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DEPARTMENT OF NATURAL AND LIFE SCIENCES



Course

General Biodiversity

Intended for

L3 Biology and Ecology of Aquatic Environments students

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Foreword

Biodiversity encompasses all living organisms and the ecosystems that host them, as well as the complex interactions that connect them. It is both the result of a long evolutionary process and a key factor in maintaining the ecological balance of our planet. Understanding biodiversity, its components, and the threats it faces is now a major challenge for the conservation of ecosystems and the sustainable management of natural resources.

This **general biodiversity** handbook aims to provide a comprehensive overview of the fundamental concepts related to biological diversity. It explores the different levels of biodiversity (genetic, species, and ecosystem diversity), the evolutionary mechanisms that shape it, and the main anthropogenic pressures contributing to its decline. By highlighting the importance of biodiversity in ecological balance and ecosystem services, this document serves as an educational tool to raise awareness about the necessity of its conservation.

Designed for students, researchers, and environmental science enthusiasts, this material provides a foundation for reflection and learning. It is based on recent scientific data and concrete examples to illustrate both the richness and fragility of life on Earth.

May this handbook serve as a resource to better understand the complexity of the living world and encourage a more responsible and respectful approach to nature.

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Subject 2: General Biodiversity

Credits: 2

Coefficient: 1

Course Objectives

This module aims to provide knowledge about the history of biodiversity, its distribution, and the factors that maintain its balance.

Recommended Prerequisites

Students should have prior knowledge of ecology and general biology.

Course Content:

1. **Definitions.**
2. **Origin of Life and Evolution of the Cell and Metabolism.**
3. **History of Biodiversity.**
 - A. Paleobiocenosis.
 - B. Mass Extinctions and Adaptive Radiations.
4. **Biogeography and Phytogeography.**
 - A. Definition of Biogeographical Regions.
 - B. Biodiversity of the Mediterranean Basin (Fauna and Flora).
5. **Biogeographical Dynamics.**
 - A. Functioning, Structure, and Assembly of Biocenoses.
6. **Eco-diversity (Example of Ecosystems).**
7. **Population Genetics.**
 - A. Definition.
 - B. Hardy-Weinberg Equilibrium Law and Gene Frequency Calculations.
 - C. Factors Affecting the Hardy-Weinberg Equilibrium (Evolutionary Factors).
 - D. Applications.

Assessment Method:

Continuous assessment (quizzes, reports) and semester examination.

Bibliographic References:

- *Biodiversity: Preserve Everything or Exploit Everything* (1997). De Book.
- *Evolution* (2003). EDP Science.
- *Biodiversity and Environment*.
- *Biodiversity*.
- *Biodiversity and Ownership: The Question of Property Rights*.

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COURSE 01. CONCEPT OF BIODIVERSITY

1. Definition and Concept of Biodiversity

1.1. History of the Biodiversity Concept

The term biodiversity, synonymous with biological diversity, is a neologism that emerged in the early 1980s within the IUCN (International Union for Conservation of Nature). However, its widespread use only began following the Rio Conference on Environment and Development organized by the United Nations in 1992, which marked a major turning point in raising awareness of the issues related to natural heritage.

The expression biological diversity was coined by Thomas Lovejoy (an American biologist specializing in the Amazon) in 1980, while the term biodiversity itself was introduced by Walter G. Rosen (an American biologist) in 1985 during the preparation of the first American forum on biological diversity, which was held the following year.

The word "biodiversity" first appeared and was popularized in 1988 by entomology professor Edward O. Wilson during the publication of the proceedings of this forum and through his book "Biodiversity." He provided the following definition: "It is the totality of all variations of all living things." The term biodiversity was considered more effective in terms of communication than biological diversity.

Since 1986, the term and concept have been widely used among biologists, ecologists, environmentalists, policymakers, and citizens. The use of the term coincided with growing awareness of species extinction over the last decades of the 20th century.

In June 1992, the Earth Summit in Rio de Janeiro marked the strong emergence of concerns and interests regarding the diversity of the living world on the international stage. During the Convention on Biological Diversity, which took place on June 5, 1992, biological diversity was defined as:

"The variability of living organisms from all sources, including, among others, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems."

1.2. Definition of Biodiversity

In its simplest form, biodiversity represents life on Earth. Ramade (1993) defines biodiversity as the variety of living species that populate the biosphere. In the broadest sense, biodiversity is measured by the total number of living species found in all terrestrial and aquatic ecosystems currently existing on the planet.

According to Fontaubert et al. (1996), biodiversity is defined as the variability of living organisms of all origins, including, among others, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part.

Levêque and Mounolou (2001) define biodiversity as "useful nature," meaning all species or genes that humans utilize, whether from natural environments or domestication. More specifically, biodiversity represents the dynamic interactions within changing environments. This concept includes the variety of life forms such as plants, animals, and microorganisms, the genes they contain, and the ecosystems they form.

In agriculture, biodiversity has been greatly enriched by humans through the domestication of wild species since prehistoric times. Humans have created plant varieties and extensively modified landscapes. They have continuously improved the genetic

expression of cultivated plants for various uses. The genetic heritage of plants is preserved in seeds, which transmit this biodiversity (GNIS, 2006).

1.3. Levels of Biodiversity

Specifically, the term "biodiversity" refers to variety at three levels:

- **Genetic Diversity:** Defined by the variability of genes within a species or population. It is characterized by differences between individuals of the same species or subspecies (intraspecific diversity).

- **Species Diversity:** Refers to the diversity of species (interspecific diversity). It includes all species on Earth, including plants, animals, fungi, algae, and microorganisms such as palm trees, elephants, or bacteria.

- **Ecosystem Diversity:** Corresponds to the diversity of ecosystems present on Earth, such as tropical or temperate forests, hot or cold deserts, wetlands, rivers, mountains, coral reefs, etc. Each ecosystem represents a series of complex relationships between biotic (living) elements and abiotic (non-living) elements such as sunlight, air, water, and nutrients.

2. Role of Biodiversity in Ecosystem Functioning

Each species has its place within the ecosystem and plays a role in maintaining ecosystem balance.

The more species an ecosystem contains, the more diverse it is. Consequently, it becomes more resilient to species loss due to human impact.

Species interact at various levels within ecosystems. The most commonly cited example is the food chain (primary producers, primary consumers, secondary consumers,

and decomposers), but other interactions also exist, such as predation and parasitism. Additionally, soil microorganisms play an essential role in recycling organic matter.

3. Ecosystem Services

The Millennium Ecosystem Assessment, published in 2005, significantly contributed to the dissemination of the concept of ecosystem services, emphasizing a utilitarian perspective on biodiversity. It identifies four types of services that ecosystems provide to humans:

By definition, ecosystem services are the benefits that humans derive from ecosystems. These benefits contribute to the well-being of human societies. The four types of ecosystem services are:

- **Provisioning Services:** These include the supply of products derived from ecosystems, such as food, water, wood, and medicinal plants.
- **Regulating Services:** Benefits obtained from the regulation of ecosystem processes, such as climate regulation, disease control, and water purification.
- **Cultural Services:** Non-material benefits, including recreational, spiritual, and aesthetic values.
- **Supporting Services:** Services necessary for the production of all other ecosystem services, such as primary production and soil formation.

In 1992, Lévêque and Glachant described several values of biodiversity:

1. **The use value**, which can be divided into three subcategories:
 - **Consumption value:** This involves the direct consumption of resources without transformation. Examples include gathering, hunting, and fishing.

