive volcanism at regional scales, the mechanisms of ecosystem collapse for particular clades, and the tempo of post-extinction recovery. Continued improvements in high-precision radiometric dating, refined stratigraphic correlation, and integrated paleoenvironmental proxies are narrowing uncertainties and clarifying how multiple stressors combined to produce one of Earth's great biotic turnovers.

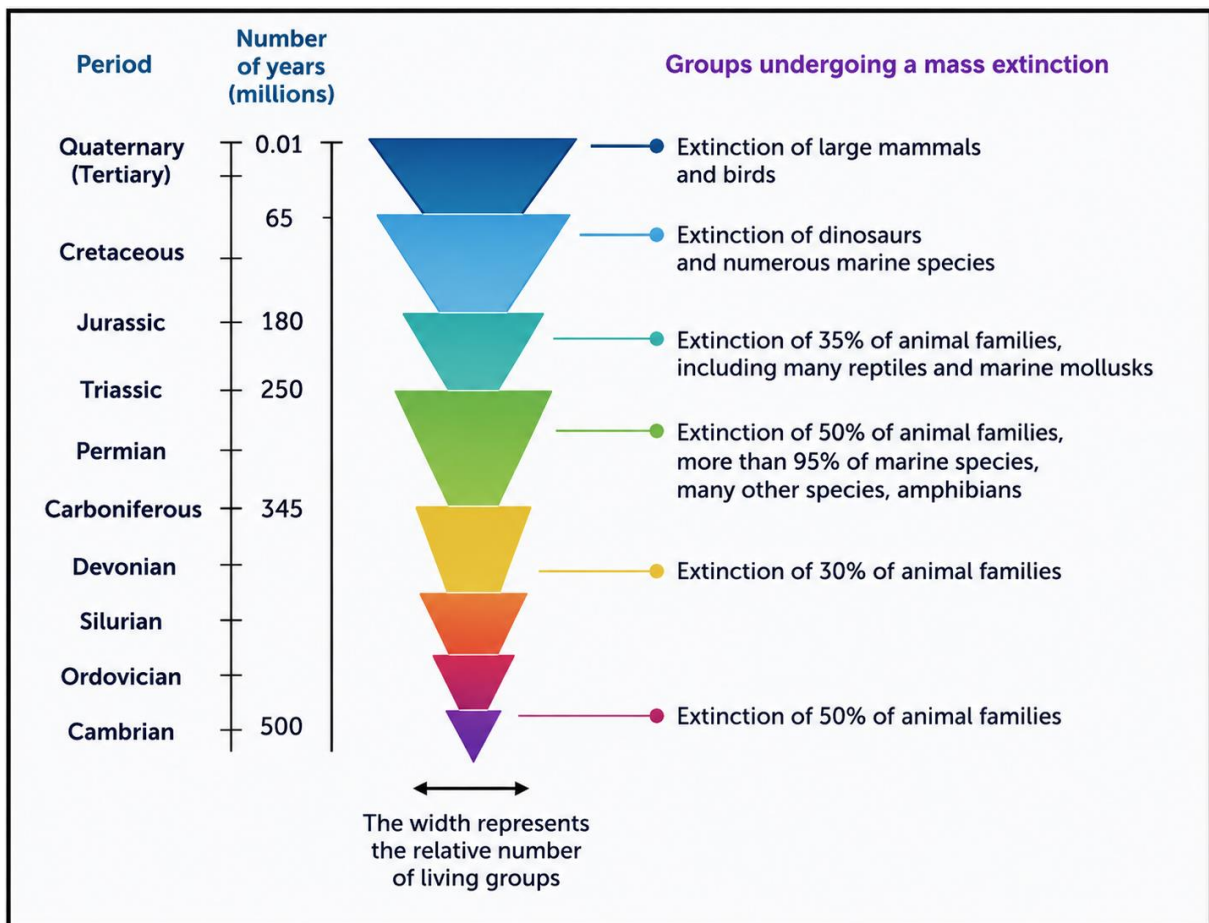


Figure 2. Groups undergoing mass extinction during the eras geological (Benton & Michael, 2015)

I.9. The risk of extinction

Ecologists have focused their studies on the factors that increase the risk of extinction:

The size of the population small changes in birth rates, death rates, or environmental conditions affect small populations more severely than large ones.

The distribution area in general, the larger a species' distribution area, the lower its probability of extinction; this is the case for bivalve and gastropod populations separated from the Cretaceous period, living in small areas (< 1000km²) average (1000-2500km²) and large (> 2500km²) distribution areas have shown that species with small distribution areas suffer from higher extinction rates.

I.9.1. The sex ratio: Two populations of the same size do not respond in the same way to an environmental disturbance; The population may produce few males or few females or have no offspring following an environmental disturbance this population may disappear.

I.9.2. The biotic potential: A population is more likely to perpetuate itself the greater the intrinsic fertility of the individuals that constitute it.

I.9.3. Consanguinity

Correlated with the decrease in genetic variability, spread of hereditary defects in particular physiological deficiencies which result in a decrease in longevity and an increase in mortality; moreover, such populations cannot survive at the slightest environmental accident.

The adaptation: The ability to colonize new sites, tolerance to environmental pollution, and the capacity of a species to adapt quickly to rapid changes in the environment are therefore crucial factors for its survival.

Chapter II

Current causes of species extinction

Introduction

Identifying the proximate causes and underlying mechanisms of contemporary species extinctions is essential for effective biodiversity conservation. Today's biotic losses are driven primarily by a combination of human-mediated pressures that interact and amplify one another.

The principal external threats are:

Habitat destruction and degradation

Conversion of natural ecosystems to agriculture, urban areas, infrastructure, and resource extraction eliminates and fragments habitats. Fragmentation isolates populations, reduces effective population size, disrupts gene flow, and increases edge effects and vulnerability to stochastic events.

II.1. Invasive and non-native species

Introduced organisms' predators, competitors, pathogens, or hybridizing relatives can outcompete, prey upon, or transmit disease to native species that lack evolved defenses. Invasions often accelerate after habitat disturbance and act synergistically with other stressors.

Overexploitation

Unsustainable harvesting for food, trade, or recreation (fishing, hunting, logging, collection for the pet and ornamental trades) can drive rapid population declines and local extirpations, especially when compounded by slow life histories or limited ranges.

II.2. Pollution and chemical contamination

Release of nutrients (eutrophication), heavy metals, persistent organic pollutants, endocrine disruptors, and plastic waste degrades habitats and directly harms organisms. Pollutants can reduce reproductive success, increase mortality, and bioaccumulate up the food chain.

II.3. Climate change and associated extremes

Anthropogenic warming shifts temperature and precipitation regimes, alters seasonality, and increases the frequency and intensity of extreme events (droughts, heatwaves, storms). Many species cannot disperse or adapt quickly enough, leading to range contractions, mismatches in phenology, and increased extinction risk.

II.4. Disease and pathogen emergence

Land-use change, global trade, and climate change facilitate the spread and emergence of pathogens. Novel diseases can decimate naïve populations, as seen in amphibian chytridiomycosis and white-nose syndrome in bats.

II.5. Synergistic interactions and indirect drivers

These direct threats are underpinned by indirect drivers such as human population growth, economic systems favoring resource extraction, weak governance, and inadequate conservation

policies. Interactions between threats e.g., habitat loss increasing vulnerability to invasive species or climate change amplifying disease impacts often cause effects greater than the sum of individual pressures.

II.6. Loss of ecological interactions and ecosystem function

Extinctions erode mutualisms (pollination, seed dispersal), predator–prey dynamics, and nutrient cycling, which can trigger secondary extinctions and reduce ecosystem resilience.

Mitigation requires integrated approaches that address both direct threats (protected areas, sustainable harvest, invasive-species control, pollution regulation) and the underlying socioeconomic drivers (land-use planning, policy reform, community engagement, and global climate mitigation). Prioritizing connectivity, protecting genetic and functional diversity, and early detection/rapid response for invasives and diseases are key strategies to slow contemporary extinction rates.

II.7. Habitat fragmentation

It represents one of the characteristics major disturbances to natural ecosystems. It leads to a decrease in the size of subpopulations. As a result of the reduction in suitable habitat areas for the species and the increasing remoteness of the habitats they colonize, their emigration possibilities are reduced. This phenomenon also increases genetic weakening linked to decreased genetic variability and inbreeding (susceptibility to diseases, defects).

genetic factors, decreased fertility, reduced population size) thus subpopulations will be more vulnerable to an accidental mortality factor such as an epidemic. Landscape fragmentation reduces the area of original habitat. For a species to survive in a landscape or watershed, it must have sufficient access to habitat resources to maintain the minimum viable population (MVP), which is defined as the smallest number of individuals required to sustain a population in the long term.

Indeed, maintaining an MVP depends on the functioning of metapopulations (wildlife populations that are spatially separated but interact through animal dispersal).

- **Deforestation**

Deforestation “stems from several factors” that can be expanded and clarified as follows:

II.7.1. Main drivers of deforestation

- Agricultural expansion is the leading cause of deforestation worldwide, accounting for roughly 85–90% of global forest loss, as forests are converted into cropland and pasture to meet rising demand for food and feed crops.
- Development of crops for livestock farming: A large share of deforestation is linked to growing soy, maize, and other feed crops, as well as clearing land for cattle pasture; livestock-related activities alone drive close to 40% of global forest loss.
- Mining of precious metals and minerals: Mining for gold, coal, bauxite, iron ore, copper, and critical minerals (like lithium and cobalt) clears vast areas for pits, roads, and housing, making mining one of the top drivers of deforestation, especially in tropical forests.
- Resource exploitation in general: This broader category includes logging, infrastructure development, fossil-fuel extraction, and settlements, all of which fragment and destroy forest ecosystems while exploiting timber, land, and energy resources.

II.7.2. Subpopulations: Definition and context

A subpopulation is a fraction or subdivision of a larger population, typically defined by distinct traits such as geographic location, age class, sex, habitat, or genetic markers. In ecology, studying subpopulations helps assess local adaptation, dispersal patterns, and extinction risk, since subpopulations may differ in density, growth rate, or vulnerability to deforestation and other habitat disturbances.

Drivers of humid tropical primary forest loss, 2015-2024

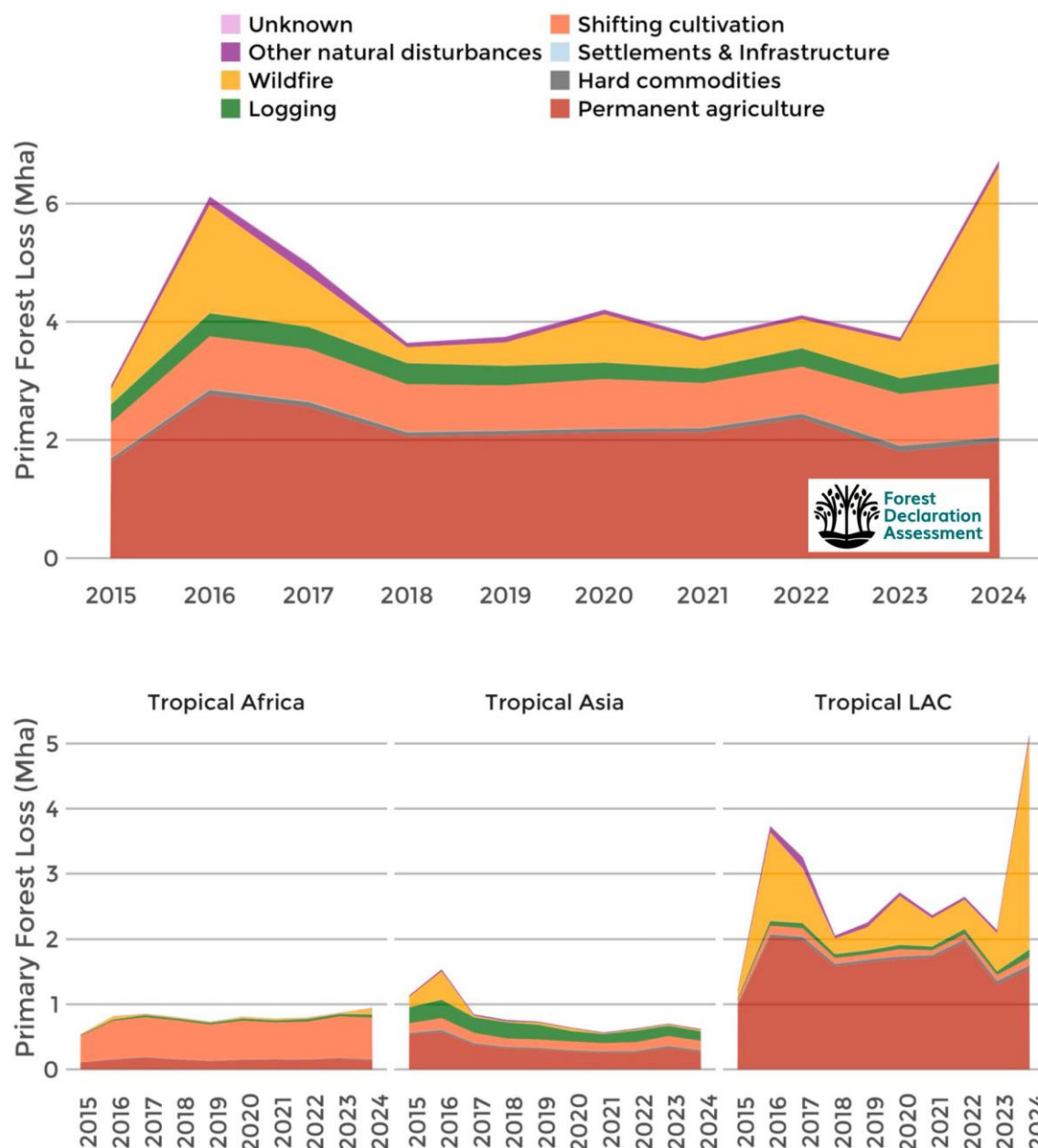


Figure 3. Drivers of deforestation, by year, 2015-2024 (Forest Declaration Assessment, 2025)

Table 1. Macro-scale deforestation estimates (FAO, 2011)

Region / type	Period	Forest cover (M ha/yr)	Source
Gross global forest loss	1990-2000	14.2	FAO 2011
Gross global forest loss	2000-2005	15.2	FAO 2011
Global forests	1990-2000	16	FAO 2010
Global forests	2000-2010	13	FAO 2010
Global primary forests	1990-2000	4.7	FAO 2010
Global primary forests	2000-2010	4.2	FAO 2010

Net deforestation	1990-2005	4.9	FAO 2011
Net deforestation	1990-2000	4.1	FAO 2011
Net deforestation	2000-2005	6.4	FAO 2011
Net deforestation	1990-2000	8.3	FAO 2010 (old)
Net deforestation	2000-2010	5.2	FAO 2010 (old)
Tropical forests	1990-2000	11.33	FAO 2010
Tropical forests	2000-2010	9.34	FAO 2010
Net tropical deforestation	1990-2000	6.3	FAO 2011
Net tropical deforestation	2000-2005	8	FAO 2011
Gross tropical deforestation	1990-2000	8.2	FAO 2011
Gross tropical deforestation	2000-2005	10	FAO 2011

II.7.3. Destruction of temperate forests

Temperate forests, especially in North America, have suffered massive conversion and degradation. In the United States, large-scale clearing for agriculture, timber, and settlement during the 19th and early 20th centuries reduced native temperate forest cover to a small fraction of its former extent. Some estimates suggest that up to 95% of original temperate forest has been lost or altered, and today these forests occupy only about 6% of the area they once did in many regions.

This “destruction of the forest biome” refers not only to the removal of trees but also to the fragmentation of habitat, loss of soil structure, disruption of nutrient cycles, and extinction or decline of species that depend on intact woodlands.

II.7.4. Logging and species extinction: the Ivory-billed Woodpecker

The logging of the Mississippi bottomland hardwood forests and coastal riverine forests in Mexico and the southern United States, beginning in the 19th century, devastated the habitat of the Ivory-billed Woodpecker (*Campephilus principalis*). This large, old-growth-dependent species required extensive tracts of mature, often flooded, hardwood forests. As those forests were cut for timber and converted to agriculture, the woodpecker lost its primary habitat.

The last widely accepted observations of the species were in the early to mid-20th century, with the last confirmed individuals recorded in 1952 in Louisiana. Although there have been disputed reports since, the species is generally treated as functionally or regionally extinct, symbolizing how the destruction of a specific forest biome can drive a highly specialized species to extinction.

II.7.8. Destruction of rainforests: loss of high-endemism ecosystems

Tropical rainforests represent some of the most species-rich and endemic-rich ecosystems on Earth, harboring a disproportionate share of global biodiversity. Latin America, Southeast Asia

(including Indonesia), and other tropical regions have seen extensive conversion of these forests for industrial agriculture.

In many areas, primary forests are cleared often by fires or selective logging and then transformed into oil palm plantations or grazed pastures and grasslands. This not only reduces total forest area but also breaks up continuous habitats, threatening specialist species that cannot survive in fragmented or secondary landscapes.

➤ **Case study: Sierra Centinella, Ecuador**

In 1978, in Ecuador's Sierra Centinella, a largely undisturbed, virgin forest was surveyed and found to harbor an extraordinary number of poorly known or previously undescribed plant species; around a hundred new plant species were discovered there. This area exemplified the hidden diversity stored in single tropical forest tracts.

By 1986, however, the site was largely converted into a cocoa plantation and other crops, representing a dramatic loss of primary habitat and a major blow to the region's botanical richness. Such cases illustrate how rapid land-use change can erase unique ecosystems before they are even fully inventoried.

➤ **Case study: Madagascar's forest loss**

Madagascar, with a total area of about 587,045 km², was once covered by vast forests supporting a highly endemic flora and fauna. Historical reconstructions suggest that fully forested areas once covered roughly 400,000–450,000 km², especially in the humid eastern belt and the central highlands.

Today, remaining native forest cover is estimated at around 40,000 km² or less, representing a loss of over 90% of the original forest cover. This destruction has led to the extinction of several endemic plant species and the decline of many others, including specialized animals dependent on intact forest habitats.

One emblematic example is the Crested Kagu (*Rhynochetos jubatus*), an unusual, flight-limited bird endemic to the forests of New Caledonia (not Madagascar, despite the similar island context). The kagu is highly sensitive to habitat loss and fragmentation, and its decline mirrors the fate of many island species that depend on intact forest ecosystems.

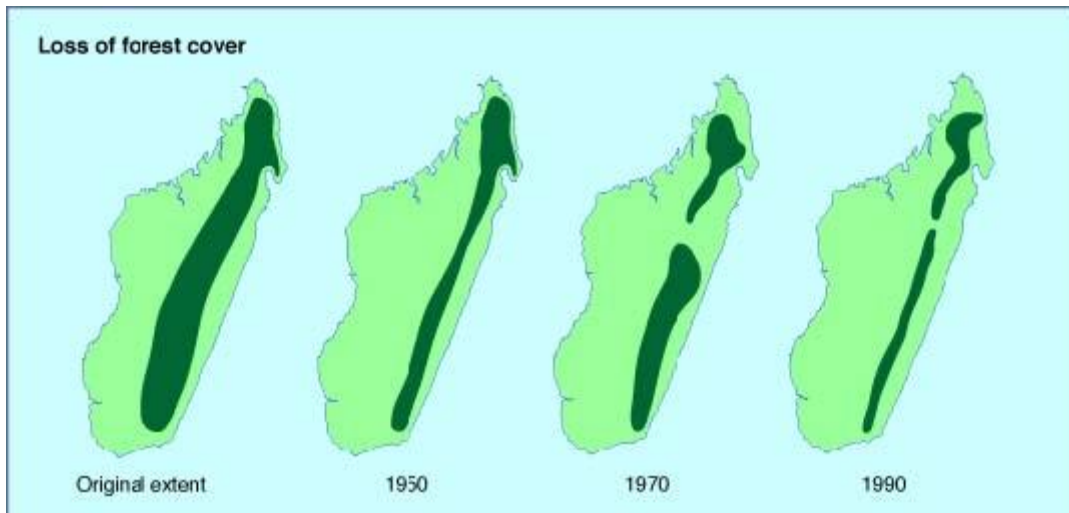


Figure 4. Madagascar's forest loss

➤ **General impact on forest biomes**

Collectively, these examples show that forest destruction whether in temperate regions of North America or in tropical and island rainforests leads to:

- Massive loss of forest cover (often >90% in some regions).
- High rates of species extinction and decline, especially among endemic and habitat-specialist taxa.
- Simplification of ecosystems and loss of functional diversity, reducing the capacity of forests to store carbon, regulate water, and provide other ecosystem services.

These patterns underscore why protecting and restoring forest biomes remains a central task in global biodiversity and climate-change mitigation strategies.

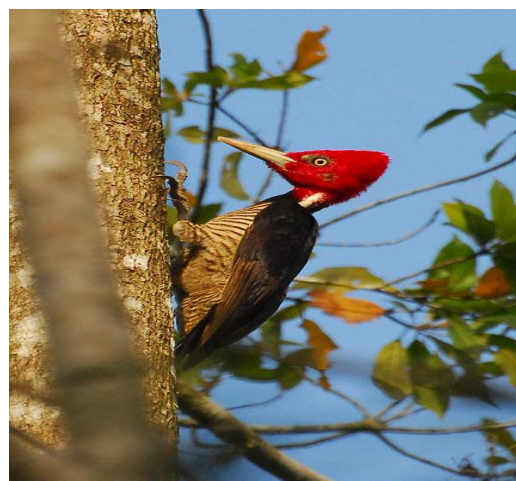


Figure 5 a. *Rhynochetos jubatus*

b. *Campephilus principalis* (Unsplash ,2024)

II.8. Wetland Drainage and Biodiversity Loss

Wetlands are among the most productive ecosystems on Earth. They form the boundary between terrestrial and aquatic environments and provide habitat for a very large share of

global biodiversity. They support migratory birds, fish, amphibians, invertebrates, and many plant species, making them essential for ecosystem stability and wildlife. The drainage and drying of wetlands cause severe ecological damage. Wetlands represent strategic ecosystems at the land-water interface and harbor a substantial proportion of the biosphere's biodiversity. However, their drainage and desiccation have resulted in the disappearance of migratory waterfowl from wintering sites and in the global decline of species whose breeding and feeding habitats are associated with these environments. The principal drivers of this degradation include hydrological alteration, water abstraction, pollution from agricultural, industrial, urban, and atmospheric sources, and the construction of large dams, which fragment rivers and obstruct the migration of aquatic organisms. When wetlands disappear, migratory waterfowl lose their wintering and resting sites, and many species that depend on these habitats for breeding, feeding, or shelter decline in number or disappear locally. On a global scale, wetland loss is a major driver of freshwater biodiversity decline, with almost 90% of wetlands lost since 1700 and many freshwater populations showing strong reductions.

II.8.1. Main Causes

The causes of wetland degradation are multiple and often act together. The most common include drainage for agriculture, urban expansion, water abstraction, and hydrological modification through dikes, channels, and dams. Pollution also plays a major role, including agricultural runoff, pesticides, industrial discharges, urban wastewater, heavy metals, and thermal or atmospheric pollution. Climate change can intensify these pressures by altering rainfall patterns, increasing evaporation, and reducing water availability.

II.8.2. Effects of Dams

Modern dam construction is another major threat to aquatic biodiversity. Large dams obstruct the natural movement of aquatic organisms, especially migratory fish such as salmon and trout, and often fragment rivers into isolated sections. Fish passes can reduce this barrier effect, but they are usually only partly effective and do not fully restore natural migration routes. Dams also alter river flow, trap sediments, and change downstream habitats, which further weakens fish populations and river ecosystem health.

II.8.3. Consequences of habitat fragmentation

- Reduced habitat area. Fragmentation converts continuous habitat into smaller, isolated patches, reducing total available area for species and populations.
- Increased isolation (distance between patches). Greater inter-patch

distances reduce movement of individuals, seeds, and propagules.

- Reduced colonization of available habitats. Longer distances and hostile matrix environments lower successful colonization rates of empty or restored patches.
- Decreased emigration and immigration. Isolation limits dispersal both into and out of patches, lowering metapopulation rescue effects.
- Reduced genetic variability. Lower gene flow among isolated populations increases genetic drift and reduces heterozygosity over time.
- Increased inbreeding. Smaller, isolated populations are more likely to breed with relatives, raising inbreeding depression and expression of deleterious alleles.
- Elevated local extinction risk. Small population size, reduced genetic diversity, and demographic stochasticity make local extinctions more likely.
- Altered species interactions and community structure. Edge effects and changed predator–prey, pollinator–plant, and competitive dynamics alter ecosystem functioning.
- Increased biological invasions and pest outbreaks. Fragmented landscapes and edges often favor generalist, disturbance-tolerant, or invasive species that can exploit altered conditions.
- Changes in ecosystem processes. Nutrient cycling, hydrology, microclimate, and fire regimes can shift in fragmented habitats, reducing ecosystem resilience.
- Reduced ecosystem services. Pollination, water purification, carbon storage, and other services decline with loss and fragmentation of native habitat.

➤ **Short example to illustrate:** A continuous forest broken into small patches by agriculture increases edge habitat and decreases connectivity. Specialist forest birds decline because they cannot cross the agricultural matrix; remaining populations are small, inbred, and vulnerable to local extinction, while generalist predators or invasive plants colonize edges and further degrade habitat quality.

Biological invasions definitions and clarifications

- IUCN (2000): An invasive alien species is an allochthonous (non-native) species introduced by humans, intentionally or accidentally, whose establishment and spread threaten ecosystems, habitats, or native species, causing negative ecological, economic, or health impacts.

- Dajoz (2008): Species considered invasive in a territory are those that, through proliferation in natural or semi-natural environments, substantially alter ecosystem composition, structure, or function. They may harm agriculture, modify environments to detriment of human activities, or greatly reduce native biodiversity by lowering abundances or causing extirpations.

II.8.4. Useful related terms (clear, concise definitions)

- **Native (indigenous) species:** A species occurring within its natural range, i.e., an area it can reach and occupy by its own dispersal abilities.
- **Allochthonous (non-indigenous, non-native) species:** A species observed outside its natural range.
- **Exotic (introduced) species:** A species that has been moved outside its natural range by human activity, intentionally or accidentally.
- **Naturalized (established) species:** An introduced species that finds suitable ecological conditions in the new area and maintains self-sustaining, reproducing populations independent of continued human assistance.

II.8.5. Additional notes (useful distinctions)

- Not all introduced or naturalized species are invasive. "Invasive" implies demonstrable negative impacts (ecological, economic, or health).
- Invasiveness depends on species traits (e.g., high reproductive rate, broad diet, phenotypic plasticity), recipient ecosystem vulnerability (disturbance, low native diversity), and propagule pressure (number and frequency of introductions).
- Fragmentation can facilitate invasions: disturbed edges, altered microclimates, and reduced native competitors/predators often create niches that invasive species exploit.

II.8.6. Intentional (voluntary) introductions motives, pathways, examples, and notes

Main motives for intentional introductions:

- Biological control. Introduce species to reduce populations of pests or disease vectors. Example: *Gambusia Holbrooke* (mosquitofish) was widely introduced to control mosquitoes but preys broadly on aquatic insects and crustaceans, often harming native fauna.
- Agriculture and livestock farming. Species introduced for food, fiber, fur, or stock improvement. Examples: coypu (*Myocastor coypus*), muskrat (*Ondatra zibethicus*), and American mink (*Neovison vison*) were introduced to Europe for the fur industry;

Procambarus clarkii (Louisiana crayfish) for aquaculture.

- Ornamental uses and horticulture/aquascaping. Plants and animals released for decorative purposes in gardens, ponds, and parks. Examples: *Ludwigia* spp. (water-primroses), *Myriophyllum aquaticum* (Brazilian watermilfoil), goldfish (*Carassius auratus*), introduced waterfowl such as Canada goose (*Branta canadensis*) and black swan (*Cygnus atratus*).
- Pet trade and companion animals. Species imported and sold as pets, some of which are later released or escape. Example: *Trachemys scripta elegans* (red-eared slider) commonly released from the pet trade.
- Commercial and international trade. Species intentionally moved for short- or medium-term economic gain (forestry, aquaculture, ornamental plant trade). High propagule pressure from trade increases establishment risk.
- Recreation and sport. Species introduced to support hunting, angling, or other leisure activities (game fish, waterfowl).
- Education, research, and ex situ collections. Species moved for zoos, botanical gardens, laboratory research, teaching collections, or demonstration sites; escapes or deliberate releases can lead to invasions.
- Tourism and landscape enhancement. Introductions meant to beautify resort areas, parks, or tourist sites to enhance visitor experience.
- Therapeutic or traditional uses. Species introduced for medicinal, cultural, or ritual uses in new regions.
- Ecosystem manipulation and restoration (sometimes misapplied). Species introduced to “restore” or modify ecosystems for example, planting non-native trees for erosion control can have unforeseen negative effects.

II.8.7. Typical intentional pathways

- Live importation for pet, aquarium, and horticultural industries.
- Deliberate release (e.g., game stocking, biocontrol releases).
- Aquaculture and stock enhancement (escape from farms).
- Botanical and zoological displays and botanical exchanges.
- Trade in live organisms and plant materials.

II.9. Consequences and caveats

- Not all intentional introductions become invasive, but intentional pathways tend to supply high propagule pressure and repeated introductions, increasing invasion risk.

- Many species introduced for benign or beneficial reasons later become harmful because of unexpected ecological interactions, broad diets, rapid reproduction, or lack of natural enemies.
- Examples of unintended outcomes: *Gambusia* harming native aquatic invertebrates and small fish; *Procambarus clarkii* altering wetland structure and outcompeting native crayfish.

II.10. Prevention and best practices

- Strict import controls and risk assessments prior to introduction, emphasizing ecological suitability and invasion potential.
- Regulation of pet, aquarium, and horticulture trade (e.g., restricted species lists, certification, public awareness).
- Best management practices for aquaculture and fur farms to prevent escapes (containment, double barriers, escape reporting).
- Promote use of native species in landscaping, restoration, and ornamentation.
- Rapid response and eradication plans for early detections of escaped or released species.

Would you like a concise single-paragraph summary for a report, or a slide-ready bullet list organized by motive with icons and one-line consequences for each example?

➤ **Unintentional introductions: ballast water and related measures**

Mechanism

- Ballasting and deballasting: Ships take on seawater into ballast tanks to stabilize the vessel when cargo is unloaded (ballasting) and later discharge that water (deballasting) when cargo is loaded or stability is regained. Ballast water often contains sediments and living organisms (plankton, larvae, microbes, cysts) that can survive the voyage and be released into distant coastal ecosystems.

A) Problems caused

- Long-distance transport of non-native species: Ballast-mediated transfers move organisms across biogeographic barriers, introducing them to regions where they may become established as non-native or invasive species.
- Ecological and economic impacts: Introduced organisms can alter food webs, outcompete native species, transmit diseases, foul infrastructure (e.g., biofouling, clogged intake pipes), and cause costly control needs.
- Examples: Globally significant introductions linked to shipping include the comb jelly *Mnemiopsis leidyi* in the Black Sea and zebra/quagga mussels in the Great Lakes

region (via ballast or hull fouling pathways).

- Management challenge: Ballast water movement is high-volume and frequent; untreated discharges create repeated propagule pressure that increases establishment probability.

B) Regulatory and technical responses

- IMO Ballast Water Management Convention (2004): The International Maritime Organization adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments to reduce the transfer of harmful aquatic organisms via ballast water. Key requirements:
 - Ships must have a Ballast Water Management Plan and maintain a Ballast Water Record Book.
 - Ships must implement ballast water management procedures following set standards, including ballast water exchange and/or treatment to prescribed biological criteria.
 - The Convention allows states to adopt stricter measures and sets deadlines for compliance; exemptions are limited and time-bound.
- Entry into force: The Convention required ratification by a sufficient number of states representing at least 35% of world merchant shipping tonnage. It entered into force on 8 September 2017 after meeting those criteria.
- Ballast water exchange guidance: Where treatment is not available, ships are recommended to exchange ballast water in open ocean deep waters (>2000 m depth) and as far from shore as practicable, to reduce survival of coastal organisms.

C) Capacity building and implementation support

- GEF–UNDP–IMO Global Ballast Water Management Programme (Globallast, later Globallast Partnerships): Launched to help developing countries build capacity to reduce ballast-mediated transfers and to implement the Ballast Water Management Convention. Activities included training, port surveys, risk assessments, development of national strategies, and demonstration projects for treatment technologies.
- Technology incentives and development: The Convention spurred investment and testing of onboard ballast water treatment systems (filtration, UV, chemical biocides, deoxygenation, heat treatment). The IMO provides guidelines and type-approval procedures for approved systems.

D) Practical recommendations and limitations

- Prioritize international compliance and national implementation: Ratify and enforce the Convention, adopt national regulations consistent with IMO standards, and allow stricter regional measures where necessary.
- Promote adoption of onboard treatment: Encourage use of certified ballast water treatment systems, especially on routes connecting biodiverse or vulnerable coasts.
- Improve port and voyage management: Use risk-based approaches to manage ballast operations (e.g., exchange in low-risk areas, minimize uptake in high-risk ports).
- Strengthen monitoring and rapid response: Establish surveillance for new introductions, early-warning networks, and contingency plans for eradication or containment.
- Support developing countries: Provide technical and financial assistance for port baseline surveys, laboratory capacity, and enforcement.
- Recognize residual risks: Even with exchange and treatment, some organisms or pathogens may survive; combine ballast measures with other pathways management (hull fouling controls, aquaculture biosecurity) and ecosystem resilience strategies.

Short illustrative note: Ballast water regulations and treatment technologies have reduced—but not eliminated—the risk of introductions. Continued vigilance, better port-level monitoring, and global cooperation are essential to limit future invasions and protect marine biodiversity.

➤ Transport-mediated unintentional introductions pathways, examples, mechanisms, and prevention Main transport pathways

- Freight (sea and air). Organisms hitchhike in or on shipping containers, pallets, packaging materials, and vehicles moving between countries and continents.
 - Example: *Vespa velutina* (Asian hornet) likely arrived in Aquitaine via goods originating from Asia.
 - Example: Seeds of Cape ragwort (*Senecio inaequidens*) were spread attached to imported sheep's wool.
- Ballast and hull fouling (marine pathways). Organisms transported in ballast water or attached to ship hulls travel long distances and colonize new ports (covered previously).
- Road and rail freight. Soil, plant material, and insects can be transported in cargo, on vehicles, or in contaminated packaging.
- Air transport and luggage. Small insects, seeds, and pathogens can be

carried in aircraft cargo holds or passenger luggage, enabling rapid long-distance jumps.

- Recreational transport. Boats, trailers, fishing gear, and outdoor equipment move species between water bodies or natural sites.
 - Example: Fragments of aquatic plants (e.g., *Myriophyllum*, *Ludwigia*) cling to hulls, propellers, anchors, or trailers.
 - Small animals (snails, crustaceans) and eggs can attach to wet gear, boots, or nets.

➤ **Movement of contaminated materials and equipment (land-use and construction)**

- Soil, fill, and excavation materials. Earth moved during road building, quarrying, landscaping, river dredging, or construction can contain seeds, bulbs, rhizome fragments, or invertebrates.
 - Example: *Reynoutria* spp. (knotweeds) spread widely when rhizome-bearing soil or fill was moved between sites.
- Machinery and tools. Excavators, trucks, buckets, earth-moving attachments, cutting equipment, and wheel ruts can carry plant fragments or mud with propagules.
 - Example: Construction equipment transported water-primrose fragments between aquatic sites when not cleaned.
- Landscaping and horticulture trades. Movement of potted plants, soil, and plant stock between nurseries and sites can introduce ornamental species that escape cultivation.

➤ **Human vectors and everyday activities**

- Anglers, boaters, and water recreational users. Moving between lakes or rivers without decontaminating boats, trailers, or gear spreads aquatic invasives regionally.
- Hikers, forestry workers, and gardeners. Seeds and spores cling to clothing, boots, wheel treads, and garden waste moved between sites.
- Live trade and escape. Plants or animals moved for trade, stocking, or pets may escape or be deliberately released into the wild.

➤ **Mechanisms that enhance establishment after transport**

- Fragment survival and regenerative capacity. Species that reproduce from fragments (rhizomes, stolons, stem pieces) or have long-lived seed banks

(e.g., many invasive plants) survive transport and establish from small propagules.

- High propagule pressure. Frequent movement of contaminated materials increases the number of individuals/propagules introduced and the probability of establishment.
- Disturbance and empty niches. Construction, land clearance, and disturbed soils provide ideal conditions for colonization by opportunistic and invasive species.
- Climatic and ecosystem matching. If arrival sites match the species' ecological requirements, establishment is more likely.

➤ **Prevention, management and best practices**

- Clean-Check-Dry and biosecurity for recreational users: Promote mandatory cleaning of boats, trailers, nets, boots, and fishing gear between sites.
- Equipment decontamination protocols: Require cleaning and inspection of earth-moving machinery, construction tools, and vehicles before moving between sites, especially across regions.
- Control movement of soil and fill: Use certified, pest-free fill; inspect and, if necessary, treat excavated materials before reuse or transport.
- Risk assessment in project planning: Screen construction, landscaping, and restoration projects for invasive species risk and include containment/detection measures in contracts.
- Awareness and training: Educate construction crews, nursery staff, landscapers, and recreational users about pathways, identification, and sanitation.
- Regulatory measures and permits: Require permits for moving large volumes of soil, plants, or equipment; enforce cleaning and reporting obligations.
- Rapid response and monitoring: Monitor disturbed sites after works for early detection and remove invasive propagules before they establish.
- Use native species in landscaping and avoid planting potentially invasive ornamentals.

Illustrative vignette: Road construction through a river floodplain excavates rhizome-bearing soils which are transported as fill to another site. Without inspection, rhizome fragments establish and form dense stands of knotweed that then spread along waterways and roadsides via mowing and further soil movement.