- **Productive value:** Genetic resources are used in productive cycles. Examples include plant-based medicines or forest exploitation for timber.
 - **Recreational value:** Biodiversity is utilized for leisure without being harvested for consumption, such as nature walks.
2. **Ecological value** refers to the role of organisms in ensuring the proper functioning of ecosystems and the sustainability of the biosphere.
 3. **Option value** represents the potential for future exploitation of genetic resources in different ways.
 4. **Existence value** is linked to the satisfaction and well-being derived from the mere existence of biodiversity.

4. Why is biodiversity so important?

Ecosystems rely on the combined contributions of each organism they host. The loss of any species can disrupt their functioning. An ecosystem with high biodiversity is more resilient to environmental changes.

- According to the IUCN Red List: 41% of amphibian species, 33% of coral reefs, 25% of mammals, 20% of plants, and 13% of birds are threatened.
- Nearly 60% of the services provided by ecosystems are at risk (MEA, 2005).

Current species extinction rate: 100 to 1,000 times higher than the average extinction rate since the emergence of life on Earth (6th mass extinction).

5. Why is biodiversity declining?

According to the UN, five major factors accelerate biodiversity loss:

1. **Habitat destruction and degradation**, caused by:
 - Agriculture (intensification, land abandonment, drainage, irrigation)

- Forestry (intensive exploitation, monoculture reforestation)
 - Industrial fishing and aquaculture
 - Infrastructure construction and urbanization (habitat fragmentation)
 - Tourism and industrial developments
2. **Overexploitation of wild biological resources** (hunting, fishing, gathering, logging) at unsustainable rates that exceed their natural renewal capacity.
 3. **Pollution**, including:
 - Eutrophication of aquatic environments
 - Deposition of atmospheric nitrogen oxides on vegetation
 - Soil acidification
 - Pesticides and heavy metals contamination
 4. **Introduction of invasive alien species**, which disrupt native ecosystems and outcompete local species.
 5. **Climate change**, leading to:
 - Rising temperatures
 - Species migration
 - Coral bleaching
 - Structural and functional modifications of ecosystems
 - Threats to vulnerable species

6. Origin of Life and Evolution of Cells and Metabolism

The origin of life and the evolution of cells and metabolism are fundamental topics in biology. From the earliest hypotheses about the formation of organic molecules to the emergence of the first cells and the development of complex metabolic pathways, various theories and experiments have attempted to explain these processes. This section explores the main hypotheses on the origin of life, the transition from prebiotic structures to the first cells, and the evolution of cellular metabolism.

6.1. The Origin of Life: Hypotheses and Experiments

One of the most widely recognized theories regarding the origin of life is the **primordial soup hypothesis**, proposed by Oparin and Haldane in the 1920s. This hypothesis suggests that the first organic molecules formed in the primitive ocean under the influence of energy from lightning and ultraviolet radiation. This idea was tested in the **Miller-Urey experiment** (1953), which demonstrated that amino acids could be synthesized under conditions simulating those of early Earth (Miller & Urey, 1953).

Other hypotheses include the **hydrothermal vent theory**, which suggests that life emerged in the deep ocean near hydrothermal vents rich in minerals and chemical compounds that promoted prebiotic reactions (Russell & Hall, 1997). Another possibility is the **panspermia theory**, which proposes that life may have an extraterrestrial origin and was brought to Earth via meteorites (Chyba & Sagan, 1992).

6.2. The Emergence of the First Cells

The first living structures were likely **protocells**, microscopic lipid-bound structures capable of containing organic molecules. Experiments have shown that lipid vesicles can spontaneously form and encapsulate biomolecules, potentially leading to the first living cells (Szostak et al., 2001).

RNA is often considered the first genetic molecule, according to the **RNA world hypothesis**. This theory suggests that RNA played a dual role, serving both as a carrier of genetic information and as an enzymatic catalyst (Joyce, 2002). Over time, the more stable **DNA** took over as the primary genetic material, while proteins replaced RNA in many enzymatic functions.

6.3. The Evolution of Cellular Metabolism

The emergence of the first cells marked the beginning of **metabolic evolution**. It is believed that the earliest cells were **heterotrophic**, using organic molecules from their environment to produce energy. However, as these molecules became scarce, more autonomous metabolic pathways emerged.

Fermentation was one of the first energy production mechanisms, allowing cells to metabolize organic molecules in the absence of oxygen (Fenchel, 2005). Later, some bacteria developed **anoxygenic photosynthesis**, a process that uses light to produce energy without releasing oxygen (Blankenship, 2010).

The evolution of **oxygenic photosynthesis**, primarily in **cyanobacteria**, dramatically transformed Earth's atmosphere by producing molecular oxygen (O₂), leading to the **Great Oxidation Event** around 2.4 billion years ago (Lyons et al., 2014). This increase in atmospheric oxygen enabled the development of **aerobic respiration**, a much more efficient metabolic pathway that generates large amounts of ATP per glucose molecule oxidized.

6.4. From Prokaryotic to Eukaryotic Cells

A major turning point in cellular evolution was the emergence of **eukaryotic cells**, which contain compartmentalized organelles, unlike prokaryotes. The **endosymbiosis theory**, proposed by **Lynn Margulis** (1970), explains that mitochondria and chloroplasts were originally free-living bacteria that were integrated into a host cell. This symbiotic relationship significantly enhanced the energy efficiency of eukaryotic cells.

The evolution of **multicellularity** then allowed for the development of complex organisms, enabling cellular specialization and the diversification of life forms.

COURSE 02. FACTORS AFFECTING BIODIVERSITY VARIATION

1. Factors Affecting Biodiversity Variation

There are considerable variations in the total richness of populations and biocenoses, as numerous ecological factors and other environmental parameters can influence the composition of a community.

Ecological factors can be classified into two categories: **abiotic factors** and **biotic factors**.

1.1. Abiotic Ecological Factors

Biodiversity, in its structure and distribution at all spatial scales, depends on the non-biological characteristics of habitats:

Climatic Characteristics

- Precipitation
- Water availability
- Temperature
- Seasonality or lack thereof

Edaphic and Geological Characteristics

- Soil structure
- Altitude

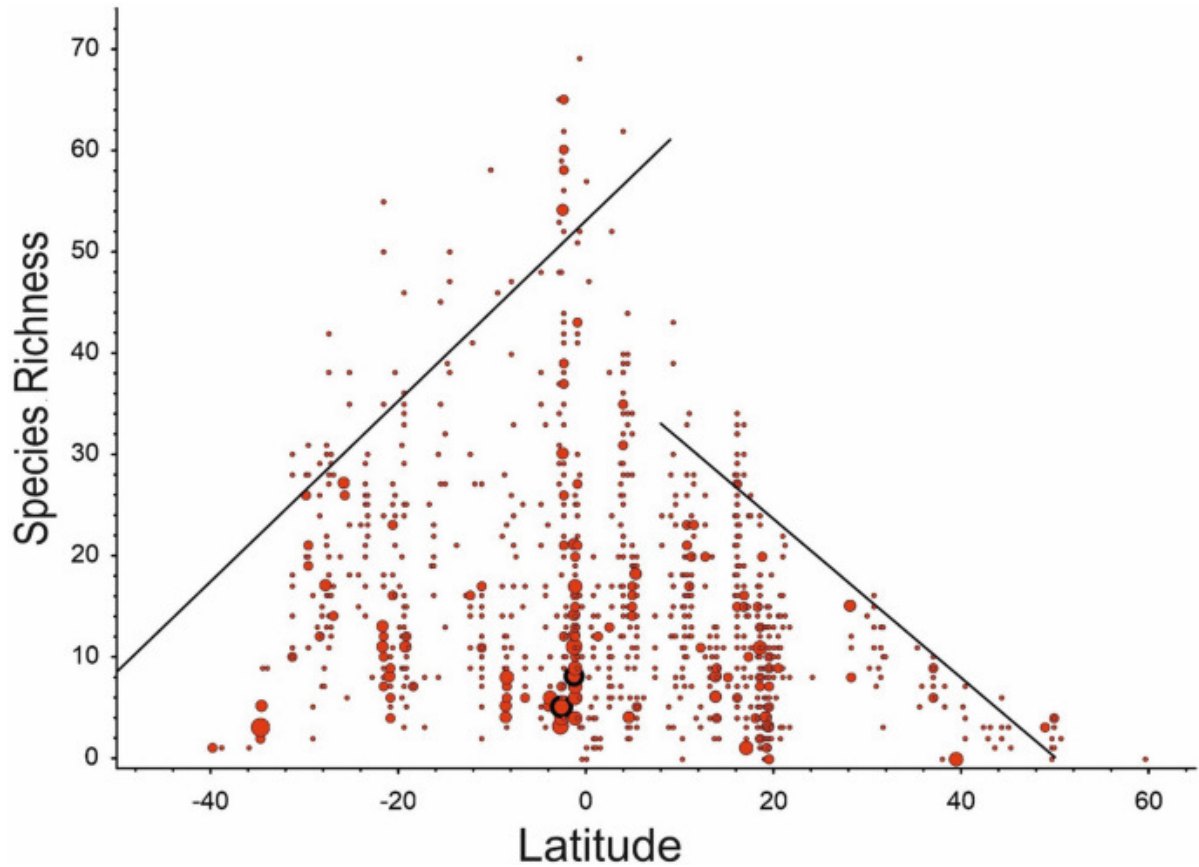


Figure 01. Relationship between Biodiversity and latitude. Illustrations of the Importance of Latitude (a Parameter on Which Climate Depends): In general, the closer one gets to the equator, the greater the biodiversity. (*According to DAJOZ, 2006*).

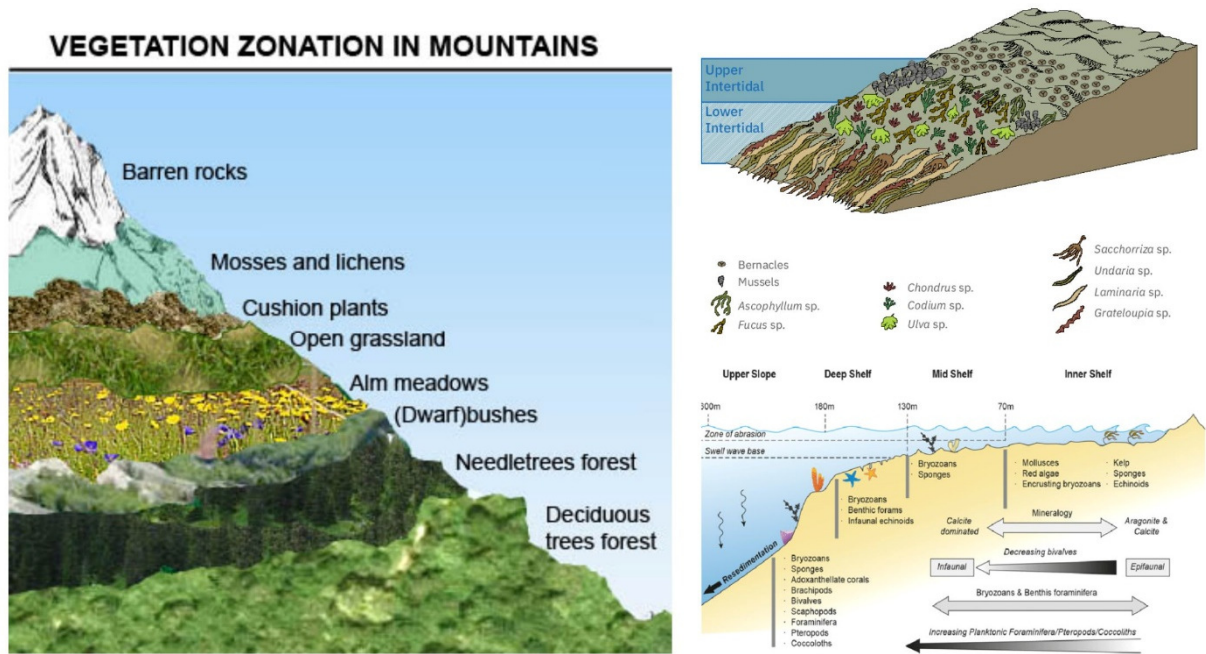


Figure 02. Role of altitude in structuring mountain species assemblages: an example of the zonation of botanical formations According to RICHARD *et al.* (2012)

1.2. Biological Factors: Intraspecific and Interspecific Interactions

At all time scales (short-term or geological), living organisms interact with individuals of the same species as well as those of other species. These interactions can either benefit or harm organisms, leading to:

- The expansion or extinction of a genotype, [*modification of genetic biodiversity*]
- The persistence or disappearance of a species, [*modification of species biodiversity*]

- A modification of species assemblages and the relationships between them, leading to changes in ecosystems, [*modification of ecosystem biodiversity*]

Intraspecific Relationships:

- Competition for resources
- Sexual competition
- Cooperation
- Reproductive behaviors

Interspecific Relationships:

- Predation
- Symbiosis and other mutualisms
- Parasitism
- Commensalism
- Competition, etc.

2. Biodiversity Assessment (Quantitative, Qualitative, and Economic Evaluation)**2.1. Quantification of Ecosystem Services**

Quantification measures the contribution of different types of ecosystems to human well-being. It involves using indicators to quantify the services provided and/or the benefits received by humans by assessing the contribution of each ecosystem type.

The economic evaluation of ecosystem services is an economic tool designed to quantify the benefits provided by an ecosystem (most often in monetary units). This is a key aspect of the economic valuation of biodiversity. It primarily serves the need to use

economic language to support the preservation of nature and biodiversity and to better integrate environmental considerations into economic dynamics.

Ecosystem services are the benefits humans derive from ecosystems (provisioning, regulating, cultural, and supporting services). The economic evaluation of these services emerged in the early 1970s. The debate that initially took place between environmental economists and ecologists has now expanded to a larger scale, encompassing the economics of nature, biodiversity, and ecosystem services.

As illustrated by the pyramid in **Figure 03**, one of the challenges of economic evaluation lies in the lack of knowledge, which limits the assessment to only a portion of the full range of environmental services. Thus, as one moves toward the top of the pyramid, less information is available on the benefits derived from ecosystem goods and services. This lack of information is represented by the *gray area* of "unspecified benefits."

Additionally, the pyramid highlights the necessity of conducting both **quantitative and qualitative analyses** of environmental services, in addition to monetary evaluation, since some of these services provide **indirect benefits** that are not directly traded in the market.