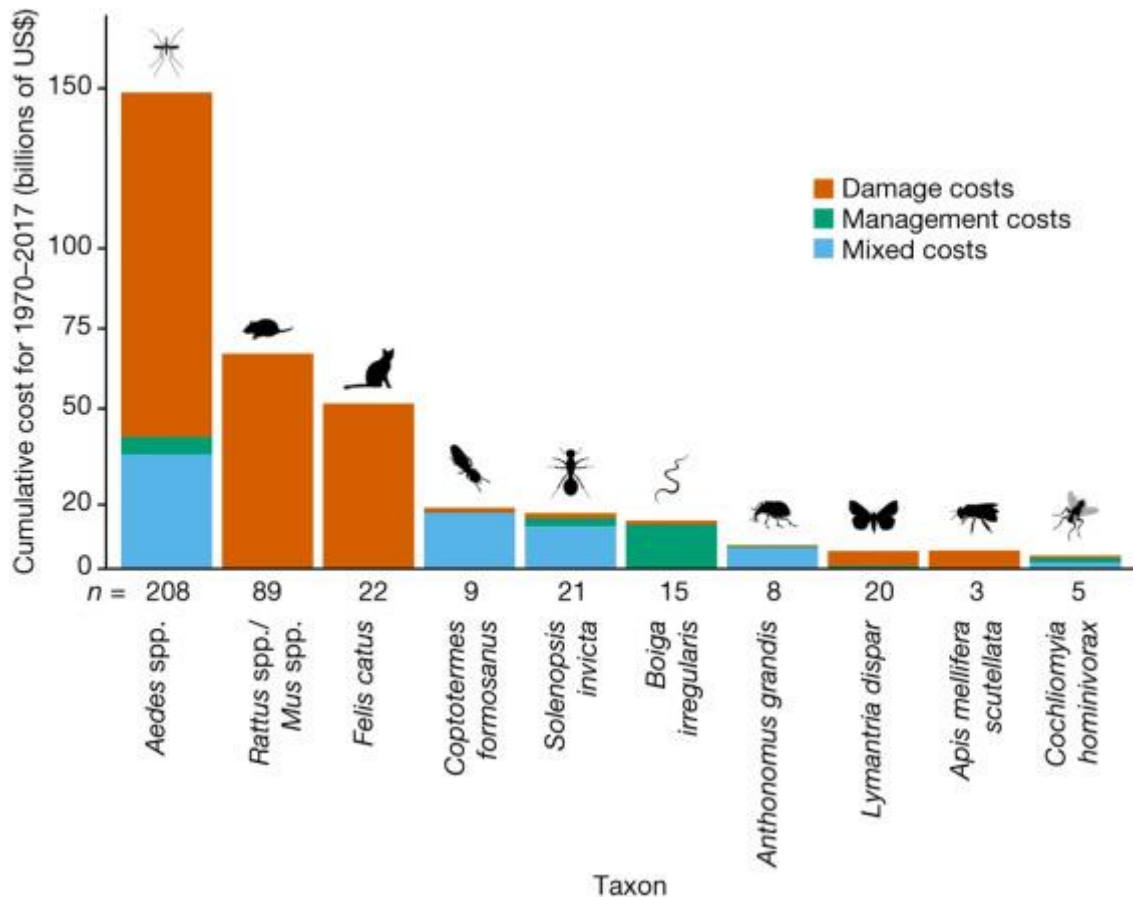


Figure 6. Invasive species (Diagne et al., 2021)

II.11. The invasion process of exotic species

➤ Overview

Invasion by an exotic species is a multi-stage process: introduction, establishment (acclimatization and naturalization), proliferation (population growth), and expansion (spread and impact). Each stage is characterized by specific barriers—geographical, environmental, reproductive, and dispersal that the species must overcome. Success at one stage does not guarantee progression to the next; most introduced species fail to become invasive. Understanding the stages, mechanisms and filters helps target prevention and management actions.

II.11.1. Introduction (transport and arrival)

- Definition: The movement of individuals, propagules or reproductive material by humans into an area outside the species' natural dispersal range.
- Mechanisms and pathways: Deliberate releases (horticulture, aquaculture, biocontrol, pets), accidental transport (ballast water, hull fouling, contaminated trade goods, machinery), and secondary transport (regional spread via vehicles, boats, people).
- Vulnerability of the species: Many propagules die during transit; small founder numbers create demographic and genetic bottlenecks.

- Management focus: Prevent introductions via pathway controls, inspections, border biosecurity, regulation of trade and intentional releases.

II.11.2. Establishment (acclimatization and naturalization)

- Acclimatization (initial survival and adjustment)
 - What happens: A fraction of arriving propagules survives and must tolerate abiotic conditions (climate, soil, salinity, seasonality) and initial biotic interactions (predation, competition, pathogens).
 - Latency: A lag period often occurs between arrival and detectable population growth; this latency reflects demographic adjustment, low initial numbers, and time needed for adaptation or finding suitable microhabitats.
 - Determinants: Propagule pressure (number/frequency of arrivals), life-history traits (phenotypic plasticity, stress tolerance), and availability of disturbed or vacant niches increase establishment chances.

II.11.3. Naturalization (formation of self-sustaining populations)

- What happens: The species reproduces successfully over multiple generations without human assistance, maintaining a viable population.
- Reproductive barriers overcome: Sufficient mating opportunities, compatible pollinators (for plants), suitable hosts (for parasites), or asexual/regenerative reproduction (rhizomes, fragmentation).
- Genetic considerations: Founder effects, genetic drift, and limited gene flow can be overcome by multiple introductions (increasing genetic diversity) or rapid evolutionary change (adaptation).
- Management focus: Early detection and rapid eradication of small, localized populations; reduce propagule pressure and restore native competitors/predators to increase resistance.

II.11.4. Proliferation (population growth)

- Dynamics: Once established and when conditions permit, populations may shift into an exponential growth phase, rapidly increasing numbers and local density.
- Drivers: High reproductive rate, absence of natural enemies, release from specialist pathogens or predators, high resource availability, and favorable climate.
- Thresholds and carrying capacity: Growth typically slows as density-dependent factors, resource limitation, or competition impose carrying capacity; however, in many invasions the new equilibrium can be at much higher densities than native species.
- Impacts emerge: During proliferation invasive species begin to modify communities and

ecosystem processes (competition, predation, habitat alteration, disease transmission).

- Management focus: Containment and control to reduce population growth (mechanical removal, chemical control, biological control where safe), and mitigation of ecological impacts.

II.11.5. Expansion (spread and landscape-scale colonization)

- Mechanisms of spread: Active dispersal (flight, seed dispersal by wind/water), passive transport (human-mediated movement of contaminated materials, vehicles, boats), and secondary range expansion from established foci.
- Range dynamics: Spread may be gradual (diffusion-like) or involve long-distance jumps (stratified dispersal), which speed invasion and create new satellite populations that can coalesce.
- Landscape and matrix effects: Connectivity, habitat corridors, disturbed habitats, and climate gradients influence the rate and direction of spread.
- Impact amplification: As range expands, ecological, economic, and health impacts grow in spatial extent and complexity; invasions may cross thresholds that lead to regime shifts (e.g., altered fire regimes, trophic cascades).
- Management focus: Strategic containment—create buffer zones, restrict human-mediated jump dispersal, prioritize protection of uninvaded refugia, and coordinate regional surveillance and rapid response.
- **The barrier framework (Richardson et al. 2000) stages as filters**
- Geographical barrier: Overcome when human activity moves organisms beyond natural dispersal limits (introduction).
- Environmental barrier: Overcome when individuals survive and acclimatize to new abiotic and biotic conditions (acclimatization/naturalization).
- Reproductive barrier: Overcome when the species can reproduce and maintain populations (naturalization).
- Dispersal barrier: Overcome when the species expands its range across the landscape (spread/expansion).

At each barrier the number of successful species declines; only a small subset of introduced species completes all stages to become widespread invaders.

A) Key modifiers of invasion success

- Propagule pressure: Frequency and number of introductions strongly increase establishment probability and genetic diversity.
- Traits of the species: Rapid reproduction, generalist diet, phenotypic plasticity, vegetative

reproduction, and preadaptation to human-modified habitats favor invasiveness.

- Recipient ecosystem vulnerability: Disturbance, low native diversity, empty niches, and climate similarity to the source region increase invasion risk.
- Human activities: Land-use change, transport networks, horticulture and aquaculture create opportunities for introduction and spread.
- Evolutionary processes: Rapid evolution and admixture from multiple introductions can increase adaptability in the new range.

B) Temporal dynamics and lag phases

- Many invasions show long lag times between introduction and explosive spread; lags can be ecological (low initial numbers), genetic (need for adaptation or hybridization), or detection-related (undetected low-density populations).
- Lags complicate management: apparent safe introductions can later become problematic, underscoring the precautionary principle.

C) Impacts and ecological thresholds

- Impacts vary: From negligible to catastrophic (local extirpation, ecosystem state shifts).
- Thresholds and feedbacks: Beyond certain densities or spatial extents invasive species may trigger feedbacks that maintain their dominance (e.g., changing fire regimes or soil chemistry), making restoration difficult.

Implications for management and policy

- Prevent first: Pathway management and stringent pre-introduction risk assessment are most cost-effective.
- Early detection and rapid response: Focus on detecting and eradicating nascent populations before they naturalize and spread.
- Prioritize interventions: Use risk assessment to prioritize species, pathways and high-value sites (biodiversity hotspots, critical habitats).
- Integrated long-term management: For widespread invaders, combine containment, control, ecological restoration, and adaptive monitoring.
- Cross-scale coordination: International, national and local cooperation is essential because invasions transcend political boundaries.

D) Illustrative example (concise)

- Asian hornet (*Vespa velutina*) arrived in Europe via human transport (introduction), survived in suitable urban/edge habitats (establishment), increased locally (proliferation) and then dispersed regionally by flight and human-aided nest movements (expansion), producing negative impacts on native pollinators and apiculture.



Figure 7. *Vespa velutina* (Unsplash ,2024)

II.12. Success of biological invasions: factors and mechanisms

- Most introduced species fail to become invasive: multiple sequential barriers (geographical, environmental, reproductive, dispersal) filter out many newcomers.
- Williamson's "tens rule" (1996, heuristic): of 1,000 species introduced, ~100 may become established, ~10 reproduce and naturalize, and ~1 become invasive and cause major impacts. Actual proportions vary by taxon, pathway, recipient ecosystems, and human activity; treat the rule as a useful rule-of-thumb, not a law.

II.12.1. Key factors influencing invasion success

A) Propagule pressure (introduction effort)

- Definition: The quantity, frequency, and number of individuals or propagules (seeds, juveniles, eggs, fragments) introduced to a new area.
- Mechanisms:
 - Larger numbers reduce stochastic extinction risk and demographic bottlenecks.
 - Repeated introductions increase genetic diversity and chances of compatible mates or founders, helping overcome Allee effects.
- Management implication: Reducing propagule pressure (trade restrictions, cleaning protocols, quarantine) is among the most effective prevention measures.

B) Traits of the invading species

- Traits that favor invasiveness include high reproductive rate, short generation time, generalist diet and habitat use, broad environmental tolerance (phenotypic plasticity), effective dispersal mechanisms, vegetative/regenerative reproduction, and absence of specialized natural enemies.
- Life history strategy matters: r-selected, opportunistic species often establish rapidly in disturbed habitats.

- Management implication: Trait-based risk screening can help prioritize species for regulation.

C) Characteristics of the recipient environment

- Disturbance and habitat modification: Human disturbance (land conversion, pollution, forestry, agriculture, infrastructure development) creates open niches, reduces competition/predation, and increases invisibility.
- Biodiversity and community resistance: Diverse, intact communities with strong biotic interactions (competition, predation, mutualisms) often resist establishment better than depauperate or simplified ecosystems.
- Availability of vacant niches and resource pulses (e.g., nutrient enrichment) facilitate establishment and growth.
- Habitat matching: Climatic and environmental similarity between source and recipient regions increases establishment probability.
- Management implication: Protecting intact habitats and reducing disturbance reduces susceptibility to invasions.

D) Biotic interactions in the new range

- Enemy release: Invaders often escape specialist predators, parasites, and pathogens from their native range, gaining a demographic advantage.
- Novel weapons and allelopathy: Some invaders bring novel biochemical traits (e.g., allelochemicals) that suppress native competitors.
- Mutualisms: Access to mutualists (pollinators, mycorrhizae) or the ability to form novel mutualisms can facilitate establishment.
- Evolving interactions: Native communities may adapt over time, but rapid impacts often precede such responses.
- Management implication: Understanding interaction networks helps predict impacts and design biological control carefully.

E) Propagule viability and reproductive biology

- Self-compatibility, asexual reproduction, and vegetative fragmentation increase establishment chances from small founder populations.
- Seed banks and long-lived resting stages (e.g., cysts, spores) allow delayed germination and persistence through unfavorable periods.
- Management implication: Target life stages (prevent seed production, remove propagule sources) to reduce persistence.

F) Residence time and propagule history

- Time since introduction (residence time) often correlates with invasion success: more time increases opportunities for population growth, spread, and adaptive evolution.
- Multiple introductions from different source populations (admixture) can increase genetic variation and adaptive potential.
- Management implication: Rapid detection and removal of newly introduced populations is critical to prevent lagged invasions.

G) Human-assisted spread and landscape connectivity

- Human transport networks and deliberate translocations enable long-distance jumps and create satellite populations that accelerate range expansion (stratified dispersal).
- Landscape fragmentation, corridors, and disturbances can facilitate or impede spread depending on species traits.
- Management implication: Control human-mediated jump dispersal (cleaning protocols, movement restrictions) and manage corridors strategically.

H) Evolutionary and genetic processes

- Rapid evolution in the introduced range (selection, hybridization, admixture) can increase invasiveness by improving performance under novel conditions.
- Founder effects can constrain adaptability, but multiple introductions often mitigate this by introducing new genetic variation.
- Management implication: Monitor genetic structure of invasive populations to detect adaptive changes and sources of spread.

I) Stochastic and demographic factors

- Chance events, demographic stochasticity, and Allee effects (reduced fitness at low densities) influence early establishment.
- Small founder populations are vulnerable to demographic collapse unless reinforced by new arrivals.
- Management implication: Early eradication of small populations exploits demographic vulnerabilities.

J) Interacting drivers and context dependence

- Invasion success is context-dependent: the same species may be invasive in one habitat and benign in another due to different combinations of traits, propagule pressure, and habitat vulnerability.
- Synergies matter: disturbance + high propagule pressure + suitable climate

dramatically increase invasion risk.

Impacts of invasions and thresholds

- Ecological impacts range from subtle community shifts to extinctions and ecosystem regime shifts (e.g., altered fire regimes, nutrient cycling).
- Some impacts are non-linear and exhibit thresholds beyond which control becomes costly or impossible.

K) Policy and management implications

- Prevention is most cost-effective: reduce pathways and propagule pressure through regulation, inspection, and public awareness.
- Prioritize species and pathways using risk assessment frameworks that consider traits, propagule pressure, and recipient vulnerability.
- Emphasize early detection and rapid response to exploit demographic and stochastic constraints.
- Combine control with ecosystem restoration to increase community resistance.
- Coordinate across scales—local actions need regional and international support because invasions cross borders.
- **Illustrative example (integrated)**
- *Procambarus clarkii* (Louisiana crayfish): High propagule pressure via aquaculture and trade, broad environmental tolerance, capacity for overland movement, high reproductive rate, and disturbance-tolerant habits enabled establishment and spread in Europe and Africa, where it outcompetes native crayfish, alters food webs, and damages rice paddies.



Figure 8. Louisiana crayfish (Unsplash ,2024)

II.12.3. Consequences of species invasions on biodiversity and society

- Invasive alien species (IAS) are a leading cause of biodiversity loss worldwide and also produce substantial ecological, economic, health, and social impacts. Their effects range from local population declines to large-scale ecosystem regime shifts.

- Impacts are often interlinked: ecological changes can propagate to economic losses, human health risks, and reduced ecosystem services. Quantifying total costs is complex, but large estimates underline the scale of the problem (e.g., DAISIE and other assessments placing European damage and management costs in the billions of euros annually).

A) Impacts on biodiversity

- Species extinctions and local extirpations: IAS can directly drive native species to extinction via predation (e.g., brown tree snake on island birds), competition (e.g., invasive plants outcompeting endemics), hybridization (genetic swamping), or disease transmission (novel pathogens).
- Reduced abundance and altered community composition: IAS often reduce the abundance of multiple native species and change relative species composition, favoring generalists and tolerant species.
- Loss of functional diversity: Replacement of specialist native species by widespread invaders diminishes trait diversity and may reduce ecosystem resilience.
- Genetic impacts: Hybridization between invasive and native congeners can cause introgression, loss of unique genotypes, or outbreeding depression.
- Example: Introduction of Nile perch in Lake Victoria caused massive declines and extinctions of endemic cichlids, reshaping fish biodiversity.

B) Impacts on ecosystem structure and functioning

- Trophic cascades and food-web reorganization: New predators, competitors, or ecosystem engineers can restructure food webs (e.g., invasive predators reducing herbivore grazers, leading to algal blooms).
- Altered nutrient cycling and productivity: IAS can change rates of decomposition, nutrient uptake, and soil chemistry (e.g., nitrogen-fixing invasive plants enriching soils and favoring further invasions).
- Hydrological and geomorphological changes: Aquatic invaders (filter feeders, burrowing species) can modify sediment dynamics, water clarity, and nutrient flows; plants can alter evapotranspiration and stream shading.
- Changed disturbance regimes: Some invaders alter fire frequency/intensity (e.g., invasive grasses increasing fire risk), leading to feedbacks that favor invaders over natives.
- Example: *Procambarus clarkii* (Louisiana crayfish) alters wetland sediment and macrophyte communities, affecting nutrient cycling and habitat structure.

C) Impacts on human health

- Direct health threats: Some IAS are vectors or reservoirs of human pathogens, or their presence increases disease risk (e.g., mosquitoes facilitating malaria or dengue; introduced rodents carrying leptospirosis).
- Allergies and toxic species: Introduced plants (e.g., *Ambrosia artemisiifolia*, common ragweed) increase allergic respiratory disease; invasive jellyfish cause stings and envenomation's that affect swimmers and fishers.
- Food safety risks: IAS can contaminate food supplies or fisheries with toxins (e.g., algal blooms associated with introduced species altering plankton communities).
- Example: Invasive mosquitoes and biting midges introduced into new areas can spread arboviruses, posing public health challenges.

D) Impacts on human security and infrastructure

- Damage to infrastructure: Biofouling organisms, burrowing invertebrates, and root-growing plants can clog pipes, damage levees, and undermine foundations.
- Threats to livelihoods: Fisheries collapses due to invaders (e.g., bivalve plagues or predatory fish) threaten food security and employment in coastal and freshwater communities.
- Transportation and safety hazards: Large aggregations of invasive species (e.g., algal mats, jellyfish) can disrupt ports, cooling systems, and navigation.
- Example: Zebra and quagga mussels clog water intake systems, leading to high maintenance costs and potential disruptions to power plants and municipal water supplies.

E) Socio-economic impacts

- Direct economic costs: Control and management expenditures, damage to agriculture, forestry, aquaculture, fisheries, and infrastructure. Europe-wide and global estimates show multi-billion euro/dollar annual burdens.
- Indirect and long-term costs: Lost ecosystem services (pollination, water purification, carbon sequestration), reduced tourism revenue (e.g., degraded beaches or lakes), and costs of health care and lost productivity.
- Cultural and recreational losses: Degradation of culturally significant landscapes, reduced hunting/fishing opportunities, and diminished recreational enjoyment of natural areas.
- Distributional effects: Impacts disproportionately affect rural, coastal, and low-income communities that rely on natural resources.
- Example: Invasive plants and pests reduce crop yields and increase pesticide costs; invasive species in forestry reduce timber value and increase management needs.

F) Mechanisms linking invasions to impacts

- Competitive exclusion, predation, and parasitism directly remove or suppress native taxa.
- Hybridization and genetic swamping reduce unique genetic lineages.
- Ecosystem engineering by invaders changes habitat structure and resource availability for many species.
- Pathogen introduction causes novel disease outbreaks in naïve host populations.
- Feedback loops (e.g., invader-driven habitat change → further invasions) can lock ecosystems into altered states.

II.12.4. Spatial and temporal scales of impacts

- Local to global: Impacts can be highly localized (a single wetland) or cascade across landscapes and regions (e.g., range shifts of invaders).
- Immediate and lagged effects: Some consequences appear rapidly after proliferation, while others emerge after decades (post-introduction lag phases or cumulative ecological shifts).
- Nonlinearities and thresholds: Once invasions pass ecological thresholds, changes may be difficult or impossible to reverse without major intervention.

II.12.5. Resilience, recovery, and restoration challenges

- Ecosystem resilience depends on native diversity, intact food webs, and restored disturbances. Once key functions are lost, ecosystem recovery is often slow and costly.
- Restoration may require removal of the invader, reintroduction of native species, soil remediation, and long-term management to prevent reinvasion.
- In some cases, eradication is feasible (especially for early detections and islands), but for widespread invaders management focuses on containment and impact mitigation.

II.12.6. Policy and management implications

- Prevention is most cost-effective: stop invasions at pathways rather than attempt large-scale eradication later.
- Prioritize high-value sites and species using risk assessments that incorporate ecological, economic, and social criteria.
- Integrate control with ecosystem restoration to rebuild resilience and reduce reinvasion risk.
- Invest in monitoring, early detection, rapid response, and community engagement to detect and manage incursions promptly.
- Consider socioeconomic impacts and equity in management decisions; involve affected stakeholders (fishers, farmers, indigenous groups).
- International cooperation is essential because invasions cross political boundaries and

require harmonized policy and trade measures.