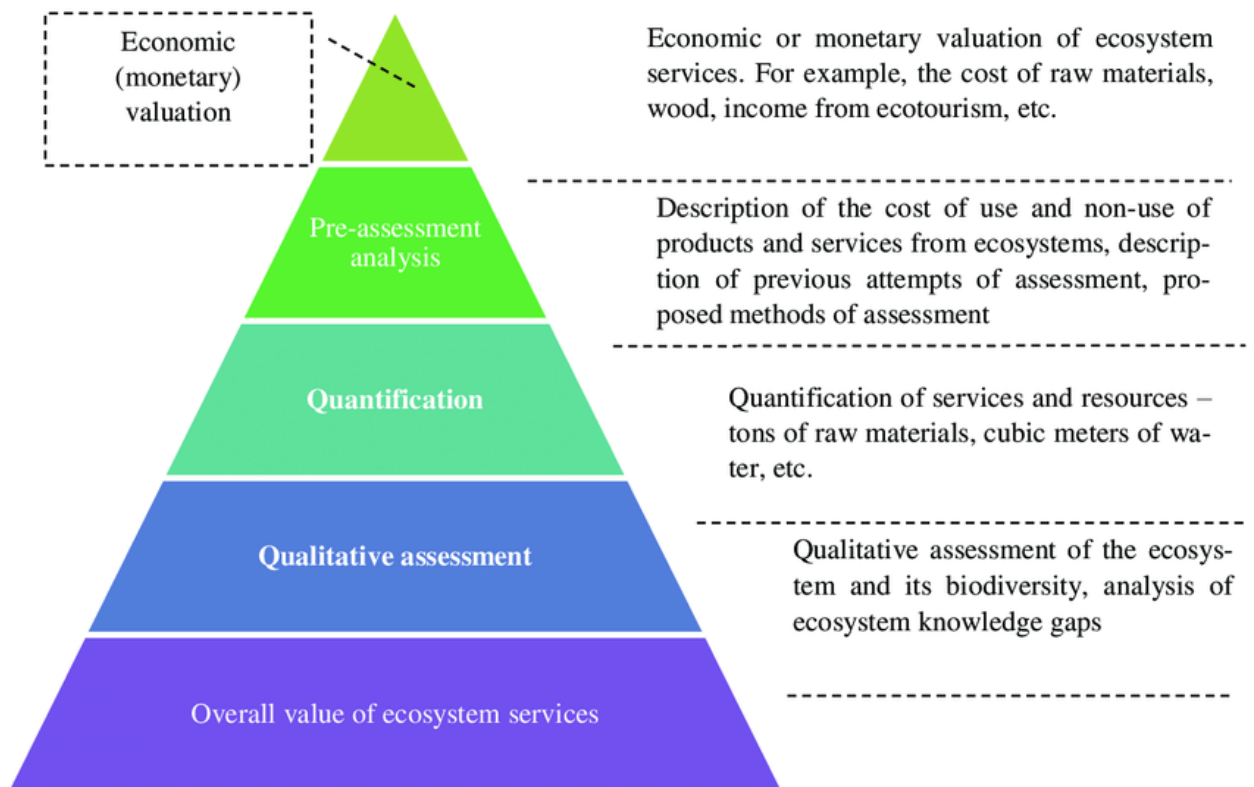


Figure 03: Evaluation of Ecosystem Services.

2.2. Total Economic Value (TEV)

Total Economic Value (TEV) is the most widely used economic analysis framework for the economic evaluation of ecosystem services (ES). Monetary evaluation methods assess one service at a time, which can then be summed to obtain a TEV. The economic importance of ecosystems can be highlighted through monetary assessments by using the concept of Total Economic Value (TEV), which generally includes:

- **Use values** (direct use value, indirect use value, option value):
 - **Direct use value:** Derived from goods that can be consumed or directly enjoyed (e.g., construction materials, food, energy resources, etc.).
 - **Indirect use value:** Refers to the regulatory services provided by ecosystems (e.g., air or water purification, flood protection, etc.).
 - **Option value:** Related to the aforementioned direct and indirect use values but represents the attachment to the possibility of benefiting from them in the future.
- **Non-use values** (bequest value and existence value):
 - **Bequest value:** The possibility of passing on the various values associated with ecosystems to future generations.
 - **Existence value:** Derived from the mere knowledge of the existence of living systems or their components.

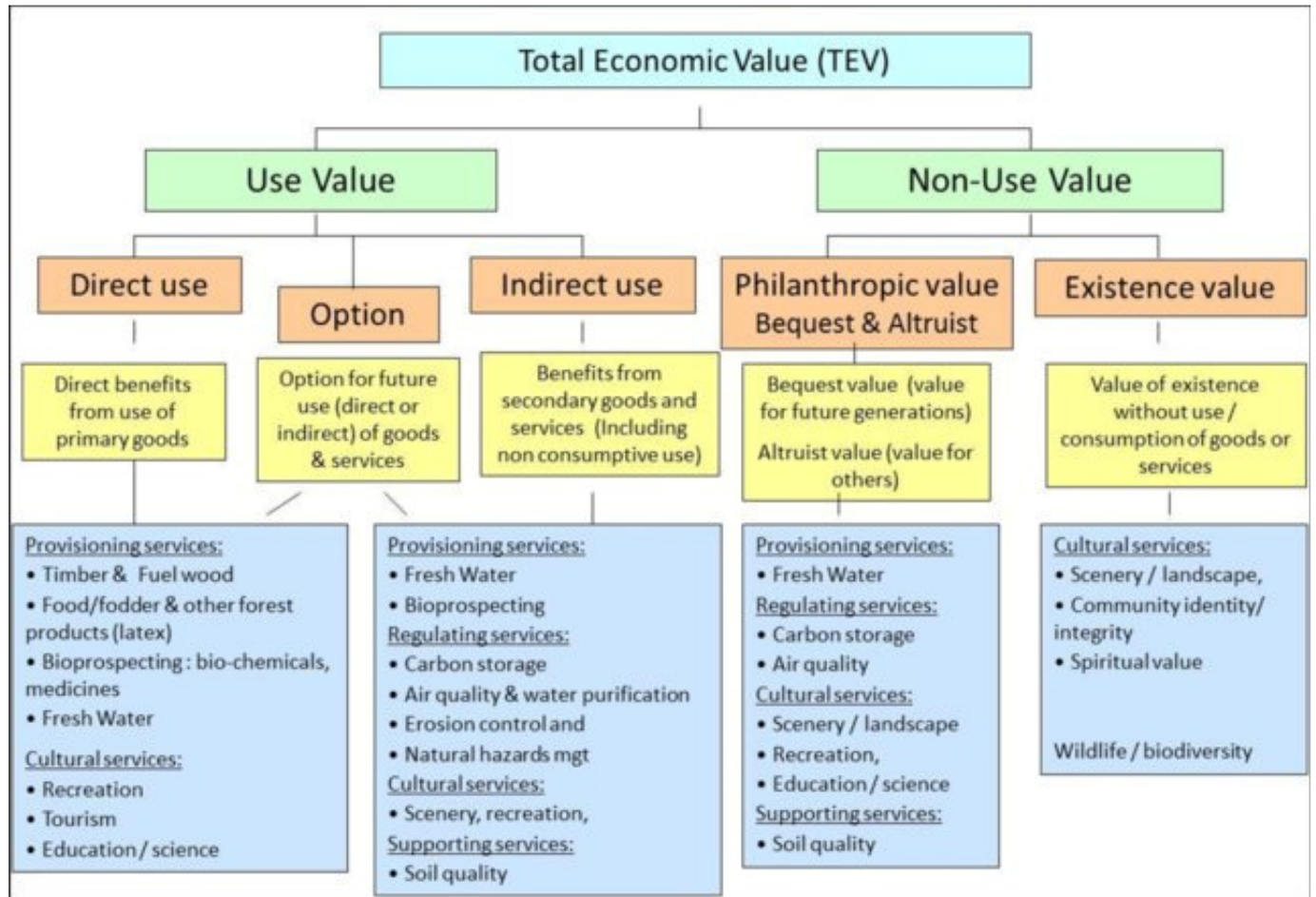


Figure 04: The Total Economic Value (TEV) framework in the context of Natura 2000

3. The Different Dimensions of Biodiversity

Biodiversity can be analyzed through three fundamental dimensions: **composition**, **structure**, and **function**. Each of these dimensions plays a crucial role in understanding and managing ecosystems.

1. Composition of Biodiversity

Composition refers to the elements present in an ecosystem, including species, genes, and biological communities. It encompasses the diversity of animal, plant, fungal, and microbial species, as well as genetic diversity within each species. Species richness (the number of species present) and the relative abundance of each species are key indicators of this dimension.