II.13. Research and assessment needs

- Improved quantification of ecosystem service losses attributable to invasions.
- Better predictive models linking species traits, propagule pressure, and recipient vulnerability to potential impact size.
- Longitudinal studies to detect lagged impacts and thresholds.
- Cost–benefit analyses comparing prevention, eradication, and long-term management scenarios.



Figure 9. Catfish (Unsplash ,2024)

II.14. Predation and Competition

Changes in species diversity may be qualitative, involving the replacement or exclusion of native species, and/or quantitative, involving a decline in the number of individuals within populations. These alterations in biodiversity are often driven by ecological interactions such as interspecific competition and predation, particularly when invasive alien species are introduced into new environments.

Interspecific competition occurs when native and invasive species rely on the same limited resources, including food, shelter, nesting sites, or breeding habitats. Because invasive species frequently possess high reproductive rates, broad ecological tolerance, and strong adaptive capacities, they may outcompete native organisms for these resources. As a result, native populations can decline, become restricted to smaller areas, or disappear entirely from parts of their natural range. However, the effects of competition are not always exclusively negative. In some ecosystems, the arrival of a new species may alter ecological relationships in ways that temporarily increase diversity or create new ecological niches. Therefore, understanding ecosystem evolution requires consideration of both temporal dynamics and the organizational structure of biological communities.

Predation by invasive exotic species represents another major cause of biodiversity loss.

Many invasive predators display generalist and opportunistic feeding behaviors, meaning they consume a wide variety of prey and can easily adapt to available food sources. Native prey species, having evolved in the absence of these predators, are often poorly adapted to defend themselves, making them especially vulnerable.

A well-known example is the American mink (*Neovison vison*) in Great Britain. Introduced originally for fur farming, escaped individuals established wild populations that have severely affected native fauna. The American mink is considered largely responsible for the dramatic decline of the European water vole (*Arvicola terrestris*), a semi-aquatic rodent whose populations have decreased sharply due to intense predation.

Another example is the Muskrat (*Ondatra zibethicus*), an invasive semi-aquatic rodent that feeds heavily on freshwater mussels and aquatic vegetation. In many freshwater ecosystems, muskrat predation has caused the local extinction of mussel populations, disrupting ecological balance because mussels play an essential role in water filtration and nutrient cycling.



Figure 10 a. *Neovison vison*



10. b. *Arvicola terrestris*



10. c. *Ondatra zibethicus* (Unsplash ,2024)

II.15. Overexploitation of species

Overexploitation occurs when humans harvest a species for food, raw materials, or medicine

at a rate that exceeds the species' ability to reproduce and replenish its population. This direct form of exploitation, together with habitat loss, pollution, and invasive species, is a major driver of population declines and extinctions worldwide. Hunting and unsustainable harvesting still threaten many taxa, particularly birds, large mammals, and commercially valuable fish and invertebrates.

II.15.1. Hunting pressure and targeted exploitation

Hunting and targeted capture continue to drive declines in many vulnerable species. Below are several illustrative cases, with corrected scientific names, conservation status, and notes on causes and conservation responses.

- Passenger pigeon (*Ectopistes migratorius*). Once among the most abundant birds in eastern North America, the passenger pigeon was driven to extinction by intense commercial hunting and habitat loss in the 19th and early 20th centuries. The last individual, "Martha," died in captivity in 1914. The passenger pigeon is a classic example of how market hunting and the breakdown of social breeding behaviors under heavy exploitation can cause rapid collapse.
- Iberian lynx (*Lynx pardinus*). Endemic to the Iberian Peninsula, the Iberian lynx was classified as Critically Endangered for decades due to habitat loss, reduced prey (especially rabbits), road mortality, and direct persecution. Concerted conservation actions—habitat restoration, captive breeding, reintroduction, and rabbit population recovery—have improved its status; by the mid-2010s the IUCN downlisted it from Critically Endangered to Endangered, though populations remain small and recovery is ongoing.
- Dama gazelle (*Nanger dama*). The dama gazelle, one of the largest gazelles, has experienced severe declines across its Sahelian range (Chad, Mali, Niger, Mauritania and possibly Sudan) from hunting, habitat degradation, and competition with livestock. It is listed as Critically Endangered in much of its range. Small reintroduction and captive-breeding initiatives have been attempted in countries such as Senegal and Morocco, but the species remains at high risk in the wild.
- Greater bamboo lemur (*Prolemur simus*). The greater bamboo lemur (formerly *Haplemur simus* in some classifications) is the largest of the bamboo-specialist lemurs native to Madagascar. It is classified as Critically Endangered due to severe habitat loss from slash-and-burn agriculture, selective logging, and local hunting. Small, fragmented populations remain; conservation focuses on protecting remaining forest fragments, community-based management, and habitat corridors.

- Darwin's fox (*Lycalopex fulvipes*, previously *Pseudalopex fulvipes*). Found on Chiloé Island and small areas of mainland Chile, Darwin's fox is an endangered South American canid. Historically assessed as Critically Endangered, it was downlisted to Endangered in 2016 after improved information about population size and distribution. Threats include habitat loss, roadkill, disease (from domestic dogs), and hunting/persecution in some areas. Conservation measures include habitat protection and disease management.
- Cross River gorilla (*Gorilla gorilla diehli*). The Cross River gorilla is the most threatened subspecies of western gorilla, occurring in a fragmented region along the Cameroon–Nigeria border. Fewer than a few hundred individuals remain. Hunting for bushmeat, habitat destruction, and small, isolated populations have driven their decline. Conservation actions emphasize cross-border protected areas, anti-poaching patrols, and community engagement.



Figure 11 a. *Ectopistes migratorius*



11 b. *Lynx pardinus*



11c. *Nanger dama*



11d. *Prolemur simus* (Unsplash ,2024)



11e. *Lycalopex fulvipes*



11 f. *Gorilla gorilla diehli* (Unsplash ,2024)

II.15.2. Causes, consequences, and responses

- Primary drivers. Direct overexploitation (hunting, fishing, logging, collection for trade), habitat destruction that magnifies exploitation effects, and market demand (local subsistence and international trade) are principal drivers. Small, slow-breeding species and those with aggregated social behaviors (e.g., colonial birds, schooling fish) are especially vulnerable.
- Ecological consequences. Loss or severe reduction of species alters food webs, ecosystem services (pollination, seed dispersal, nutrient cycling), and ecological resilience. For example, the extinction of the passenger pigeon likely affected forest composition across eastern North America.
- Socioeconomic drivers. Poverty, weak governance, weak law enforcement, and lucrative markets for wildlife products (meat, skins, traditional medicine) sustain overexploitation. Globalized trade can rapidly transform local subsistence hunting into commercial extinction pressure.
- Conservation responses. Effective actions include legal protection and enforcement, community-based resource management, captive breeding and reintroduction, habitat restoration, alternative livelihoods, demand-reduction campaigns, and cross-border cooperation for transboundary species. Monitoring and research (population surveys, genetic studies) guide adaptive management.
- **Example of an integrated recovery approach**
 - Iberian lynx recovery programs combined captive breeding, release of individuals into restored habitat, rabbit population restoration, public awareness, and stricter protection of remaining habitat. This multi-pronged approach demonstrates how combining species-focused and landscape-scale actions can reverse declines when sustained funding and political will exist.

II.16. Overfishing, trade, and rational exploitation of marine resources

Introduction

Rising global demand for animal protein during the 20th and 21st centuries, driven by population growth, economic development, and changing diets, led many maritime nations to massively expand their fishing capacity. From the mid-20th century onward, fleets grew in size and technological power (motorization, sonar, industrial trawlers, refrigerated holds), enabling extraction rates far beyond many stocks' capacity to replenish. This pattern of uncontrolled exploitation has occurred across both the Global North and Global South and now threatens the long-term sustainability of marine fisheries and the communities that depend on them. China, as the world's largest fishing nation by catch volume, is often highlighted in discussions of global overfishing, but overexploitation is driven by many nations and by industrial and illegal fleets alike.

II.16.1. Scope and ecological consequences

- Evidence of decline. Scientific assessments since the late 20th century have documented major declines in global marine biomass and fisheries productivity. Indicators include falling catch per unit effort, shrinking average size and age of target species, and declines in mean trophic level of landings (the “fishing down the food web” phenomenon). These changes indicate not only fewer fish but altered ecosystem structure and function, with cascading effects on food webs and biodiversity (Faurie et al., 2012; Ramade, 2012).
- Affected taxa: Overfishing has impacted finfish (e.g., sardines, anchovies, cod), crustaceans (shrimp, lobsters), cephalopods (squid, cuttlefish), and bivalves (clams, mussels), among others. Local extirpations and population collapses have occurred in many regions, threatening both ecological resilience and fisheries-dependent livelihoods.
- Technological drivers. Modern fishing vessels operate like floating factories. GPS, radar, fish-finding sonar, satellite-based vessel monitoring and mapping, and highly efficient gear (bottom trawls, purse seines with dolphin- or FAD-associated fishing, longlines) enable high-volume, targeted extraction and rapid depletion of previously inaccessible stocks.
- **II.16.2. Indicators of overfishing**
- Declining catch despite increasing effort (a classic sign of stock depletion).
- Decreasing mean size or age of caught individuals, indicating recruitment

overfishing.

- Falling spawning biomass or recruitment failures revealed by stock assessments.
- Shifts in species composition and lower trophic-level dominance in catches.
- **Illustrative collapses**
 - Pacific sardine (*Sardinops sagax* or *S. caeruleus* complex). Sardine fisheries have experienced boom-and-bust cycles linked to overfishing and environmental variability (e.g., Pacific Decadal Oscillation, El Niño), causing dramatic stock collapses in some regions.
 - Peruvian anchovy (*Engraulis ringens*). One of the world's largest single-species fisheries, it has shown large fluctuations due to intense fishing and strong environmental variability (El Niño), with major socioeconomic impacts when stocks collapse.

II.16.3. Principles of rational exploitation (sustainable fisheries)

- Maximum sustainable yield (MSY) and limits. Rational management aims to estimate maximum sustainable harvests that maintain stock productivity over time. Modern approaches increasingly favor precautionary reference points and ecosystem-based management over single-species MSY when data are uncertain.
- Protecting life stages. Effective management protects spawning adults and critical habitats, and avoids removing too many juveniles—measures that include size limits, seasonal closures during spawning, and gear restrictions.
- Harvest control rules. Implement adaptive harvest control rules based on scientific monitoring (stock assessments, catch-per-unit-effort, spawning biomass) to reduce quotas when stocks decline.
- Ecosystem-based management. Account for species interactions, habitat impacts (e.g., from bottom trawling), and bycatch; protect sensitive habitats such as seagrass beds, coral reefs, and nursery grounds.
- Socioeconomic tools. Co-management with fishing communities, rights-based fisheries (e.g., individual transferable quotas or community quotas), catch shares, and alternative livelihoods reduce illegal and excessive fishing pressure.

II.16.4. Trade and wildlife exploitation

- Global trade pressures. International and domestic trade in wild-caught

species whether for food, luxury goods, traditional medicines, or pets—drives overexploitation. Trade includes legally regulated commerce and large illegal markets for products such as high-value fish, shark fins, and shellfish, as well as terrestrial wildlife.

- Conservation status and extinction risk. Many taxa face elevated extinction risk due to overharvesting and trade. Current global assessments report that significant proportions of vertebrates and plants are threatened: for example, roughly 13% of bird species, 25% of mammals, and 41% of amphibians are threatened (figures vary by source and year). Globally, tens of thousands of species appear on the IUCN Red List as threatened or near threatened.
- Illegal wildlife trade. Illegal trade smuggling, poaching, and unregulated collection constitutes a major environmental crime and undermines sustainable management. Estimates of its value vary widely; some reports place the wildlife trafficking market in the multi-billion-dollar range annually. Illegal fishing (IUU—illegal, unreported, and unregulated) itself is a large fraction of global catches in some regions and exacerbates stock declines.

II.16.5. Regulation and international response

- CITES and international agreements. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1973) regulates cross-border trade in listed species to prevent overexploitation. Several marine species and products appear on CITES appendices (e.g., some sharks, sturgeons, and live corals).
- UN and multilateral efforts. The United Nations and regional fisheries management organizations (RFMOs) develop rules to control fishing on the high seas, combat IUU fishing, and support sustainable fisheries. The UN General Assembly resolution A/RES/69/314 (2015) on wildlife trafficking highlighted global commitment to monitoring and combating illegal trade, including measures relevant to fisheries crime and trafficking in marine species.
- National management. Effective fisheries management requires robust monitoring, control and surveillance (MCS), reliable catch reporting, scientific assessment capacity, enforcement against illegal fishing, and development of equitable, community-inclusive governance.

II.16.6. Strategies to reduce overfishing and illegal trade

- Strengthen monitoring and enforcement: vessel monitoring systems, port state measures, and coordinated international patrols.
- Improve stock assessments and data sharing: invest in scientific surveys, fisheries-independent monitoring, and open data platforms.
- Promote sustainable markets: eco-certification (e.g., Marine Stewardship Council), public procurement policies, and consumer awareness to reduce demand for overexploited species.
- Support fishers' livelihoods: co-management, fisher cooperatives, alternative income programs, and training in selective gear to reduce bycatch.
- Habitat protection: marine protected areas (MPAs) and seasonal closures to protect spawning and nursery areas.
- Combat wildlife trafficking: strengthen legal frameworks, cross-border cooperation, and capacity for prosecution.

II.17. Consequences of overexploitation for biodiversity

A) Reduction in population size

Human harvesting adds an extra source of mortality beyond natural death rates. When removals exceed a population's reproductive capacity, population growth becomes negative and numbers decline. Persistent overharvesting can drive local extirpation or global extinction. Declines in a given species also ripple through ecosystems: loss of a predator can release prey species (trophic release), while loss of a prey species can starve predators and reduce their populations. These cascades change community composition, reduce ecosystem resilience, and can degrade services such as fisheries yields, pollination, and nutrient cycling.

B) Change in population structure (age, sex, size)

Selective exploitation often targets specific age classes, sexes, or larger individuals (for meat, trophies, ivory, or market value). Removing the largest or most fecund individuals reduces reproductive output disproportionately and can slow population recovery. Examples:

- Elephants and rhinoceroses: poaching for ivory or horn preferentially removes large adults, reducing breeding stock and skewing sex ratios where males may be targeted for tusks or horns.
- Large fish (cod, tuna): size-selective fishing removes older, more fecund females, lowering egg production and increasing recruitment variability.
- Ungulates hunted for trophies: disproportionate loss of dominant males can disrupt

social structure and mating systems.

- Over time, harvesting can induce evolutionary shifts (fisheries- or hunting-induced evolution) toward earlier maturation at smaller size, which can lower long-term productivity.

C) Change in spatial distribution and range

Heavy exploitation can force surviving individuals into suboptimal habitats to avoid hunters or fishing gear. Range contraction, fragmentation, or shifts to marginal areas reduce access to resources and suitable breeding sites, increasing mortality and reducing reproductive success. Edge populations in degraded habitat often have lower fitness and higher vulnerability to stochastic events, further reducing population viability.

D) Non-target mortality and bycatch

Many fishing gears and harvesting methods are nonselective. Bottom trawls, gillnets, longlines, and drift nets capture a wide array of non-target species (bycatch), including juvenile fish, marine mammals, sea turtles, seabirds, and sharks. High bycatch rates cause additional declines across taxa. Examples and impacts:

- Shrimp trawling often yields high bycatch ratios, sometimes catching far more non-target biomass than target shrimp.
- Longlines for tuna and swordfish capture seabirds and sharks as bycatch.
- Gillnets and drift nets entangle marine mammals and turtles.
- Discard practices—throwing non-target or low-value catch back to sea—commonly result in high post-release mortality, so bycatch is effectively wasted and contributes to biodiversity loss.

E) Ecosystem-level effects

Overexploitation alters food-web structure and ecosystem functioning:

- Fishing down the food web: removal of large predators shifts fisheries toward lower trophic-level species (small pelagic), changing energy flow and nutrient cycling.
- Trophic cascades: removal of key predators or herbivores can produce unchecked increases of some species and declines of others, with consequences for habitat (e.g., overgrazing or algal blooms).
- Habitat damage: destructive gears (bottom trawls, dredges) physically damage benthic habitats seagrass beds, coral reefs, sponge and cold-water coral communities reducing nursery and feeding grounds.
- Loss of functional diversity: extirpation of species that perform unique ecological roles (seed dispersal, bioturbation, predation) reduces ecosystem resilience to

environmental change.

F) Genetic consequences

Population reductions and fragmentation reduce genetic diversity through inbreeding and genetic drift. Low genetic variability lowers adaptive potential to disease, climate change, and other stressors and increases extinction risk. Small, isolated populations often show inbreeding depression and accumulation of deleterious alleles.

G) Socioeconomic and cultural consequences

Biodiversity loss from overexploitation undermines ecosystem services that human societies rely on:

- Food security: collapsing fish stocks reduce protein availability and livelihoods for coastal communities.
- Economic loss: fisheries collapse can devastate local and national economies.
- Cultural impacts: many communities have cultural and spiritual ties to particular species; their loss erodes cultural heritage.
- **Examples**
 - Atlantic cod (*Gadus morhua*): decades of overfishing led to stock collapses and long-term socioeconomic hardship in parts of the North Atlantic.
 - Sea turtles: bycatch in fisheries and direct harvest of eggs and adults have driven several turtle species to threatened status; this loss alters beach and marine ecosystem processes.
 - Sharks: targeted fishing and bycatch have reduced apex predator numbers, producing cascading ecosystem effects and lowering reef resilience.

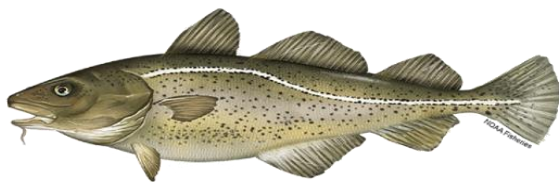


Figure 12. *Gadus morhua* (Unsplash ,2024)

- **Mitigation measures**
 - Gear selectivity and bycatch reduction: use turtle excluder devices, circle hooks, acoustic pingers, and modified trawl gear to reduce non-target mortality.

- Spatial management: marine protected areas, no-take zones, and seasonal closures protect spawning and nursery grounds.
- Size and catch limits: minimum size limits, slot limits, quotas, and harvest control rules protect reproductive individuals.
- Community co-management and rights-based systems: empower local users, assign clear rights (e.g., territorial use rights), and involve fishers in monitoring and enforcement.
- Habitat protection and restoration: protect seagrass, mangroves, coral reefs, and other critical habitats to sustain populations.
- Monitoring and enforcement: vessel monitoring systems, port-state measures, observer programs, and penalties reduce illegal and unreported catches.
- Genetic management: maintain connectivity among populations, support captive-breeding with genetic protocols when necessary.
- Alternative livelihoods and demand reduction: support economic alternatives for resource users and consumer campaigns to reduce demand for threatened species.

II.18. Pollution and its impacts on biodiversity

Overview

Pollution degrades habitats and directly poisons organisms, and it indirectly alters the physical and chemical conditions species need to survive (for example, by causing eutrophication, acidification, or hypoxia). Pollutants travel through water, soil and air, accumulate in biota, and can persist for decades. These effects reduce population sizes, disrupt reproduction and behavior, fragment ranges, and undermine ecosystem services such as pollination, water purification and fisheries.

II.18.1. Types and mechanisms

A) Organic pollution and persistent organic pollutants (POPs)

- Sources and forms: organic pollution includes high loads of biodegradable organic matter (sewage, manure, food waste) and synthetic organic compounds such as organochlorine pesticides (DDT), polychlorinated biphenyls (PCBs), dioxins and certain industrial by-products.
- Mechanisms: high organic loads increase biological oxygen demand (BOD), reduce dissolved oxygen and cause hypoxia or anoxia in aquatic systems; some organics increase turbidity and smother

benthic habitats. POPs are lipophilic and resistant to degradation, so they bioaccumulate in fat tissues and biomagnify up the food chain.

- Ecological effects: mortality, reduced growth, endocrine disruption and lowered reproductive success in fish, birds and mammals; population declines in top predators; long-term contamination of sediments and food webs.
- Examples: historical DDT/PCB contamination in many wetlands and estuaries causing eggshell thinning in birds and reproductive failure; ongoing POP residues in Arctic food webs affecting polar bears and seals.

B) Chemical pollution (pesticides, detergents, heavy metals, pharmaceuticals)

- Pesticides: organophosphates, carbamates, neonicotinoids, and anticoagulant rodenticides affect non-target wildlife (birds, mammals, beneficial insects, aquatic invertebrates) through direct toxicity, sublethal behavioral effects, immune suppression, and food-web impacts.
 - Example: neonicotinoids contribute to pollinator declines by impairing navigation, learning and reproduction in bees.
 - Example: anticoagulant rodenticides cause secondary poisoning in raptors and carnivores that feed on poisoned rodents.
- Heavy metals: mercury, lead, cadmium, chromium and others persist in soils and sediments, enter food webs, and cause neurotoxicity, reproductive impairment and growth defects. Some metals (mercury) bioaccumulate and biomagnify in aquatic predators.
 - Example: methylmercury contamination in fish leads to reproductive and neurological harm in fish-eating birds and mammals, and human health risks from seafood.
- Pharmaceuticals and personal care products: veterinary drugs (e.g., ivermectin) and human pharmaceuticals (e.g., diclofenac) enter the environment via manure, sewage and wastewater effluents, causing mortality or sublethal effects in non-target organisms.
 - Example: diclofenac used on livestock caused catastrophic

declines in Gyps vultures in South Asia via kidney failure after scavenging treated carcasses; ivermectin residues in dung reduce dung-beetle populations and impair nutrient cycling.

- Detergents and nutrients: excess nutrients (nitrogen, phosphorus) from agricultural runoff, sewage and detergents cause eutrophication, algal blooms, hypoxia and loss of biodiversity in freshwater and coastal ecosystems.
 - Example: seasonal “dead zones” (hypoxic areas) in the Gulf of Mexico and other costs linked to nutrient runoff.

C) Plastics and marine debris

- Mechanisms: ingestion and entanglement cause direct mortality, reduced feeding and reproductive impairment. Plastics also act as vectors for persistent organic pollutants and invasive species.
- Microplastics: small particles can be ingested by a wide range of organisms, transfer chemicals, and potentially cause physical and physiological harm.
- Example: sea turtles ingest plastic bags mistaken for jellyfish; seabirds and marine mammals are entangled or starved due to plastic ingestion.

D) Oil spills and acute contamination events

- Mechanisms: acute toxic exposure, smothering of animals and habitats, long-term contamination of sediments and shorelines.
- Impacts: mass mortality of birds, marine mammals, fish and invertebrates; long-lasting economic and ecological damage to fisheries and coastal communities.
- Example: major tanker spills (e.g., Exxon Valdez, Deepwater Horizon) caused widespread mortality and long recovery times for affected ecosystems.

II.18.2. Biological consequences for species and ecosystems

A) Reduced reproductive success and increased mortality

- Pollutants cause direct toxicity and endocrine disruption (e.g., reduced fertility, malformed offspring), leading to reduced recruitment and population declines.
- Example: endocrine-disrupting chemicals reduce egg production or

hatchling viability in fish and birds.

B) Changes in population structure and demographics

- Higher mortality of juveniles or breeding adult's skews age/sex distributions, reduces effective breeding population and slows recovery.
- Selective mortality (e.g., targeting large individuals or those foraging in contaminated areas) disproportionately removes the most fecund segments of a population.

C) Range shifts and habitat abandonment

- Polluted habitats become unsuitable, forcing species into marginal areas with lower survival or reproductive success. Local extirpations and range contractions follow.

D) Loss of non-target species (bycatch, collateral damage)

- Nonselective agricultural chemicals and fishing gears kill or injure many non-target organisms pollinators, scavengers, benthic invertebrates, sea turtles, seabirds and marine mammals causing broad biodiversity losses.
- Example: high bycatch rates in trawl and longline fisheries reduce populations of seabirds, turtles and sharks.

E) Genetic and population-level effects

- Small, polluted populations experience reduced genetic diversity and increased inbreeding, lowering adaptive potential to future stressors.

F) Trophic and ecosystem-level effects

- Removal or impairment of key species (apex predators, pollinators, decomposers) alters food-web dynamics, can cause trophic cascades, and reduces ecosystem resilience.
- Eutrophication can shift communities from diverse macrophyte- or coral-dominated systems to algal-dominated states with lower biodiversity.
- **Illustrative cases**
- Vultures in South Asia: diclofenac poisoning caused >90% declines in several Gyps species in the 1990s–2000s, demonstrating how a single veterinary drug can collapse scavenger populations and disrupt carcass removal services.

- Polar bears: POPs and heavy metals, combined with habitat loss from sea-ice decline, are linked to immunosuppression and reduced reproductive success.
- Coral reefs: nutrient pollution, sediments and chemicals increase coral disease and bleaching susceptibility, reducing reef biodiversity.
- Fisheries: mercury contamination affects top predators and human consumers; eutrophication-driven hypoxia causes fish kills and habitat loss.

II.18.3. Human health and socioeconomic dimensions

- Food safety: contaminated fish, shellfish and crops pose direct health risks to consumers (mercury, POPs, pathogens).
- Livelihoods: fisheries, tourism and agriculture suffer when pollution degrades resources.
- Cultural loss: species declines (e.g., vultures, charismatic megafauna) erode cultural practices and local knowledge.

II.18.4. Mitigation and policy responses

A) Source control

- Reduce pollutant inputs through improved waste treatment, sustainable agricultural practices (precision fertilizer use, buffer strips), integrated pest management (reduce pesticide reliance), and stricter industrial discharge controls.

B) Regulation and bans

- Phase-outs or bans of highly harmful substances (e.g., DDT, certain POPs, veterinary diclofenac) combined with safe alternatives and veterinary guidance.

C) Treatment and remediation

- Upgrade wastewater treatment to remove nutrients, pharmaceuticals and microplastics; remediate contaminated sediments and soils where feasible.

D) Best practices and technological fixes

- Promote eco-friendly pesticides, biodegradable materials, livestock carcass management (to prevent wildlife poisoning), and safer drug choices for veterinary use.
- Use oil-spill response plans, rapid containment and cleanup

technologies.

E) Protected areas and buffer zones

- Protect and restore wetlands, riparian buffers, mangroves and seagrass beds that filter pollutants and provide habitat refuges.

F) Monitoring, research and early warning

- Implement contaminant monitoring in water, sediments and biota; biomonitoring of sentinel species; and ecological risk assessments to guide management.

G) Public awareness and consumer action

- Reduce plastic use and improve disposal, support certified sustainable seafood, and pressure for safer chemical alternatives.

H) International cooperation

- Use global agreements (Stockholm Convention on POPs, Minamata Convention on Mercury, regional marine pollution agreements) to phase out persistent contaminants and coordinate cross-border action.

II.19. Characteristics that make species vulnerable to extinction

Certain biological, ecological and geographic traits increase a species' risk of becoming endangered or extinct. These traits reduce demographic resilience, limit adaptive capacity, or increase exposure to human threats. Below are common vulnerability characteristics, why they matter, examples, and conservation implications.

Low reproductive rate (low fecundity).

- Why it matters: Species that produce few offspring per breeding attempt or reproduce infrequently cannot replace losses quickly after mortality events (harvest, disease, catastrophic weather). Low fecundity slows recovery from population declines and increases extinction risk from stochastic events.
- Examples: Blue whale (*Balaenoptera musculus*), polar bear (*Ursus maritimus*), California condor (*Gymnogyps californianus*), whooping crane (*Grus americana*). Passenger pigeon (*Ectopistes migratorius*) is a historical example that went extinct due to massive exploitation combined with social breeding behaviour.
- Conservation implication: Protection of adults, long-term monitoring, and captive-breeding or head-start programs can be necessary to recover populations.

A) Small population size

- Why it matters: Small populations suffer from genetic drift and inbreeding, loss of

genetic diversity, reduced adaptive potential, demographic stochasticity and Allee effects (reduced reproductive success at low densities). Small numbers also make populations vulnerable to single catastrophic events.

- Examples: Many island endemics, some large mammals (e.g., Amur leopard), and narrowly distributed plants. Dajoz's colony-threshold examples illustrate Allee effects: some colonial species require minimum numbers of individuals for successful reproduction.
- Conservation implication: Maintain or restore population size and connectivity, manage genetic diversity through translocations or captive programs, and reduce local threats.

B) Specialized diet or narrow ecological niche

- Why it matters: Specialists rely on a limited set of resources (specific prey, host plants, or habitats). If that resource declines or shifts (habitat loss, climate change, invasive species), the specialist cannot easily switch to alternatives.
- Examples: Koala (*Phascolarctos cinereus*) largely depends on certain Eucalyptus species; giant panda (*Ailuropoda melanoleuca*) depends on bamboo; some seabirds and insectivores depend on specific prey species or seasonal food pulses.
- Conservation implication: Protect and manage the key resources and habitats; consider habitat restoration and ex situ food resource programs when feasible.

C) High trophic level (apex or large predators)

- Why it matters: Top predators have lower population densities, larger home ranges, slower reproduction, and accumulate threats via biomagnification (pollutants). They are sensitive to prey declines and habitat fragmentation.
- Examples: Tiger (*Panthera tigris*), bald eagle (*Haliaeetus leucocephalus* — historically threatened by DDT), sharks, large raptors and large felids.
- Conservation implication: Protect landscape connectivity and prey populations, reduce pollutant loads, and implement human–wildlife conflict mitigation.

D) Large body size

- Why it matters: Large animals often have slow life histories (late maturity, fewer young), require large home ranges, and are preferred targets for hunting, trophy trade, or intensive exploitation. Large bodies also make them more vulnerable to habitat fragmentation.
- Examples: African elephant (*Loxodonta africana*), rhinoceroses (family

Rhinocerotidae), bison (*Bison bison*), grizzly bear (*Ursus arctos*), some large lemurs of Madagascar.

- Conservation implication: Anti-poaching measures, protected areas large enough to encompass home ranges, and international trade controls (e.g., CITES).

E) Restricted geographic range or endemism

- Why it matters: Species confined to small areas or single islands are vulnerable to habitat loss, invasive species, disease, and extreme events. A single local threat can affect the entire species.
- Examples: *Carabus olympiae* (a ground beetle endemic to limited sites), *Microtus bavaricus* (Bavarian vole) historically known from very small ranges; many island endemics (birds, reptiles, plants).
- Conservation implication: Protect remaining habitat, control invasive species, establish ex situ populations and, where possible, create additional viable populations.

F) Restricted or specialized breeding habitat

- Why it matters: Species that breed only in particular habitats, substrates, or age-classes of vegetation (e.g., specific forest successional stages, particular beaches) are vulnerable when those sites are degraded or lost.
- Examples: Kirtland's warbler (*Setophaga kirtlandii*) historically nested almost exclusively in young jack pine stands; sea turtles that nest on a few beaches; whooping cranes that depend on undisturbed wetlands for nesting.
- Conservation implication: Protect and manage critical breeding sites, use habitat restoration and artificial nesting programs, and control human disturbance during breeding seasons.

G) Aggregated or colonial behavior

- Why it matters: Species that breed or forage in dense aggregations (colonial seabirds, some bats, passenger pigeons historically) can be catastrophically affected by a single disturbance (disease outbreak, storm, targeted harvest) and are easier to exploit commercially.
- Examples: Many seabird colonies, colonial waterbirds, some bat roosts.
- Conservation implication: Protect colonies and roosts, reduce local threats, and monitor disease and disturbance risks.

H) Low dispersal ability or poor habitat connectivity

- Why it matters: Poor dispersers cannot recolonize suitable habitat patches or track

shifting climate envelopes,
making populations more isolated and extinction-prone.

- Examples: Some flightless island birds and many plants with limited seed dispersal.
- Conservation implication: Maintain habitat corridors, assist range shifts (translocations) where necessary.

I) Dependence on human-mediated or ephemeral resources

- Why it matters: Species relying on ephemeral phenomena (seasonal insect outbreaks, migratory stopovers) or human-created resources (traditional pasturelands, cultural fire regimes) may suffer when those patterns change.
- Examples: Migratory shorebirds dependent on intertidal feeding grounds that have been degraded; species tied to traditional agro-pastoral landscapes.
- Conservation implication: Protect seasonal habitats and maintain traditional land-use practices where compatible with biodiversity goals.

J) Susceptibility to introduced species, disease or climate change

- Why it matters: Species with no coevolutionary history with invasive predators, competitors or pathogens, or with narrow climatic tolerances, are at high risk when new threats arrive or climates shift.
- Examples: Many island species devastated by introduced rats, cats or diseases (e.g., Hawaiian birds and avian malaria); amphibians vulnerable to chytrid fungus.
- Conservation implication: Biosecurity, disease monitoring, captive assurance populations, and assisted migration or refugia planning.

K) Combination of traits and extrinsic threats

- Why it matters: Risk increases when intrinsic vulnerabilities coincide with strong extrinsic pressures (habitat loss, overexploitation, pollution, climate change). For example, a large carnivore with slow reproduction and a restricted range facing habitat fragmentation and persecution is at very high risk.
- Conservation implication: Use threat analyses and IUCN Red List assessments to prioritize actions that target both species traits and external threats.

• Brief note on management priorities

- Focus on protecting reproductive adults and breeding habitats for low-fecundity species.
- Maintain or restore population size and genetic diversity for small populations; ensure connectivity to reduce isolation.
- Protect key resources (food plants, prey species), manage invasive species, and

reduce pollutant loads for specialists and top predators.

- Implement landscape-scale conservation for wide-ranging and large species; local site protection for endemics and species with restricted breeding sites.
- Use ex situ measures (captive breeding, seed banks) as a last resort or to support reintroductions, coupled with long-term habitat protection.

Chapter III

Sustainable Development

III.1. History: Key dates in sustainable development

Sustainable development is the idea that human societies should improve quality of life today without damaging the environment, economy, or social systems needed by future generations. Its history is not a single event but a sequence of global milestones that gradually turned an idea into an international agenda.

1) The first global turning point: 1972

The modern story begins in 1972 with the UN Conference on the Human Environment in Stockholm. This was the first major global conference to treat environmental protection as a shared international responsibility, and it led to the creation of UNEP. At that time, the world was starting to recognize that economic growth and environmental degradation could no longer be addressed separately.

2) The concept takes shape: 1980

In 1980, the term “sustainable development” appeared in the World Conservation Strategy. This matters because it gave the emerging idea an official name and connected conservation with long-term development planning. The message was simple but powerful: development should not consume the natural base it depends on.

3) The defining report: 1987

A key milestone came in 1987 with the publication of Our Common Future, also known as the Brundtland Report. This report made sustainable development famous by defining it as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It also helped move sustainability from an environmental slogan into a serious policy framework linking social, economic, cultural, and environmental concerns.

4) Climate science becomes central: 1988

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created. Its role was to assess scientific knowledge about climate change and provide governments with reliable evidence for decision-making. This was important because climate change soon became one of the biggest challenges to sustainable development.

5) Rio Earth Summit: 1992

The year 1992 is one of the most important dates in the history of sustainable development. At the United Nations Conference on Environment and Development in Rio de Janeiro, countries adopted Agenda 21, the Rio Declaration, the UN Framework Convention on Climate Change (UNFCCC), and the Convention on Biological Diversity (CBD). This conference showed that sustainability must be tackled through international cooperation, action plans, and legal agreements, not only through ideas.

6) Social development enters more fully: 1994–1995

After Rio, the agenda widened further. In 1994, the International Conference on Population and Development in Cairo emphasized the relationship between population, health, and development. In 1995, the World Summit on Social Development in Copenhagen highlighted poverty, unemployment, and social exclusion as major barriers to sustainability. These events reinforced the idea that sustainable development is not only ecological; it is also deeply social.

7) Millennium goals: 2000

In 2000, the UN Millennium Summit launched the Millennium Development Goals (MDGs). The MDGs focused on poverty reduction, education, gender equality, child health, maternal health, disease, and global partnership. They were a major step because they introduced measurable development targets for the international community.

8) Implementation and partnerships: 2002

In 2002, the World Summit on Sustainable Development in Johannesburg renewed the global commitment made in Rio. The emphasis shifted toward implementation, partnerships, and practical progress rather than declarations alone. This summit underlined that sustainable development requires action by governments, civil society, and the private sector together.

9) A broader policy framework: 2012

In 2012, the Rio+20 Conference revisited the sustainability agenda. It focused on two major themes: the green economy and the institutional framework for sustainable development. Rio+20 helped prepare the world for a more integrated global agenda that would combine poverty, environment, and governance.

10) The SDG era: 2015

The most recent landmark is 2015, when the UN adopted the 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs). The SDGs expanded the vision beyond poverty reduction to include climate action, biodiversity, clean water, responsible consumption, peace, equality, and strong institutions. In practice, they became the global roadmap for sustainability in the 21st century.

11) A simple chronology

The timeline in order:

- **1972:** Stockholm Conference and creation of UNEP.
- **1980:** “Sustainable development” appears in the World Conservation Strategy.
- **1987:** Brundtland Report defines sustainable development.
- **1988:** IPCC is created.
- **1992:** Rio Earth Summit, Agenda 21, UNFCCC, CBD.
- **2000:** Millennium Development Goals.
- **2002:** Johannesburg World Summit.
- **2012:** Rio+20 Conference.
- **2015:** Sustainable Development Goals and 2030 Agenda.

12) Why this history matters?

This history shows that sustainable development grew in stages. First, the world recognized environmental limits; then it defined the concept; then it created treaties and action plans; and finally, it adopted global goals with measurable targets. In other words, sustainable development is the result of decades of negotiation between science, policy, and global cooperation.

A useful way to remember it is this: Stockholm introduced the issue, Brundtland defined it, Rio organized it, the MDGs measured it, and the SDGs broadened it.

III.2. Principles of Sustainable Development

Sustainable development is built on a set of guiding principles that help societies make decisions that are fair, practical, and respectful of environmental limits. These principles are useful because they remind us that development is not only about economic growth; it is also about social justice, environmental protection, and long-term responsibility.

III.2.1. Intergenerational equity

This is the principle of fairness between generations. It means that the present generation should meet its needs without reducing the ability of future generations to meet theirs. For example, overusing water, destroying forests, or exhausting non-renewable resources may bring short-term benefits, but it creates serious problems for future people.

This principle is at the heart of sustainable development because it introduces a moral responsibility toward the future. It asks decision-makers to think beyond immediate profit or convenience and consider the consequences of today's actions over decades.

III.2.2. Intragenerational equity

This principle refers to fairness within the present generation. It means that all people should have a fair chance to access resources, opportunities, and a decent quality of life. Sustainable development cannot be achieved if wealth, power, and environmental benefits are concentrated in only one part of society.

This is why poverty reduction, access to clean water, education, health care, and decent jobs are all part of sustainability. A society that grows economically but leaves large groups behind is not truly sustainable.

III.2.3. Integration of the three pillars

One of the most important ideas in sustainable development is the integration of economy, society, and environment. These are often called the three pillars of sustainability. A good policy should support economic activity, improve social well-being, and protect natural systems at the same time.

This principle teaches us that the three dimensions are interconnected. For example, a mining project may create jobs and income, but if it pollutes groundwater or destroys farmland, the social and environmental costs may outweigh the gains. Sustainable development requires balance, not one-sided progress.

III.2.4. Precautionary principle

The precautionary principle says that when an action may cause serious or irreversible harm, we should not wait for complete scientific certainty before taking protective measures. In simple terms, it is better to prevent damage early than to wait until the harm becomes obvious and difficult to repair.

This principle is especially relevant in climate change, biodiversity loss, toxic pollution, and groundwater contamination. If evidence suggests a serious risk,

governments and communities should act carefully and responsibly, even if every detail is not yet fully known.

III.2.5. Polluter pays principle

This principle states that those who cause pollution should bear the cost of managing it. Instead of letting society pay for environmental damage, the source of the damage should pay for prevention, control, and restoration.