2. Structure of Biodiversity

Structure describes the organization and spatial arrangement of biological elements within an ecosystem. It includes species distribution, vegetation stratification (canopy, understory, soil), interactions between organisms (trophic relationships, symbiosis, competition), and habitat connectivity. A well-structured ecosystem enhances ecological stability and resilience to disturbances.

3. Function of Biodiversity

Function refers to the ecological processes that sustain biodiversity and influence its structure and composition. These processes include primary production (photosynthesis), biogeochemical cycles (carbon, nitrogen, phosphorus), decomposition of organic matter, pollination, climate regulation, and water filtration. Functional biodiversity is essential for ensuring ecosystem sustainability and maintaining ecosystem services.

Thus, these three dimensions are interdependent: composition determines the species and genes present, structure organizes these elements in space, and function regulates the

interactions and ecological processes that sustain biodiversity. A better understanding of these dimensions helps implement more effective conservation strategies to preserve biodiversity and its benefits for humanity.

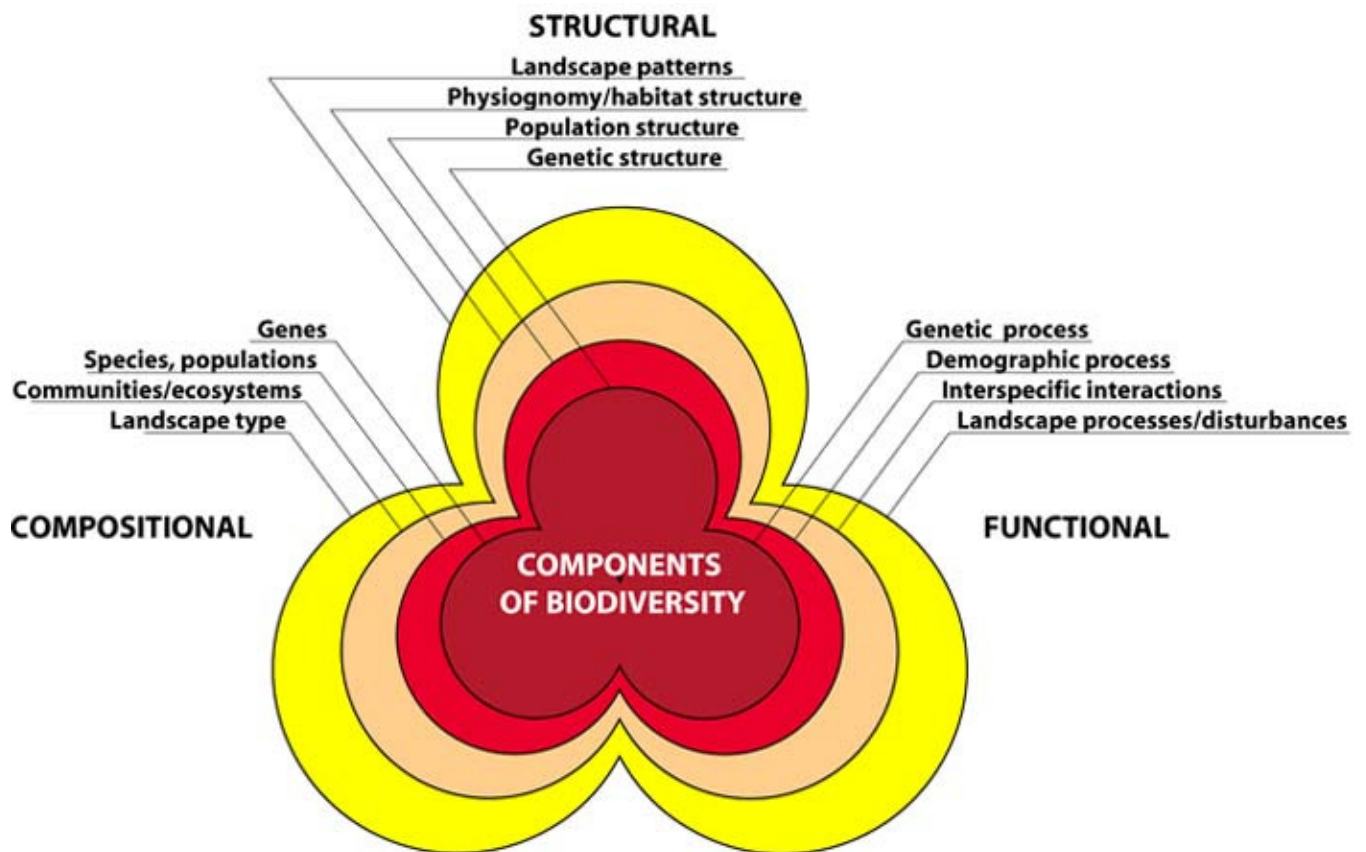


Figure 05. Composition, Structure, and Functions of Biodiversity (after Noss, 1990)

Composition Indicators

- Gene frequencies
- Species richness
- Number of habitats

Structural Indicators

- Size or age distribution of a population
- Relative abundance of species in a community
- Habitat fragmentation indices

Functional Indicators

- Genetic exchange rates between populations
- Population growth rates
- Nutrient recycling rates

4. Species Inventory

Biodiversity relies on systematics to distinguish one organism or taxon from another. However, it faces challenges related to time and numbers: while 1.75 million species have been described, estimates range from 3.6 million to over 100 million species. Although systematics is only one aspect of biodiversity, it plays a crucial role in understanding ecosystems, the biosphere, and their functions and interactions.

Estimates of Species Numbers

The level of knowledge varies across taxonomic groups. Comprehensive surveys are available for only a few zoological or botanical groups. For example, mammals and birds are currently known to more than 95%. However, the number of insect species is likely much higher than the already substantial figure of 1,000,000 recorded so far. Insects account for nearly two-thirds of newly described species.

Fungi are estimated to range between 1 and 2 million species, while nematodes, small parasitic worms of plants and animals, may number in the hundreds of thousands. New species are primarily discovered in tropical regions, coral reefs, deep-sea environments, and, across all latitudes, in hard-to-access habitats, small organisms (such as soil fauna and marine meiofauna), and parasites.

For other groups, such as bacteria and viruses, identifying species is more complex than for vertebrates or insects. As a result, their actual numbers are likely far greater than those currently known.

Table 1. Estimation of the number of currently recorded species and the number of probable species.

This estimated number of species is a rather hypothetical extrapolation but provides an order of magnitude regarding the richness of the living world.

Taxonomic Groups	Approximate Number of Recorded Species	Estimated Number of Species
Viruses	4,000	500,000 ?
Bacteria	4,000	1,000,000 ?
Fungi	72,000	1 to 2,000,000
Protozoa	40,000	200,000 ?
"Algae"	40,000	400,000 ?
Ferns	12,000	
Plants	270,000	320,000
Invertebrate Animals		10,000,000
Sponges	10,000	
Cnidarians	10,000	
Flatworms	20,000	
Nematodes	30,000	400,000
Arachnids	92,000	750,000
Crustaceans	55,000	150,000
Insects	1,000,000	8,000,000
Mollusks	85,000	200,000
Annelids	12,000	
Echinoderms	7,000	
Vertebrate Animals		
Fish	29,000	30,000
Amphibians	5,800	6,000
Reptiles	8,300	8,500
Birds	9,900	10,000
Mammals	5,400	5,500

**COURSE 03: BIOGEOGRAPHY – PHYTOGEOGRAPHY AND
ZOOGEOGRAPHY**

01. Biogeography

a. Definitions

Biogeography is the scientific study (combining biology and ecology) of the distribution of plant and animal species across the Earth's surface and the changes affecting this distribution.