This principle is important because it promotes accountability. It also creates a financial incentive for industries, businesses, and individuals to reduce pollution. If polluters must pay for the consequences of their actions, they are more likely to adopt cleaner technologies and responsible practices.

III.2.6. Public participation

Sustainable development works best when people are involved in decisions that affect their lives. Public participation means that communities, local residents, civil society groups, and other stakeholders have the right to contribute to planning and decision-making.

This principle improves transparency, trust, and fairness. It is especially important in projects related to land use, water management, urban planning, and environmental protection. When people participate, policies are often more realistic and more widely accepted.

III.2.7. Good governance

Good governance means that decisions should be transparent, accountable, fair, and based on reliable information. It also means that institutions must work effectively and serve the public interest. Without good governance, even well-designed sustainability policies may fail.

This principle is essential because sustainable development requires long-term planning, coordination, and enforcement. Laws, regulations, and institutions must be strong enough to protect the environment and ensure social justice.

III.2.8. Partnership and cooperation

Sustainable development cannot be achieved by governments alone. It requires cooperation among governments, universities, communities, businesses, NGOs, and international organizations. This principle emphasizes shared responsibility.

Partnerships make it easier to exchange knowledge, mobilize resources, and coordinate action. For example, protecting biodiversity or improving water quality often requires collaboration between scientists, local authorities, farmers, and

citizens.

III.2.9. Systems thinking

Systems thinking means seeing problems as part of a larger connected whole rather than in isolation. Environmental, social, and economic issues influence one another, so solutions must consider these connections.

For instance, urban expansion may affect water availability, energy demand, waste production, and public health at the same time. Systems thinking helps avoid “fixing” one problem while making another worse. It encourages more intelligent and sustainable planning.

III.2.10. Long-term responsibility

Sustainable development requires a long-term view. This principle means that decisions should be evaluated not only by their immediate benefits, but also by their future effects. A project that looks successful today may become harmful later if it increases pollution, weakens ecosystems, or creates social inequality.

Long-term responsibility is especially important in areas like agriculture, energy, transport, and natural resource management. It pushes planners to choose solutions that remain useful, affordable, and safe over time.

III.3. Why these principles matter?

These principles are not just theoretical ideas. They are practical rules for making better choices in real life. They help governments design policies, guide industries toward responsibility, and support communities in protecting their environment and welfare.

Together, they show that sustainable development is about more than growth. It is about creating a future that is economically viable, socially fair, and environmentally safe.

III.3.1. Conservation biology

This science emerged in the late 1970s. Its objectives are to assess the impact of human actions on species, communities, and ecosystems, and to make concrete proposals and suggest appropriate methodologies for nature conservation. It is a crisis discipline, at the intersection of science and management. It operates under pressure, as threatened species and habitats risk rapid disappearance without effective measures. The conservation of flagship or charismatic species, habitat restoration and rehabilitation, and species reintroduction play important roles in restoring biodiversity.

III.3.2. Implementation of conservation

A) Safeguarding endangered species

Given the large number of vulnerable species, not all can benefit from protection measures. These are the species whose extinction is most imminent. Knowledge of a species' status and range determines the urgency of conservation. Scientists assign conservation urgency to the following species:

- Threatened throughout their range

- Whose distribution area is limited

- Undetermined status

- Belonging to a monotypic family or genre.

A genus is described as monotypic if it comprises only one species.

Example Dwarf palm, monotypic genre *Chamaerops*

- **Safeguarding keystone species**

Within a community, there are species that, while not the most Abundant or most spectacular in size, play an essential role because they structure the community and condition its specific wealth.

Example: Salmonids in a lake.

If Trout are absent, the planktonic community is made up of Cladocera: Daphnia which exclude other planktonic communities.

At average density of trout, their predation on Daphnia zooplankton grazing phytoplankton reduces the intensity of this interspecific competition and allows a diversification of zooplankton

species Cladocera and Copepods.

At high density, diversification is maximal with the appearance of crustacean species that prey on zooplankton.

B) The reintroduction of species

The disappearance of a growing number of animal and plant species from their native range has led scientists to reintroduce various species into the regions where they are extinct. Between 1950 and 1990, 26 species were introduced. Between 1973 and 1986, at least 700 operations were successfully undertaken.

- **Example: The Arabian Oryx (*Oryx algazel*)**

This species was saved from extinction due to rampant hunting by American zoologists in 1950. It was reintroduced to Oman and Arabia (Taif National Park) in the 1980s where its numbers have rapidly increased.

C) Ecosystem Conservation

How to determine which ecosystems require protection measures and where to locate the areas to be protected, an essential condition for conservation *in situ*?

Unique, unmodified or minimally altered ecosystems that serve as migratory habitats for animal species.

Determine the areas to be protected which contain high endemism; indeed, the minimum surface area of protected areas, their optimal location and their relative arrangements are the parameters conditioning the success of conservation measures.

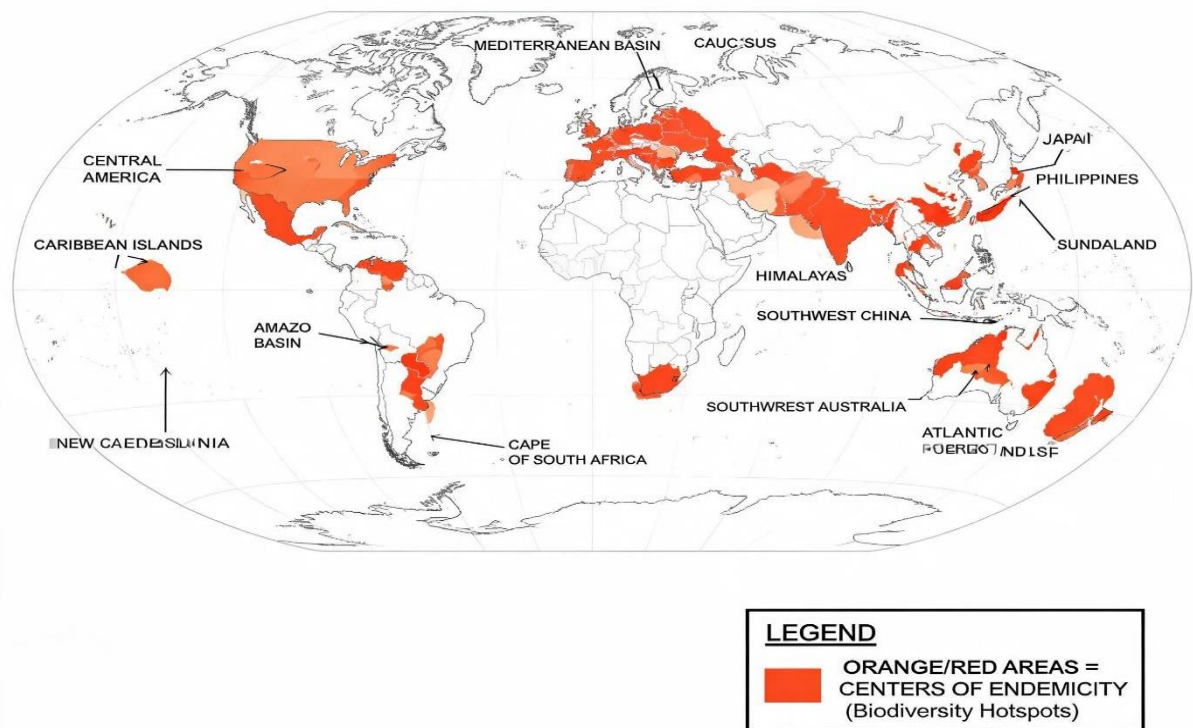


Figure 13. World map showing the main centers of endemism

III.3.3. Conservation of biodiversity

Managing genetic resources involves inventorying, characterizing and evaluating, conserving, regenerating and disseminating them. Three overall management strategies are used.

A) **Conservation *in situ***

It consists of maintaining living organisms in their natural environment. This type of conservation allows animal and plant communities evolution by adapting to environmental changes. national and regional parks

B) **Conservation *ex situ***

to continue them example: parks

It is the preservation of species outside their natural habitat in zoological and botanical gardens and public aquariums.

In vitro The animals are not kept alive and "whole". Certain biological materials (semen, oocytes, embryos, somatic cells, DNA, etc.) are taken at a given time from living animals and kept frozen, generally in liquid nitrogen at -196°C: this is the principle of cryobanks (Lévêque and Mounolou, 2008).

III.4. Protected areas

➤ **Definition:** A protected area (PA) *protected area* (PA) is "a space a clearly defined, recognized, and managed geographical area, by legal (judicial) or other means, to promote the long-term conservation of nature and related ecosystem services and cultural values."

NB/A marine protected area (MPA) is defined as a geographical area benefiting from protected status that includes, for the most part or entirely, a marine zone. The concept has been popularized by the Convention on Biological Diversity (CBD), which recommends protecting particularly threatened marine and coastal areas through specific measures,

In 1992, the United Nations Conference on Environment and Development took place in Rio de Janeiro, Brazil. The 178 participating countries demonstrated their collective capacity to manage natural problems (global warming, deforestation, desertification...) and affirm the need for respect, preservation and restoration of the environment

III.4.1. Consequences of Rio: Implementation of the three conventions

United Nations Framework Convention on Climate Change (UNFCCC)

The Convention on Biological Diversity (CBD)

The United Nations Convention to Combat Desertification (UNCCD)

III.4. 2. Classification of protected areas

The International Union for Conservation of Nature (IUCN) has defined numbered categories from 1 to 6, which can characterize each protected area according to the intensity of protection (from 1: total protection to 6: management of human activities with an objective of management, restoration and protection).

The World Commission on Protected Areas is a commission of the IUCN for the protection of natural areas. Its mission is to promote the establishment of a globally representative network of terrestrial and marine protected areas. Its headquarters are located in Gland, Switzerland.

Table 2. IUCN Category (Dudley, 2008)

IUCN Category	Name	Characteristics and management objective
Ia	Integral nature reserve	Management of protected areas for scientific purposes or for the protection of wild resources
Ib	Wilderness area	Management of the AP for protection purposes wild resources
II	National Park	Management of protected areas for ecosystem protection for recreational purposes
III	Natural monument	Management of the protected area with the aim of preserving specific historical natural features
IV	Area managed for habitat and species	Management of the protected area for conservation purposes, with intervention at the management level
V	Protected terrestrial or marine	Management of protected areas to ensure the conservation of terrestrial or marine landscapes

	landscape	for recreational purposes
VI	Protected area of managed natural resources	Management of protected areas for the sustainable use of natural ecosystems

III.4.3. The ranking criteria

Any activity taking place within the territory or on a portion thereof must not alter the essential biological character of the area: incompatible activities are:

Forest plantations

Mining

Development of the land for hydroelectric purposes

Resource extraction (hunting and fishing)

- The area must be managed using effective means (law and regulations)

Abroad, the protection of a protected area (PA) falls to the government, NGOs, the private sector, or a local community. The important thing is that the local authority is capable of achieving the objectives specified to ensure the protection of the area.

A) CATEGORY Ia. Integral nature reserve

Protected area, administered primarily for scientific study purposes.

This refers to a terrestrial or marine area, comprising ecosystems, geological or physiographic features. fragile species of national and international importance, or representative or threatened species. The size of this area must be determined by the minimum area necessary to ensure the conservation of these species; it is administered primarily for scientific research and ongoing environmental monitoring. The management objectives are to:

To preserve biotopes, ecosystems and species in the most natural or least modified conditions possible;

Maintain genetic resources in a dynamic and evolving state;

To preserve structural elements of the landscape or rock formations;

To preserve exemplary natural environments for the purposes of scientific study, continuous environmental monitoring and education, including reference

areas, excluding any access that can be avoided;

Minimize disruptions and limit public access.

Physiographic: Geomorphological description of the natural aspects of a region (relief, climate) and the phenomena related to it.

B) CATEGORY Ib. Wilderness area

Protected area, administered primarily for the purpose of resource protection wild.

This area comprises a vast expanse of land or sea, untouched or minimally altered, retaining its natural character, devoid of permanent or significant habitation, and protected and managed to preserve its natural state. The management objectives are to:

To guarantee future generations the opportunity to enjoy regions that have remained largely untouched by human activity for a long period;

To preserve the essential natural qualities and elements of the environment in the long term;

Allow non-motorized public access, within limits compatible with the physical and spiritual well-being of visitors, while preserving the wild natural qualities of the region;

To enable low-density indigenous communities living in harmony with available resources to maintain their way of life.

C) CATEGORY II National Park

Protected area, administered primarily for the purpose of preserving ecosystems and for recreational purposes.

This category includes a natural area, terrestrial or marine, designated:

has) To protect ecological integrity in one or more ecosystems for the benefit of current and future generations;

To exclude any exploitation or occupation incompatible with the objectives of the designation;

To offer opportunities for visits, for scientific, educational, spiritual, recreational or tourist purposes, while respecting the natural environment and the culture of local communities.

The management objectives are as follows:

To protect natural regions and landscapes of national and international importance, for their use for scientific, educational, spiritual, recreational or tourist purposes;

To perpetuate, under conditions as natural as possible, representative examples of physiographic regions, biological communities, genetic resources and species, while ensuring ecological stability and diversity;

Limit the number of visitors, so that the area remains in a natural or almost natural state;

Eliminate and subsequently prevent any form of exploitation or occupation incompatible with the objectives of the conservation status; guarantee respect for the ecological, geomorphological, sacred or aesthetic elements justifying the status;

Take into account the needs of indigenous populations, including the use of resources for subsistence purposes, insofar as these do not have any negative impact on other management objectives.

D) CATEGORY III Natural Monument/striking natural element

Protected area, administered primarily for the purpose of preserving elements specific natural elements.

This category designates a small area containing one or more particular natural and/or cultural features of exceptional or unique importance, deserving of protection due to their rarity, representativeness, aesthetic qualities, or intrinsic cultural significance. The management objectives are as follows:

To protect or preserve, forever, particular natural elements, exceptional because of their natural importance, their unique or representative character, or their spiritual connotation;

To an extent consistent with the aforementioned objective, to offer opportunities for research, education, interpretation and leisure;

Eliminate and subsequently prevent any form of exploitation or occupation incompatible with the objective of the conservation status;

To offer the resident population benefits that are compatible with other management objectives (e.g., recreational activities such as caving, or cultural activities such as a traditional ceremony among Indigenous peoples).

- Examples: Devils Tower Natural Monument (Wyoming, USA), famous for its volcanic dike which is one of the most remarkable in the world; it also hosts one of the last colonies of prairie dogs (*Cynomys ludovicianus*).

E) CATEGORY IV Area managed for habitat and species

Protected area, administered primarily for conservation purposes, with

intervention in this which relates to management.

This type of terrestrial or marine area is subject to active intervention in its management, in order to guarantee the maintenance of habitats or to meet the requirements of species.

specific species (sedentary or migratory). Human intervention is necessary to maintain optimal conditions for these communities. However, it must not alter their original natural state. Furthermore, extensive but sustainable exploitation of wildlife resources is permitted within the area, but this must not modify their essential biological character.

The management objectives are as follows:

To guarantee and maintain the habitat conditions necessary for the preservation of species, groups of species, biological communities or important physical elements of the natural environment, when human intervention is required to optimize management;

Prioritize research activities and continuous environmental monitoring, alongside sustainable resource management;

Dedicate limited areas to public education, in order to raise awareness of the characteristics of the habitats concerned and the work of managing wildlife species;

Eliminate and, subsequently, prevent any exploitation or occupation incompatible with the objectives of the conservation status;

To offer communities living within the area opportunities for activities that are compatible with other management objectives.

Examples: The Neouvielle Nature Reserve (1936) protects high-altitude coniferous forests and several glacial areas in the western Pyrenees.



Figure 14. Néouvielle Nature Reserve in the Western Pyrenees

F) CATEGORY V Protected terrestrial or marine landscape

Protected area, administered primarily for the purpose of ensuring the conservation of

landscapes, both terrestrial and marine, and for recreational purposes.

This refers to a land area, sometimes encompassing the coast and the sea, whose landscape possesses particular aesthetic, ecological, or cultural qualities resulting from the long-standing interaction between humans and nature, and often exhibiting high biodiversity. Maintaining the integrity of this traditional interaction is essential for the protection, preservation, and evolution of such an area. The management objectives are as follows:

Maintain the harmonious interaction of nature and culture, by protecting the terrestrial or marine landscape and ensuring the maintenance of traditional forms of land use and construction, as well as social and cultural manifestations;

To encourage lifestyles and economic activities in harmony with nature, as well as the preservation of the socio-cultural fabric of the communities concerned;

Maintain the diversity of the landscape and habitat, as well as the associated species and ecosystems;

Eliminate and subsequently prevent any form of land occupation and any activity incompatible with the objectives pursued, due to their scale or their particularity;

To offer the public a whole range of outdoor leisure activities respecting the essential qualities of the area;

To encourage scientific and educational activities that contribute to the long-term well-being of resident communities, while raising public awareness of the protection of their landscapes;

To provide benefits to the local community and contribute to its well-being in the form of natural products (e.g. forestry or fishing) and services (drinking water or income from sustainable forms of tourism).

Category V refers to landscapes modified or shaped by humans over time, that is, where human presence in nature has always been expressed through traditional (and not modern) practices. The primary objective is to maintain a harmonious interaction that has long fostered a diversity of landscapes, habitats, or of species. Sustainable and traditional use of resources, locally, is permitted in this type of area.

G) CATEGORY VI Protected area of managed natural resources

Protected area, managed primarily for the purpose of sustainable ecosystem use natural.

This is an area containing largely unmodified natural systems, managed in a way that ensures the long-term protection and maintenance of biological

diversity, while guaranteeing the sustainability of the natural functions and products necessary for the well-being of the community. The management objectives are as follows:

To ensure the protection and long-term maintenance of the biological diversity and other natural values of the site;

To promote rational management practices in order to ensure sustainable productivity;

To protect the natural resource capital against any alienation caused by other forms of land use that could harm the biological diversity of the region;

Contribute to regional and national development.

This sixth category was added in 1994 by the IUCN to encompass predominantly natural areas "managed to protect their biological diversity in such a way as to ensure a sustainable flow of goods and services to the community." The key is to ensure management that guarantees, in the long term, the protection and maintenance of the area's biological diversity. In particular, the area must meet the following four conditions to be classified in this category:

It must be compatible with the general definition of protected areas;

At least two-thirds of its surface area must be in natural conditions and remain so;

It cannot include large commercial plantations;

A management authority must be in place.

Any use of resources within a protected area must obviously be sustainable; therefore, it must not cause any harm to the natural conditions that prevail over two-thirds of its area. Category VI areas should be large enough to accommodate the sustainable use of the resource without compromising the long-term maintenance of the site's natural values.

Category VI falls between categories III and IV, based on the level of human intervention recognized in each. To meet the criteria for Category VI classification, the area must remain largely (two-thirds) in its natural state and must not involve any large-scale logging or reforestation. Consequently, logging may only be carried out on a small portion of the area and according to environmentally sustainable practices.

In return, we are introducing some flexibility in the interpretation of the IUCN

guidelines (1994) regarding the extent of sport hunting. In this respect, Category VI differs from Categories II and III by including areas where wildlife resources are harvested. As practiced in Quebec, this activity would not alter the essential biological character of the protected area. Sport hunting (and trapping) is subject to quotas and governed by law (*Wildlife Conservation and Enhancement Act*, LRQ, c. C-61.1); it generates significant economic benefits for the regions. Apart from sport fishing, hunting is the only permitted resource harvesting activity across the entire protected area, while all other forms of environmental exploitation are either restricted, prohibited, or inapplicable.

H) Category VII: Biological Regions / Anthropological Reserves

In these regions live inhabitants who do not have not yet been affected by technology modern (Traditional way of life). These Aboriginal people are important for human cultural diversity; they are hunter-gatherers. Intensive farming is not authorized.