This branch of ecology identifies both the potential and actual distribution areas of different species and examines how these areas evolve in response to environmental changes or human activities. In essence, biogeography explores how and why plants and animals live where they do, providing further evidence for the theory of evolution.

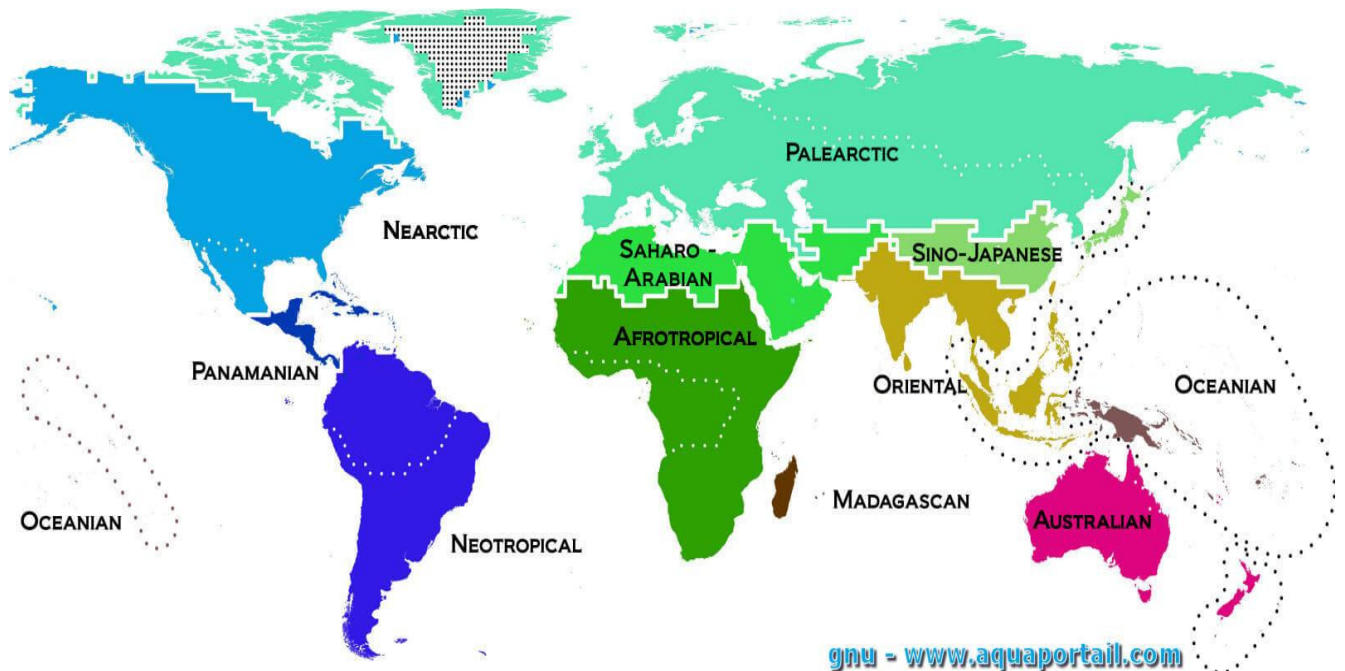


Figure 06. Biogeography divides the world into several major regions, such as Holarctic (Nearctic, Palearctic), Neotropical, Oriental, Australian, Oceanian, Panamanian, Sino-Japanese, Afrotropical, and Saharo-Arabian, as well as Archinotic (Antarctic).

b. Explanations

Biogeography studies the distribution of living organisms on Earth, as well as the processes that have shaped, modified, and may eventually cause their disappearance. It is closely related to geobiology (geobotany, geozoology), a sub-discipline of biology, with both fields having highly similar areas of study.

This interdisciplinary synthetic science incorporates knowledge from climatology, soil science (pedology), hydrology, and geomorphology, extracting biologically relevant insights. A modern approach integrates molecular biology, phylogenetics, and paleontology with scenarios of genetic lineage dispersal or higher taxon propagation, forming the basis of phylogeography.

Simply put, biogeography—studied by biogeographers—is the science that examines the distribution of living organisms and ecological environments across the Earth's surface. It is divided into zoogeography (the study of animals and faunal realms) and phytogeography (the study of plant distribution and vegetation communities), sometimes collectively referred to as geonymy.

This branch of geography focuses on the natural distribution of living organisms, excluding humans. On continents, modern biogeography tends to focus more on plant distribution, as animal populations are often significantly influenced by human activity.

c. History

Biogeography is as old as science itself. However, it faces new challenges brought by globalization, as well as issues related to nature conservation, land management, natural resource use, and biodiversity preservation. Over the past 20 years, it has undergone rapid advancements and a surge in new terminologies, reflecting its growing importance in contemporary ecological and environmental sciences.

1.1. Phytogeography

Phytogeography is a multidisciplinary study of the geographic distribution of plants and plant communities across different regions of the globe. It examines how climatic

zones and environmental factors influence their adaptation, with a primary focus on physical environmental conditions.

Phytogeography (or geobotany) is a branch of biogeography that, within the framework of geonymy, studies the distribution areas of plant taxa.

a. Explanations

Phytogeography is the plant equivalent of zoogeography, which studies animal distribution, but applied specifically to plants and botany. It is closely linked to phytosociology, and together with phytoecology, it forms the broader field of synecology.

Phytogeography can be divided into two main branches: **floristic phytogeography** and **ecological phytogeography**. Floristic phytogeography examines the distribution of a specific taxon based on its evolutionary history, while ecological phytogeography focuses on the distribution of plant communities or taxa due to current environmental conditions.