I) Category VIII: Natural areas developed for multiple uses

The areas in this category are vast, encompassing territories suitable for forestry, grazing, and the productivity of terrestrial wildlife and marine. Some parts of its areas can be exploited and transformed by humans.

- In addition to these areas defined by the IUCN, there are other areas defined by UNESCO from 1970 onwards which sometimes overlap with the categories already mentioned.
- Example: Cévennes Biosphere Reserve which largely covers the national park in question.

III.4.4. Biosphere reserves

It was created to preserve at least one representative area of each major ecosystem type existing in the world and where human activity is tolerated in the peripheral part of the area.

1) Goals

Conserving the different types of ecosystems to preserve fundamental ecological processes as well as the genetic diversity of fauna and flora;

To serve as witnesses for the evolution of ecosystems, whether natural or anthropogenic;

These are prime sites for the continuous monitoring of the environment;

There is a concentric zoning: a central area (almost integral reserve) of natural land, a strictly delimited buffer zone and finally at the periphery a transition area of stable crops and the least ecologically disruptive.

- The "natural" sites of world heritage

The Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO, 1972) stipulates that areas of outstanding universal value may be designated as World Heritage sites upon a proposal from the State: These are protected areas I to V.

Example: Kakadu National Park which contains Aboriginal petroglyphs containing 40,000 rock paintings attesting to the biodiversity of the region at the end of the Pleistocene who lived in mainland Australia.

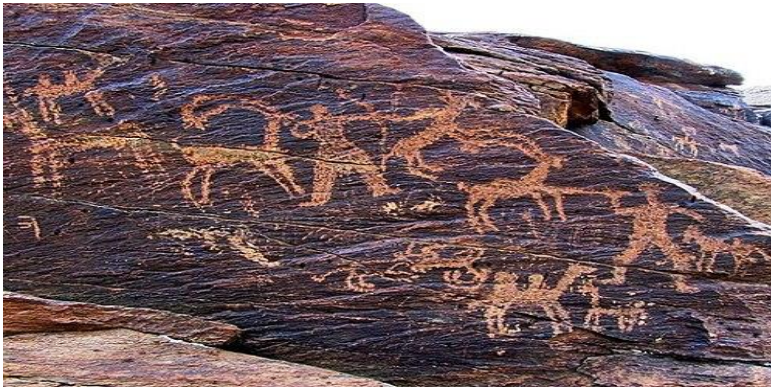


Figure 15. Petroglyph painting

2) Examples of protected areas in the world, in the Mediterranean and in Algeria

• Examples of protected areas around the world

More than 100,000 protected areas exist worldwide, and their number continues to grow. to increase, the ten largest protected areas are with an area of 972,000 square kilometers, Greenland National Park is the largest.

The Ar-Rub'al-Khali Wildlife Management Area in Saudi Arabia which covers 640,000 square kilometers comes in second place.

The Great Barrier Reef Marine Park in Australia (345,000 km²) East the third largest protected area,

Northwest Hawaiian Islands Coral Reef Ecosystem Reserve (United States) with over 345,000 square kilometers

The Amazon rainforest reserve in Colombia (320,000 km²)

The Qiang Tang Nature Reserve in China (nearly 250,000 km²)

The Cape Churchill Wildlife Management Area in northern Canada (140,000 km²)

The Northern Wildlife Management Area in Saudi Arabia (100,000 km²)²

Alto Orinoco-Casiquiare Biosphere Reserve in Venezuela and Bolivia (80,000 km²)

The Valo do Javari Indigenous Area in Brazil (80,000 km²) (23.24)

- **Quebec's ecological reserves**

Ecological reserves are protected areas dedicated to education and research, closed to the public with the exception of the Serpentine-de Coleraine, the Forêt la Blanche, the Lanoraie Bogs, and Brion Island. They are classified in the category 1a (the highest level of protection in the world). There is no resource exploitation, no roads pass through the reserve, no energy infrastructure, no hunting or fishing.

- **List of protected areas in the Mediterranean**

In Morocco: Morocco's natural resources are certainly of high quality, but they remain fragile and require sustained efforts for their preservation. In this regard, several actions have been undertaken for the conservation and sustainable use of biodiversity:

The Protected Areas Master Plan, developed in 1996, identified 154 Sites of Biological and Ecological Interest (SIBEs) classified for their ecological, scientific, socioeconomic, or heritage value, proposing the designation of about ten of them as national parks.

Spread over an area of 2.5 million hectares, these SIBEs represent almost all of the country's natural ecosystems.

From 1942 to 1991, Morocco created four national parks: Toubkal in 1942, Tazekka in 1950, Souss-Massa in 1991 and Iriki in 1994.

In 2004, four other national parks were created: Al Hoceima, Talassemtane, Ifrane, High Atlas Oriental.

In 2006, the Kingdom's first Saharan national park was created; the Khnifiss National Park.

In 2008, Khénifra National Park was created, bringing the total number of protected areas in Morocco to 10, covering a total area of approximately 810,400 hectares. In addition to this network of national parks, Morocco has established three Biosphere Reserves, which promote solutions that reconcile biodiversity conservation with its sustainable use. These are:

- **The Arganeraie Biosphere Reserve**

The Biosphere Reserve of the Oases of Southern Morocco.

The Intercontinental Biosphere Reserve of the Mediterranean.

Regarding wetlands, four sites were designated Ramsar sites in 1980: the Merja Zerga Reserve, the Sidi Bou Ghaba Reserve, the Khnifiss Lagoon Reserve, and the Aguelmame Afenourir Lake Reserve. In 2005, twenty more sites were added to the Ramsar list (25).

In Tunisia: The Atlas of Protected Areas was developed by the General Directorate of Forests to disseminate information on Tunisia's National Parks and Nature Reserves. Each protected area is represented in this Atlas by a fact sheet describing its main features and presenting the animal and plant species that characterize it (26).

National Parks of Tunisia A national park is defined as a relatively large territory which presents one or more ecosystems generally little or not altered by human exploitation and occupation, where the plant and animal species, geomorphological sites and habitats offer special interest from a scientific, educational and recreational point of view, or in which there are natural landscapes of great aesthetic value. (Chapter III of the Tunisian Forestry Code, Law No. 88-20 of April 13, 1988) (26).

- Examples: O Ezzen, El Feija, jbel Chitana, Ichkeul, Zembra, Zembrata, Boukonine, jbel Zeghouan, jbel serj, jbel Zerdoud, Chaambi, Mghilla, jbel Orbata, Bouhedma, Dgoumes, jbil Saditoui Senghar Jabbes (26)
- **Nature Reserves of Tunisia** A nature reserve is defined as a small site whose purpose is to maintain the existence of individual species or groups of natural species.

animal or plant species, as well as their habitat and the conservation of migratory fauna species of national or global importance. (Chapter III of the Tunisian Forestry Code, Law No. 88-20 of April 13, 1988).

- Examples: Jbel Khoufa, Ain Zana, Majen Chitane, Jebel el Ghorra, Jebel Bent Ahmed, Botanical Garden, Chickly Island, Bat Cave, Jebel Hammamet, Mellegue Essif, Jebel Saddine, Kef Erai, Jbel serj, Ain Chrichira, Sebkhate Kolbia, Jebel Touati, Khechem El Kelb, Jebel Rihana, Goulebe, El gonna (26).

- **List of protected areas in Algeria (24.25)**

With its extreme ecological diversity, Algeria ranks among the most unique Mediterranean countries, unparalleled in its bioclimatic, floral, and faunal

features. This diversity has given rise to a wealth of landscapes and high-quality natural environments, conferring exceptional heritage value in the field of natural environment protection. To safeguard this heritage, Algeria has established a network of protected areas comprising 11 national parks and 5 nature reserves, encompassing unique ecosystems representative of the country's biological diversity.

A) National parks

Taza National Park It was created by decree no. 84-358 of November 3, 1984, but only became operational in 1987. This park aims to protect flora and fauna, especially endangered species, as well as geomorphological sites (caves and cliffs). Its area is 3,807 hectares of coastal terrain, and it is part of the Jijel province. Nearly thirty mammal species reside there: the hyena, the wildcat, the hedgehog, the golden jackal, the red fox, and the monkey. Birdlife includes egrets, the Audouin's gull, the great cormorant, and the common shelduck. The national park is also a forested area where the zeen oak is the main species, along with the afares oak, ash, white poplar, black poplar...

El Kala National Park: Created under decree no. 83-462 of July 23, 1983, it encompasses a unique wetland and was classified as a biosphere reserve in 1990 by the MAB (Man and Biosphere) program of UNESCO (United Nations Educational, Scientific and Cultural Organization (UN)).

These are areas where the maintenance of biodiversity is associated with reasonable human activities compatible with sustainable development.

Its area is 80,000 hectares, it is part of the wilaya of El Taref, and it covers 40 km of coastline from Cap Rose to Cap Roux. The main wadis that cross it are the Oued Bougous, Oued Melila and Oued El Kebir. It includes Lakes Tonga and Oubeira (classified as an area of international importance under the Ramsar Convention). It is home to 29 species of mammals: wild boar, porcupine, otter, lynx and Barbary deer... Birds are represented by 189 species, the majority of which are forest birds; aquatic fauna include greylag geese, white-headed ducks, spoonbills, fish (barbel, mullet and eels), reptiles and amphibians are represented by 26 species, and insects, which are very rare species and whose inventory is far from complete.

The lake ecosystem: At the lakes, there is a very diverse flora with a predominance of white and black poplar, black alder, bald cypress, as well as

yellow-flowered water lilies which are very rare species.

Gouraya National Park: It was created by decree no. 84-327 of November 3, 1984, but was not officially established until 1993. It covers an area of 2,080 hectares of coastal terrain and is located northeast of Bejaïa. Its altitude reaches 672 meters. The vegetation consists of kermes oak, olive trees, Aleppo pine, and a few rare juniper and wormwood trees. Wild boar, wildcat, porcupine, and caracal lynx are found there. Furthermore, birdlife is quite significant and includes the griffon vulture, turtle dove, Barbary partridge, Eurasian eagle-owl, as well as other endangered species such as Bonelli's eagle and various buzzards.

The area is characterized by a multitude of sites:

The Gouraya fort at the highest point

The tomb of Lala Gouraya

The Aiguades, which are small bays lined with pebbles and ideal for swimming

Cap Carbon site with its lighthouse

The caves, which are more or less important.

Theniet El Had National Park The aim of this park is to Protect and develop the faunal and floral heritage (Cedar Forest)

To raise visitors' awareness of the different aspects of nature conservation

To develop and organize scientific research related to the natural environment.

It was created in 1983 (Decree No. 83-459 of July 23, 1983) on an area of 3435ha, it is part of the wilaya of Tissemsilt.

The park is home to more than 17 mammal species, eight of which are on the list of protected species in Algeria: the wild boar, the wildcat, the weasel, the genet, the mongoose, the European hare, the European rabbit, the hedgehog, the European trunked rat, the wood mouse, and the house mouse; a multitude of birds such as the sparrowhawk, peregrine falcon, Barbary partridge, common quail, common wood pigeon, European turtle dove, and common cuckoo. The forest birdlife includes 3 species of tits, the goldcrest, the black flycatcher, the green woodpecker, and the great spotted woodpecker.

- **Belezma National Park**

Its objective is to safeguard the 15,000 hectares of cedar (threatened with extinction), to enable and maintain the return of animal species, to develop tourism while prioritizing technical studies and scientific research in

collaboration with specialized institutes.

It was created by decree 84-326 of November 3, 1984, but only became operational in 1987.

Its area is 26,250 hectares, and it is located 7 km north of Batna. The area is rich in water sources, most of which have a low flow, with the exception of the hot spring. The vegetation is abundant and varied: Aleppo pine, cedar with its associated flora represented by holly (an endangered species) and wild rose. Holm oak and ash trees can also be found. The park's distinctive feature is the presence of the only stand of Etruscan honeysuckle, an endangered species, and the presence of various orchids.

The birdlife is represented by the Barbary partridge, Bonelli's eagle, black kite, European turtle dove, skylark, barn swallow, wren, robin, blue tit, coal tit, and blackcap, as well as the presence of the rose-winged bullfinch, a rather rare bird in Algeria. Mammals include the jackal, fox, hare, wild boar, wildcat, hyena, caracal, and the woodpecker. Recently, the gazelle and Barbary sheep have also been reintroduced. The site is characterized by the presence of Roman archaeological sites, including the Kasserou swimming pool.

- **Chrea National Park**

Its objective is the protection of exceptional natural landscapes, animal and plant species threatened with extinction, to offer recreational opportunities, and to develop scientific research. Its creation dates back to 1925 (Decree of September 3, 1925) with an area of 1,351 hectares. It was declared a national park in 1983 (No. 83-461 of July 23, 1983). Extending over an area of 26,600 hectares, it is spread across the slopes of the Blida Atlas Mountains. The altitude ranges from 174 meters to 1,650 meters, allowing for the discovery of 500 plant species: Holm oak, cedar, cork oak, Aleppo pine, 17 species of orchids, medicinal species, mycological species, and lichens. Barberry, holly, and yew are species threatened with extinction. The park is home to 100 species of birds and about twenty species of mammals, such as the Barbary macaque, genet, lynx, mongoose, golden jackal, fox, and wild boar. Otters and weasels remain rare and/or are declining. Birds of prey are mainly represented by the golden eagle, Bonelli's eagle, peregrine falcon, and griffon vulture. We also encounter lizards and amphibians. As a natural curiosity:

- **The "Col des Fougere" trail**

The towering peaks and sharp ridges, located to the Southeast of Douar Ima Alima.

The path to Sidi Abdelkader, lined with centuries-old trees and clusters of yew and holly mixed with cedars

The monkey streams forming splendid landscapes.

- **Tlemcen National Park**

Created under Executive Decree No. 93-117 of May 12, 1993, with an area of 8,225 hectares. The majority of the park is covered by mountains, giving it a mountainous character with an average altitude of 1,100 meters. The flora consists of forests:

The Zariffet state forest (944ha) where cork oak, zeen oak and holm oak predominate.

The Haffir state forest (1207 ha) consisting of holm oak and zeen oak

The Montas forest of Zeen oak.

The park contains very important natural archaeological treasures:

The Sidi Boumediene Mosque, built in 739 AH

The mosque and minaret of Mansourah

The mosque of Sidi Bou Ishaq El Tayar

The ruins of Mansourah

The Sultana's Tomb

The minaret of Agadir

The sources of Ourit

The Boumaaza caves

The Safsaf Gorge.

Djurjura National Park: This park was created to protect wildlife, particularly the Barbary macaque, as well as flora, soil, and subsoil all ecosystems of particular interest to preserve. It was established by decree no. 83-460 of July 23, 1983.

Located in northern Algeria, 150 km east of Algiers, it incorporates portions of the Bouira and Tizi Ouzou provinces. The vegetation includes Atlas cedar, holm oak, cork oak, field maple, Montpellier maple, and Prunus avium. The Djurdjura massif is home to 129 bird species, making it the richest in northern Algeria: Bonelli's eagle, tawny owl, griffon vulture, weasel, golden jackal, common kestrel, long-legged buzzard, Eurasian eagle-owl, bearded vulture, song thrush,

common nightingale, common crossbill, European green woodpecker, and hoopoe. The insect fauna includes caterpillars, ladybugs, and lacewings.

- **Djebel Aissa National Park**

Established by decree no. 3-148 of March 29, 2003, the Djebel Aissa covers an area of 24,400 hectares and is located in the wilaya of Naama. It is part of the Ksours Mountains, the westernmost section of the Saharan Atlas, reaching an altitude of over 2,200 meters. The endemic flora dates back to the Quaternary period and is threatened with extinction. The majority of the area consists of steppes, including esparto grass and white wormwood. In the depressions, jujube and Atlas pistachio trees thrive. The Saharan Atlas is forested, with Phoenician juniper trees present. At higher altitudes, holm oak and Aleppo pine are found. The birdlife is represented by 25 species, all of which are listed as protected species. Mammals are represented by the Hare, the Wild Boar, the Jackal, the Fox, the Bustard, the Barbary sheep, the Dorcas gazelle.

The park represents a majestic sanctuary that must be saved: the Ksours mountains, in particular Tiout, contain around fifty rock engraving sites considered to be the first discoveries in the world, which risk being totally damaged.

- **Tassili National Park**

Created in 1972. In 1982, the famous prehistoric rock engravings earned it a place on the UNESCO World Heritage List and in 1986 it was classified as the first Saharan Biosphere Reserve by the MAB (Man and the Biosphere).

With an area of 80,000 km² The Tassili N'Ajjer National Park boasts a flora composed of species native to the African desert, the Mediterranean, and the tropics. Its endemism rate is 50%: the Tassili cypress, a fossil, and the Laperrine olive tree are among the species overexploited for timber, including the acacia and tamarisk, as well as plants like common reed (*Phragmites communis*). The fauna includes the Barbary sheep, Dorcas's gazelles (numerous in the large wadis of the Tassili), the endangered cheetah, the fennec fox, the addax, the sand cat, the spiny-tailed monkey, and the red fox. In the lakes, the fauna includes barbel and catfish. The birdlife includes the golden eagle, the long-legged buzzard, and the owl. This park represents the largest prehistoric open-air museum in the world. The diversity of fauna, flora,

and landscapes is linked to the contrast between arid and humid areas.

- **Ahaggar National Park**

Created by decree no. 87-231 of November 3, 1987. Proposed for inclusion on the UNESCO World Heritage List in 1988; it covers an area of 450,000 km². It is located in the far south of Algeria. It is part of the wilaya of Tamanrasset and has a checkpoint in Timiaouine in Adrar.

The vegetation is characterized by the coexistence of three types of flora:

A Mediterranean flora based on Olive, Myrtle, Lavender and Mugwort

A tropical flora based on Calotropis and Acacias

A Saharan flora based on Palm, Tamarix and Drinn.

Rock engravings and paintings attest to the abundance of fauna during the wet period: elephants, rhinoceroses, hippos, buffalo, giraffes, lions, and ostriches. Currently, the fauna is represented by the Barbary sheep, the fennec fox, the Dorcas gazelle, the red fox, the cheetah, the spiny rat, and the rock hyrax (an endangered species). Birdlife is represented by 91 species: the steppe eagle, the hen harrier, the black stork, the white stork, the pintail, the desert warbler, the Eurasian collared dove, and the short-toed eagle. Fish and reptiles can also be found there.

The Park is of considerable interest because it contains a vast reservoir of prehistoric sites dating from 600,000 to 1 million years ago, bearing witness to the earliest human manifestations. Among the most famous sites are: the Tafadest massif, the Immidir, the Hhnet, the engraving and painting sites of Tit-Aguenar-Silet, the Tassili du Hoggar, the Tassili Tin Missao, the Kasbah of Silet, the "Badjouda" Kasbah in Ain Salah, and the Tin Hinan monument in Abalessa.

B) Algeria's nature reserves

The Habibas Islands Marine Nature Reserves: Officially established by Executive Decree No. 3-147 of March 29, 2003, its area is 2,684 hectares off the Algerian coast, west of the Bay of Oran and Mersa El Kebir. Some plant species have an exclusively western distribution: *Withania frutescens* and *Lycium intricatum*, "Ibero-Moroccan" species, are characteristic of Algeria. The marine flora is represented by red algae (Florideophyceae: 64 species) and brown algae (Phaeophyceae: 24). The rarest species are Audouin's Gull, Eleonora's Falcon, and the European Shag. The majority of aquatic species are protected: Giant Limpet (*Patella ferginea*) and the noble pen shell (*Pinna nobilis*), the largest

mollusk in the Mediterranean. There are 7 species of rare birds protected by law; there is also a picturesque lighthouse built in 1879 at over 110 meters.

- **The Macta Nature Reserve**

Its objective is to protect and maintain the ecological balance of fauna and flora species threatened with extinction. Covering an area of 19,750 hectares, the Macta Marshes are located in northwestern Algeria, about twenty kilometers west of Mostaganem. They feature a homogeneous vegetation, primarily aquatic and halophytic. *Juncus acutus*, *Juncus maritimus*, *Juncus subulatus*, *Cyperus Laevigatus*, *Atriplex halimus*, *Salicornia fruticosa*, *Tamarix gallica*. This area is an attractive site for flamingos, glossy ibises, common teals, purple swamphens, and Bonelli's eagles. It should be noted that the mouth of the Macta River is rich in fish species.