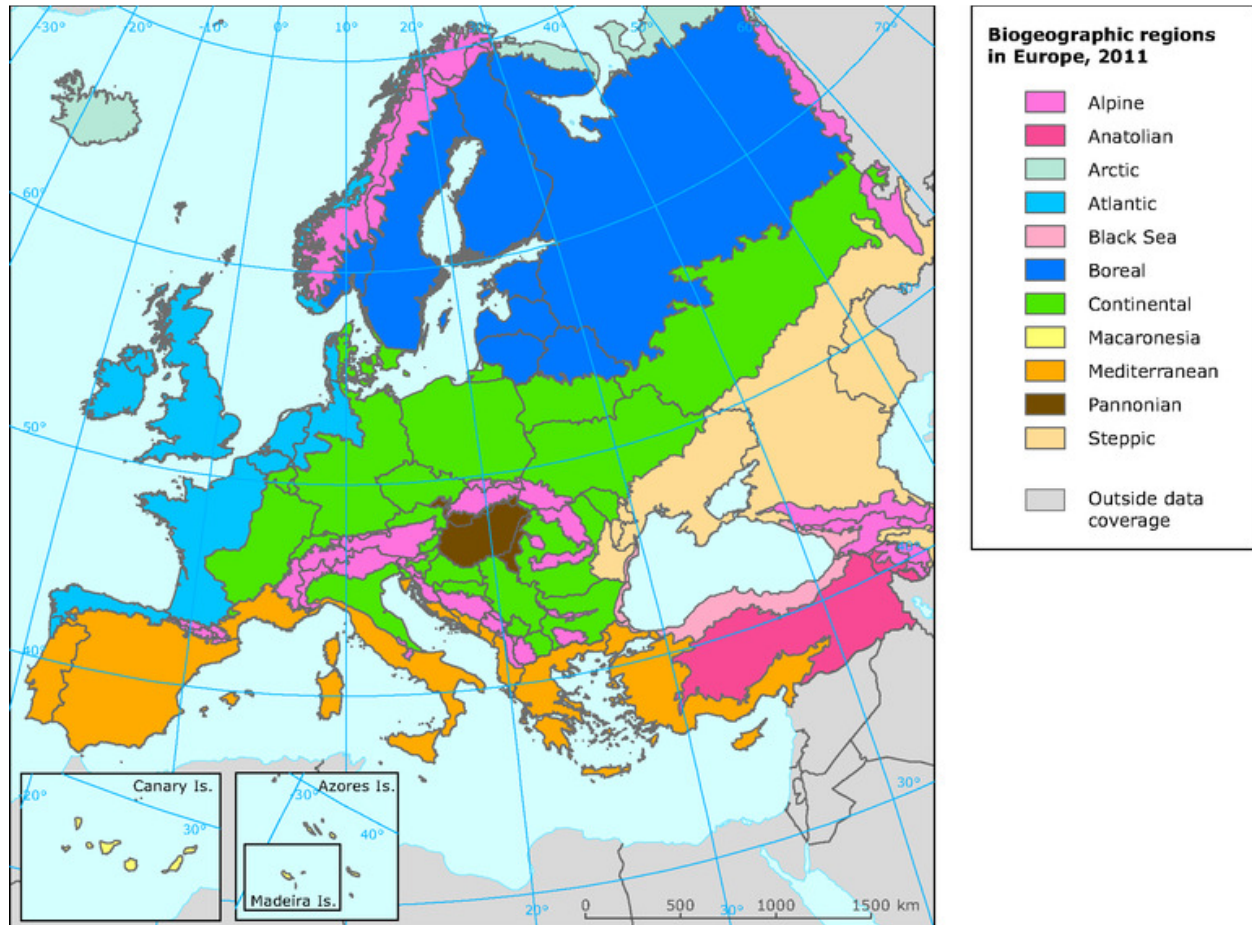


Figure 07. Phytogeographical Regions of Europe

The 11 Phytogeographical Regions of Europe are: Arctic, Boreal, Atlantic, Continental, Alpine, Pannonian, Mediterranean, Macaronesian, Steppe, Black Sea, and Anatolian.

b. Phytogeographical Factors

The primary factors determining the geographic distribution of plant formations include the presence of light, heat with temperature cycles, the availability of water through

the hydrological cycle, climatic factors, the relationship between vegetation and soil type, and adaptation strategies.

Modern phytogeography has adopted new investigative methods using geoprocessing and mapping techniques to study the dynamics of plants and vegetation cover across geographical space. Research in this field is primarily conducted by ecologists, botanists, and geographers.

The distribution of plants and their communities depends on several factors such as **light, water, temperature, soil, wind, and biological interactions**. Human activity has significantly altered the planet's natural landscapes over time, influencing the global distribution of organisms.

Geomorphological factors contribute to differentiating habitats within ecosystems. Over time, these changes can be so significant that they alter the geographical limits of biotic community distributions. Disturbances caused by **natural disasters** can damage or destroy ecosystems and modify habitats.

Various climate types exist, including **dry, humid, alternately dry and humid, hot, cold, temperate, and hybrid climates**. These different climates impact vegetation cover, influencing leaf structure, trunk thickness, plant height, vegetation physiognomy, and more.

Humidity and Plant Adaptations

Based on humidity levels, leaf morphology, and plant dynamics, plants can be classified into:

- **Hygrophytes (hygrophilous plants):** Adapted to humid environments.
- **Hydrophytes (hydrophilous plants):** Living in aquatic environments.

- **Mesophytes (mesophilous plants):** Thriving in moderately humid environments.
- **Xerophytes (xerophilous plants):** Adapted to arid conditions.
- **Halophytes (halophilous plants):** Surviving in saline environments.
- **Tropophytes (tropophilous plants):** Adapted to both dry and wet seasons.

Leaf Structure and Adaptation

- **Aciculifoliate (needle-like leaves):** Found in plants such as pine trees. Smaller leaves reduce transpiration and enhance water retention.
- **Latifoliate (broad-leaved plants):** Common in highly humid regions, promoting intense transpiration.
- **Deciduous (seasonal foliage loss):** Plants that shed their leaves according to seasonal changes.
- **Evergreen (perennial foliage):** Plants that retain their leaves throughout the seasons.

Sub-disciplines of Phytogeography

Broadly, **phytogeography (or geobotany)** consists of three sub-disciplines based on their focus on environment, flora, or vegetation:

- **Plant Ecology (Mesology):** Studies vegetation and biomes with an ecological approach.
- **Vegetation Geography (Phytogeography in a strict sense, Chorology, Floristics):** Focuses on the geographic distribution of plant species.
- **Plant Sociology (Phytosociology, Synecology):** Examines plant communities, their interactions, and associations.

1.2. Zoogeography

Zoogeography is a sub-discipline of biogeography that focuses on the origin and distribution of animal species across the Earth. It complements phytogeography, which studies the geographic distribution of plant species.

The **range (distribution area)** is the fundamental concept in zoogeography, representing the geographical zone occupied by a given species. This range includes both the **breeding area** and the various territorial zones that a species occupies regularly, seasonally, or occasionally.

These zones may not always overlap, as in the case of migratory organisms that occupy entirely different areas depending on the season.



Figure 08. Zoogeography: Distribution of Different Types of Animals Across Various Regions of the Earth.

The Distribution Ranges of Species

The distribution ranges of species can be either continuous or discontinuous. A **continuous range** is one where the species occupies an area without significant gaps, while a **discontinuous range** consists of two or more separate zones, often divided by dispersal barriers.

A **biogeographical relict** refers to a species whose original distribution has been significantly reduced or fragmented. On the other hand, a **phylogenetic relict** is a group of animals that has survived the general extinction of its original taxon.

A species (or a higher taxon) is considered **endemic** when it is found only in a specific, usually restricted, geographic area. In contrast, a **cosmopolitan species** is one that is widely distributed across most suitable habitats worldwide.

For a long time, zoogeography relied primarily on observations of the current distribution of animals on Earth and fossil records from paleontology as investigative tools. However, with advancements in **molecular taxonomy**, scientists can now analyze **phylogenetic relationships** in much greater detail. This has significantly enhanced our understanding of species evolution and migration patterns. Zoogeography also plays a crucial role in validating the plausibility of phylogenetic reconstructions.

The **theory of continental drift** provided some of its earliest evidence through the seemingly “impossible” distribution of certain fossil reptiles from the **Permian period**, such as *Lystrosaurus* and *Mesosaurus*. These fossils were found on continents that are now widely separated, supporting the idea that landmasses were once connected. The **Australian continent** is a prime example of how isolation has led to **unique evolutionary pathways**, resulting in highly distinctive faunal assemblages.

In the second half of the 20th century, the fundamental factors in zoogeographic studies were the growing interest in **ecosystem research**, particularly in **endemism**, and the global development of evolutionary studies. These studies aimed to capture both **hereditary and acquired characteristics** of species in relation to their **reference biomes**. This shift in focus allowed scientists to better understand how species adapt to their environments and how geographic distribution patterns influence biodiversity and evolution.

2. Biodiversity of the Mediterranean Basin (Fauna and Flora)

The Mediterranean region is considered one of the world's **biodiversity hotspots** due to its exceptionally high concentration of plant and animal species. It harbors a remarkable biological diversity with a **high rate of endemism**, meaning that many species found in this region exist nowhere else on the planet.

However, this unique richness is **severely threatened**. The biodiversity of the Mediterranean Basin is **rapidly declining** due to increasing human pressure. The main threats include **habitat fragmentation, degradation, and destruction**, as well as **overexploitation of resources, urbanization, intensive agriculture, and climate change**. These factors are leading to the **progressive disappearance of ecosystems** and an **alarming rate of species extinction**.