- **The Babors Nature Reserve**

Its aim is to protect and restore endemic flora and fauna species. It has been the subject of discussions since 1930. It covers an area of 2,367 hectares and is located on the edge of the High Plateaus of the Setif region. Vegetation includes the only known site of the Algerian fir (*Salvia fir*) in Algeria, as well as cedar, holm oak (*Salvia holm*), and Numidian fir (*Salvia fir*). The fauna includes the Kabyle nuthatch, among others.

Mammals: Barbary macaque, jackal, fox, wild boar, weasel, hyena, mongoose, genet. At 1250-1300m altitude, reptiles are reported: two lizards have been identified, *Lacertasecula* and *Lacerta oscillata*. In 1975, Villiard discovered an endemic crab of the Babors: *Carabus marrothorax*, which overwinters under the snow; and grasshoppers.

- **The Mergueb Nature Reserve**

In 1979, the Mergueb area was transformed from a hunting reserve to a Nature Reserve. It covers 13,482 hectares and is located 55 km north of Bousaâda. Its landscape ranges from steppe to esparto grass. Lichens include *Psora decipens* and *Toninia coeruleon-nigricans*, *Salsola vermiculata* and *Artemesia campestris*, as well as Atlas pistachio and couch grass. Mammals include rare populations of Cuvier's gazelle, lynx, fennec fox, jackal, hare, and zorilla (a type of skunk with a foul odor). Birdlife includes the Houbara bustard, golden eagle, booted eagle, peregrine falcon, barn owl, little warbler, lanner falcon, grey heron, and goldfinch. Reptiles are represented by the Desert Monitor and the Spiny-

tailed Lizard. The reserve constitutes a unique steppe ecosystem.

- **The Béni-Salah Nature Reserve**

It is responsible for conserving and protecting the Barbary deer (*Cervus elaphus barbarus*). This is an endangered species. It was created in 1972/1973 by the forestry services of the Guelma wilaya in cooperation with Canadian technical assistance. It covers an area of 2000 hectares and is located northeast of the Bouchegouf district (Guelma wilaya) and south of the El Karma forest house. The altitude varies from 600 to 900 meters. Vegetation covers 95% of the total area and consists of cork oak, zeen oak, heather, eucalyptus, maritime pine, and cypress.

Demet in 1989, inventoried the existing mammals which are represented by the Barbary Deer, the Wild Boar, the Jackal, the Hyena, the Fox, the Weasel, the Hare, the Rabbit, the Hedgehog; The vegetation is characterized by cork oak and zeen oak forests which extend from Seybouse in the West to the Tunisian Border in the East.

3) Convention on Wetlands of International Importance

The Ramsar Convention, named after the Iranian town where it was adopted (December 21, 1973), ensures the protection of wetlands, particularly for birds. Ratified by 131 countries, it protects 1,150 sites covering 97 million hectares.

- **In Algeria**

There are 50 of them, and they cover an area of 2,991,013 hectares

- **In France**

There are 18 Ramsar sites, including "Grand Lieu Lake near Nantes, 6300 ha (the largest wintering site for waterfowl)."

The Camargue: This predominantly lacustrine region includes numerous marshes and ponds, the most important being the Etang du Vaccarès.

- **THE Camargue Regional Natural Park**

It is a regional natural park located in the south of France, in the west of the Provence-Alpes-Côte d'Azur region. It was created on September 25, 1970. It encompasses a large part of the Grande Camargue between the arms of the Rhône delta. Located in the Bouches-du-Rhône department, its area is 856.9 km². 2343 km² (sailor) Population 7,436 inhabitants.

1982 The Ministry of the Environment has created "Natural Areas of Ecological,

Faunistic and Floristic Interest" ZNIEFF: these areas do not benefit from any protection but must be taken into account in development projects.

Creation of the Natura 2000 network: it is from the application of the Council of Europe Birds Directive of 1981(1)

The Habitats Directive of the Council of Europe in 1992(2)

Objective: To provide member states with a common framework for action in support of the preservation of species and habitats at European level; it currently includes 1674 sites.

It consists of ZPS ((Special protection zone)

ZSC (special conservation area);

Two types of sites are involved: SPAs and SACs

ZPS: Special Protection Zone: (1) These are areas considered particularly important for bird conservation within the union, whether for breeding or birds, their diet, or their migration. Ensuring the good conservation status of threatened, vulnerable, or rare bird species

ZSC: Special Area of Conservation: (2) conservation of ecological sites

Natural or semi-natural habitats of community interest (rarity, ecological role)

Species of fauna and flora of community interest (rarity, symbolic value, role in the ecosystem)

➤ Procedure

Each state inventories potential sites within its territory

Submission of proposals to the European Commission in the form of PSICs (Proposals for Sites of Community Interest)

After approval, the PSIC is registered as a SCI for the European Union and is integrated into the Natura 2000 Network.

A ministerial decree designates the site as a ZSC (Zone of Special Conservation Areas).

• Natura 2000 at sea

Each Member State with a coastline must designate a coherent network of natural habitats and species of Community interest present in the maritime area before 2008. The European Commission has published a guide, "Guide to the application of Natura 2000 at sea," which specifies the legal and political aspects (Water Framework Directive), (European Maritime Policy).

- **Human-induced causes**

The current factors contributing to biodiversity loss are linked to human activities.

Habitat modification,

The overexploitation of natural resources,

pollution, both local and global (pollution of groundwater, seas and oceans, industrial discharges, etc.),

Invasive alien species

climate change.

III.5 Alarming scenario: Population growth in the coming decades

An increasing consumption of resources;

Greater occupation of space, therefore fragmentation of habitats;

Human negligence;

Aggression towards nature;

Ignorance of the value of biodiversity;

Development of activities based on the exploitation of natural resources;

Inadequate policies to combat biodiversity loss;

Poverty: When you're hungry, you don't worry about preservation.

Corruption: a phenomenon fairly well shared by all countries;

The race for profit short term, for example, marine fisheries which are heading towards extinction;

Economic incentives of the subsidy type. If we want to combat the erosion of biodiversity, we must address these root causes.

III.5.1 Solution: Sustainable development

Reduce pollution, - reduce waste, - better manage and better distribute natural resources, etc.

The erosion of biodiversity is linked to human activities.

We need to find ways to remedy this.

-in the behavior of societies: value systems,
economic systems

Existing political systems, in terms of development options.

How to maintain natural capital?

III. 5.2. Indicators of biodiversity loss

WWF Living Planet Index: World Wide Fund (World Wide Fund for Nature 1961:

NGO (Switzerland). This indicator measures the status of 1686 vertebrate species across 5000 populations worldwide.

It reflects the state of the planet's ecosystems.

III.5.3. Monitoring the application of international and national regulations

Scientific study for diagnosis or proposal;

Restoration of degraded natural areas

Training, education, or raising awareness about the environment for all audiences of all ages

III.6. IUCN Red List

Objective: To alert the public, planners, and policymakers to the scale of the extinction risk facing numerous species and the urgent need to develop conservation policies. This list of endangered species is regularly updated and exists at the international, national, and even regional levels. It details the status of more than 65,000 species out of the 1.8 million known species and constitutes the most comprehensive global inventory of the conservation status of animal and plant species.

III.7. Hot spot

This term designates regions that meet two strict criteria: they contain at least 1,500 endemic vascular plant species (more than 0.5% of the world total), and have lost at least 70% of their natural habitat. These threatened biodiversity hotspots represent 50% of the species recorded to date.

III.8. The Living Planet Index

The Living Planet Index (LPI) is an indicator of the state of global biodiversity: it measures trends in vertebrate populations living in terrestrial, freshwater and marine ecosystems worldwide.

Includes terrestrial species (1100 species) from ecosystems other than forests: grasslands, savannas, deserts and tundras.

III.9. Ecological Footprint

On a global scale, it measures humanity's demand on the biosphere in terms of "biologically productive land and sea areas" needed to provide the resources we use and absorb the waste we produce. It is calculated by country. On average, at the global level,

Demand per person in 2005 was 2.7 hectares, exceeding the land's biological

capacity.

III.10. Desertification threatens biological diversity

- Land degradation transforms fertile soils into deserts that are no longer arable.
- Organisms that cannot adapt to these hostile living conditions will not survive

To ensure the balance of arid ecosystems, it is important to maintain a wide diversity of species.

The adaptations of animals and plants to live in arid environments are determined by their genetic characteristics, which have evolved over centuries.

- The coexistence of plants and animals adapted to their ecosystem is the foundation of a balance that allows life in arid environments and provides essential resources to the populations that depend on them.

- The rapidity of the desertification process means that organisms are unable to keep up with these rapid changes.

III.11. The consequences of desertification on the environment

- a loss of nutrients (due to agricultural overexploitation);

a loss of surface soils due to rain and wind erosion (especially due to the disappearance of vegetation)

Landslides caused by water (especially due to the disappearance of vegetation)

- soil salinization or acidification (due to improper irrigation)

➤ Combating biodiversity loss and desertification

- Global awareness of the problem of desertification

- United Nations Convention to Combat Desertification (UNCCD) resulting from the Rio 1992 summit (Brazil) but adopted in 1994 in Paris by 172 countries.

- Focus action on Africa, the continent most affected by drought and desertification in partnership with other countries of the world.

- Promoting access to new technologies and exchanging knowledge and know-how among populations to mitigate the effects of drought and combat desertification.

III.12. These technological tools include

A) Remote sensing

To provide general overviews of the state of vegetation in a region and to quickly obtain information

The same work carried out by observers at ground level would be very time-consuming and much more expensive.

-Continuously monitor and observe changes: degradation, reforestation, etc.
Taking photographs over several years allows us to understand the evolution of vegetation and to make decisions about which crops to favor or avoid in case of drought.

B) GIS (Geographic Information System)

In order to produce maps, charts, and virtual images.

The objective: Quickly and comprehensively present the characteristics of a region: evolution of drought, rainfall, temperature, water availability, human settlements (villages, camps), infrastructure (tracks, roads).

C) Concrete methods to combat desertification

Fertilize the soils to restore them

Fighting against the wind, reforestation, prohibiting livestock from grazing in this planted area to protect it;

Do not deplete the land (When carrying capacity is exceeded, productivity decreases);

Diversify production (A plot of land can support different types of plants for very long periods)

Use renewable energies (solar, wind or biogas);

Rehabilitating new knowledge with new agricultural practices.

III. 13. Management of genetic resources of wild and domesticated populations

Livestock biodiversity is essential for food security. These animals provide meat, milk, eggs, fiber, hides, manure for use as fertilizer or fuel, and a range of products and services.

Domesticated animals also contribute to the ecosystems in which they exist, providing services such as seed dispersal and nutrient recycling.

Livestock exposed to extreme climatic conditions acquire adaptive characteristics that help them survive. They adapt locally and gradually become resistant to diseases and parasites. Natural selection plays a role, but today's breeds with their unique gene combinations would not have appeared without active and continuous management and selection by settled farmers and nomadic herders since the first livestock species were domesticated 12,000 years ago (27).

- **Maintaining the gene pool of livestock**

A real challenge. Establishing and maintaining animal gene banks is more

expensive than maintaining gene banks for cultivated plants. Conserving animal genetic heritage requires materials, equipment, skilled personnel, and a constant energy supply. In reality, however, gene banks should primarily serve as a safety net to maintain animal breeds within the production systems in which they were developed. The general aim should be to encourage the long-term, sustainable use and development of livestock breeds thus meeting the economic and social needs of farmers and minimizing pressures on the environment and natural resources while preserving genetic options for the future. However, there are constraints to overcome, given that:

Knowledge is still insufficient regarding the characteristics of many species of the world, including their geographical distribution and population sizes;

Few countries have implemented conservation programs for their endangered species or structured breeding programs that would improve productivity and quality and allow the continued use of animal breeds;

Policies and laws relating to the livestock sector rarely take into account the sustainable management of genetic resources, let alone the need to provide them with sufficient support; in fact, they sometimes discourage the maintenance of genetic diversity.

Without concerted action, there are few possibilities of achieving the conservation, sustainable use and enhancement of animal genetic resources (27).

III.14. Genetic erosion: Counting the losses

Despite their considerable potential contribution to sustainable development and the reduction of hunger and poverty, animal genetic resources for food and agriculture are underutilized and under conserved. Of the 7,600 animal breeds reported to FAO by its Member States, more than 1,500 are threatened with extinction or have already disappeared.

In the last few years of this century, more than 60 breeds almost one per month have disappeared forever, taking their unique genetic characteristics with them. Losing these breeds is like losing a global insurance policy against threats to food security. It undermines the ability to adapt livestock populations to ecological changes, emerging diseases and changes in consumer demands.

III.15. The Commission on Genetic Resources for Food and Agriculture: The time to act

In 2007, the FAO published *The State of Animal Genetic Resources for Food and Agriculture in the World*, the first global assessment of the status and trends of animal genetic resources. This is an authoritative reference for planning management plans.

A) Historical

Late 1990s: The drafting of *The State of Animal Genetic Resources for Food and Agriculture in the World* began when the Commission on Genetic Resources for Food and Agriculture requested that FAO coordinate a country-led assessment of animal genetic resources. At that time, the Commission also established a subsidiary intergovernmental technical working group on animal genetic resources for food and agriculture.

In 2005; 169 countries submitted reports which, together with those prepared by international organizations and contributions from renowned scientists and experts, formed the basis of the publication. The final report was presented at the International Technical Conference on Animal Genetic Resources for Food and Agriculture, held in September 2007 in Interlaken, Switzerland. The FAO Conference, the governing body,

The FAO's sovereign, welcomed this report which represents the first comprehensive global assessment of the state of animal genetic resources.

The Interlaken Conference also adopted a Global Action Plan for Animal Genetic Resources, for the improved management of animal breed diversity. This Global Action Plan contains strategic priorities for the sustainable use, development and conservation of animal genetic resources, as well as provisions for financing its implementation and monitoring.

At the national level, governments will need to assess the capacity of existing institutions to manage animal breed conservation and selection programs, and to adapt policies as needed to strengthen their capacities.

At the global level, the Commission has been tasked with overseeing and evaluating the implementation of implementation of the Global Action Plan and to define the financing strategy for its implementation.

A new era of cooperative participation will require the mobilization of financial resources, the strengthening of international networks, particularly

at the regional level, the promotion of the development and transfer of relevant technologies, and measures that can give new impetus to training and capacity-building activities worldwide.

Guidelines for national action plans and for the management of animal genetic resources are now available to countries, and further technical guidelines are being developed. These are some of the many challenges that the Commission will address over the next decade with the help of its multiannual work programmed.

III.16. Socio-economic aspects of the conservation and management of biological resources

- The benefits of biodiversity: Values and uses
- Genetic resources: The Convention on Biological Diversity defines genetic resources as genetic material of animal or plant origin.

or microbial, containing functional units of heredity and having actual or potential value.

For animals, this includes wild populations, standardized breeds, and selected lines or strains.

For plants, it includes old or modern cultivated varieties, local cultivars, and wild or related forms. For microbes: strains, isolates, populations, and microbial communities.

Food use of living resources: Harvesting from the natural environment (gathering, fishing) is a very ancient practice. Wild and semi-wild plants (leaves, roots, tubers, fruits, fungi, etc.) contribute to the food security and health of rural populations who live from subsistence farming. Some tropical societies consume invertebrates: caterpillars, molluscs,

Several vertebrate species are hunted (for their meat (mammals, continental reptiles, birds). Fishing at sea or in waters is the main source of protein in the world.

The products of extractivism: This term refers to the commercial exploitation of non-timber forest products: fruits, gums, resins, oils, and fibers. Cotton, flax, wool, silk, and rubber (extracted from the rubber tree, lianas, and euphorbias) also come from plants and animals. All these products are still used despite competition from synthetic products.

The wood: the timber trade is an important activity at the level Internationally; forests represent 3.4 billion hectares of the Earth's land surface. Wood is used for domestic purposes (firewood), construction, and in industry (paper pulp). Overexploitation of these resources has led to their degradation.

III.17. The industrial prospects of biotechnology

The industry is interested in certain elements of biodiversity: microorganisms, genes and molecules.

Industrial microbiology uses the enzymatic and metabolic capabilities of microorganisms for two types of transformation:

Fermentation: (Brewery, cheese factory)

The production or modification of various molecules (antibiotics, hormones, flavorings, etc.); As early as 1970, bacteria were genetically modified to synthesize molecules such as insulin, erythropoietin which stimulates the production of red blood cells, etc.

Biofuels: Biofuels (plant-based fuels intended to partially replace petroleum-derived fuels, whose reserves are rapidly dwindling) are produced from oilseed crops such as rapeseed or sunflower, or from alcohol obtained by fermenting sugar beets. In Brazil, two-thirds of cars run on alcohol, but with a modified engine.

Animals and ornamental plants: Today, the number of plant species cultivated for ornamental purposes is greater than the number of plants used for agricultural purposes, and new hybrid species are the subject of constant innovation and are regularly marketed. On the other hand, the trade in animals is significant (for zoos, aquariums, and research). Certain products, such as ivory, tortoiseshell, snake or crocodile skins, furs, and bird feathers, have multiple uses: decorative, symbolic, clothing, or cultural, and their trade has endangered the survival of several species.

Annual withdrawals are estimated at 100 million tonnes and are close to acceptable limits so

that resource renewal is not compromised.

- **Ecotourism:** It has become a new industry. The promotion of biodiversity through wildlife observation is a source of income for some countries that have developed a tourism policy based on showcasing their natural heritage: national parks and trekking (trekking has also become a particularly important source of income for a portion of the local population (guides, porters, muleteers, drivers, hotel owners, cooks, etc.), however, it is also responsible for certain ecological problems (trampling, fires).

- Research, education and surveillance: Much remains to be learned about how to best utilize biological resources, how to maintain the genetic base of harvested biological resources, and how to rehabilitate ecosystems.

Natural areas provide excellent living laboratories for such studies, and for other valuable research in ecology.

III.18. Biodiversity maintains the integrity of the environment through

Biological nitrogen fixation Nitrogen is the most important building block for plants after carbon. This additional nitrogen comes from the biological fixation of atmospheric nitrogen (N^2) by prokaryotes, which allows its introduction into the biosphere. There are two groups of bacteria:

the group of Rhizobiums associated with legumes (Papilionaceae, Mimosaceae, Caesalpinaceae);

Frankias, filamentous spore-forming bacteria (actinomycetes) associated with trees of the genera *Alnus*, *Casuarina*.

Mineralization of organic matter: *Prokaryotes* play a fundamental role in biogeochemical cycles by decomposing detrital organic matter to release inorganic elements that will be used to synthesize new organic molecules.

Maintaining CO_2/O_2 balance It is through biodiversity that this balance (of CO_2 and O_2 is maintained).

Absorption and decomposition of pollutants and waste: In trophic networks and food chains where the flow of energy passes through production, consumption and decomposition.

Without biodiversity, there is no healthy environment for humans:

It is man's primary source of medicine and food

Reduces the risk of pandemics

Reduces the risk of natural disasters (fires, floods, erosion)

Purifies water, air and soil (28). The economy is dependent on biodiversity

Primary production is entirely dependent

Secondary production is highly dependent; many industrial processes require the use of organisms or transform products derived from living organisms.

Tertiary production, like other productions, depends on the environmental services of biodiversity in terms of energy and purification of the environment.

III.19. Biodiversity is a source of social development

Biodiversity is a source of social development because it creates jobs directly and indirectly in sectors such as agriculture, fisheries, forestry, ecotourism, and natural resource management. It also supports public health by providing medicinal resources, cleaner ecosystems, and restorative spaces that help people recover physically and mentally.

In addition, biodiversity strengthens social well-being by improving food security, water quality, and the resilience of communities to environmental change. By maintaining healthy ecosystems, it contributes to better living conditions and long-term human development.

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