In response to this critical situation, **awareness of biodiversity's importance is growing**. It has become essential to implement **urgent and effective measures** at local, national, and international levels to **preserve this biological wealth**. Key strategies include **habitat conservation, the creation of protected areas, sustainable resource management, and public awareness campaigns** to ensure the survival of Mediterranean ecosystems and the species that depend on them.

2.1. The Mediterranean: A Threatened Biodiversity Hotspot

The Mediterranean Basin is recognized as a **biodiversity hotspot**. Its floral diversity is remarkable, with an estimated **15,000 to 25,000 species, 60% of which are unique to the region**. Additionally, around **one-third of Mediterranean fauna is endemic** (IUCN, 2008).

Although in many cases, data on biodiversity and its trends—especially regarding **marine biodiversity**—remain incomplete, there is **sufficient evidence** indicating that the region's biodiversity is **at serious risk**.

According to the **IUCN Red List of Threatened Species (2008)**, **19% of Mediterranean fauna species**—including amphibians, birds, cartilaginous fish, endemic freshwater fish, crabs and crayfish, mammals, dragonflies, and reptiles—are **threatened with extinction (5% critically endangered, 7% endangered, and 7% vulnerable)**.

Moreover, at least **16 irreplaceable species have already gone extinct**, including some **endemic species** such as the **Hula painted frog (*Discoglossus nigriventer*)**, the **Canary Islands black oystercatcher (*Haematopus meadewaldoi*)**, and the **Sardinian pika (*Prolagus sardus*)**.

2.2. Direct and Indirect Factors of Biodiversity Loss in the Mediterranean Region

According to the **Millennium Ecosystem Assessment (2005)**, *"Changes in biodiversity due to human activities have been more rapid in the last 50 years than at any other time in human history, and the drivers of biodiversity loss and ecosystem service changes are either stable, show no evidence of declining over time, or are increasing in intensity."*

Human actions are fundamentally responsible, to a significant extent, for the changes affecting the diversity of life on Earth. The most important **indirect drivers** of biodiversity loss and ecosystem service changes in the Mediterranean region include **overpopulation, urbanization, coastal development, unsustainable consumption patterns, trade, and tourism.**

Meanwhile, the **direct drivers** of biodiversity loss include:

- **Habitat fragmentation** of marine, freshwater, and terrestrial ecosystems
- **Destruction caused by the overexploitation of natural resources**
- **Rapid and large-scale land-use changes**
- **Physical modification of water bodies and excessive water extraction from rivers**
 - **Damage to seabeds due to dredging, drilling, and trawling**
 - **Various forms of pollution**, including biological/microbial pollution
 - **Introduction of non-native species**
 - **Overharvesting and unsustainable use of wildlife resources** (hunting, fishing, etc.)

The **impacts of climate change** on Mediterranean biodiversity are also particularly severe, as the region is expected to become one of the **most affected areas**. Climate models predict that the Mediterranean will experience **decreasing precipitation, rising land and sea temperatures, and progressive desertification**, all of which will significantly impact species distribution and survival (**Bates et al., 2008**).

The **northward migration of flora and fauna** due to rising temperatures will pose serious challenges, particularly for the many Mediterranean **islands**, and will also threaten the future **viability of staple crops and tree cultivation** in the region.

2.3. Proposed Measures to Manage Biodiversity Loss in the Mediterranean Region

To advance biodiversity conservation and prevent the accelerated and catastrophic loss of life forms in the Mediterranean region, there is an urgent need for a set of **closely linked short-term and long-term actions**. These measures must effectively **address both the direct and indirect causes** of biodiversity decline in the region.

The **initial step** would be to establish **ambitious yet realistic short-, medium-, and long-term objectives**. These objectives should be based on **strong scientific evidence**, considering both **challenges and opportunities**, while actively engaging **all relevant stakeholders**.

The **post-2010 biodiversity protection objectives** should align with the commitments made by **the Contracting Parties to the United Nations Convention on Biological Diversity (CBD) during its 10th session (Nagoya, Japan, October 18-29, 2010)**. However, they should go beyond merely slowing regional biodiversity loss by **implementing measures to restore ecological integrity and diversity**. This includes ensuring the **continued availability of ecosystem goods and services** and **significantly expanding protected areas** within the region.

The **new Strategic Plan for Biodiversity 2011-2020**, reaffirmed during the **RIO+20 Conference**, introduced the vision of “*Living in Harmony with Nature*” and incorporated the **Aichi Biodiversity Targets**. This framework serves as a strong foundation for integrating biodiversity conservation into **national and global programs**, promoting **multi-sectoral actions** to achieve the long-term vision:

"By 2050, biodiversity is valued, conserved, restored, and wisely used, maintaining ecosystem services, ensuring a healthy planet, and delivering essential benefits to all people."

Additionally, the **EU Biodiversity Strategy for 2020**, titled "*Our Life Insurance, Our Natural Capital*", provides a concrete foundation for EU biodiversity policy. This strategy also acts as a **catalyst for strengthening the EU's contribution** to tackling the **global biodiversity crisis**, including efforts throughout the Mediterranean region.

COURSE 04: Ecosystem Diversity (Eco-diversity)

1. Definition and Importance of an Ecosystem

An **ecosystem** is a dynamic ecological unit resulting from the interaction between two fundamental elements:

- **The Biotope:** It represents the **physical and chemical environment** in which living organisms evolve. It is determined by several factors, including:
 - **Climatic factors**, such as temperature and precipitation, which directly influence the distribution and survival of species.
 - **Soil composition**, which affects the availability of nutrients and water, thereby impacting plant growth and local biodiversity.
- **The Biocenosis:** This includes all **living organisms** (flora, fauna, and microorganisms) that coexist within a given biotope. These organisms interact with each other and with their environment, forming a complex network of biological and ecological relationships.

Factors Influencing the Nature of Ecosystems

- **Geographical location and geological history** of a region determine the nature of the biotope, thereby influencing the type of ecosystem that develops there. For example, a **hot and humid climate** will favor the formation of a **tropical forest**, while an **arid climate** will give rise to a **desert**.

- There is a **great diversity of biotopes** across the world, each hosting **communities of organisms adapted** to its specific conditions.

The Interdependence of Living Beings and Their Environment

- The diversity of **biotopes** leads to a vast variety of **biocenoses**, which explains the multiplicity of **terrestrial and aquatic ecosystems**.
- To survive, living organisms must **exchange matter and energy** with their environment. This interdependence is based on essential biological processes such as **photosynthesis, respiration, decomposition, and biogeochemical cycles**.
- The environment consists of both **living organisms** and **non-living elements** (water, air, soil). If any of these elements were to disappear or be disturbed, the **ecosystem's balance** would be threatened, endangering the species that depend on it.

Biodiversity: A Fundamental Pillar of Ecosystems

Biodiversity refers to the **full range of life's diversity** and is observed at three levels:

1. **Ecosystem biodiversity**: This represents the variety of ecosystems on Earth, ranging from **tropical forests to coral reefs, grasslands, and wetlands**.
2. **Species biodiversity**: This refers to the diversity of species within a given ecosystem. Some species are **dominant**, while others are **rare but play a crucial role** in maintaining ecological balance.
3. **Genetic biodiversity**: This corresponds to the diversity of **genes within a species**, enabling adaptation to environmental changes and ensuring **long-term survival**.

In summary, an **ecosystem** is a **complex living system** where each element plays a **crucial role**. The **diversity of biotopes and biocenoses** shapes a vast array of ecosystems, each

contributing to the overall functioning of the **biosphere**. Therefore, preserving **biodiversity** is essential to maintaining the **balance and resilience** of ecosystems in the face of **natural and human-induced disturbances**.

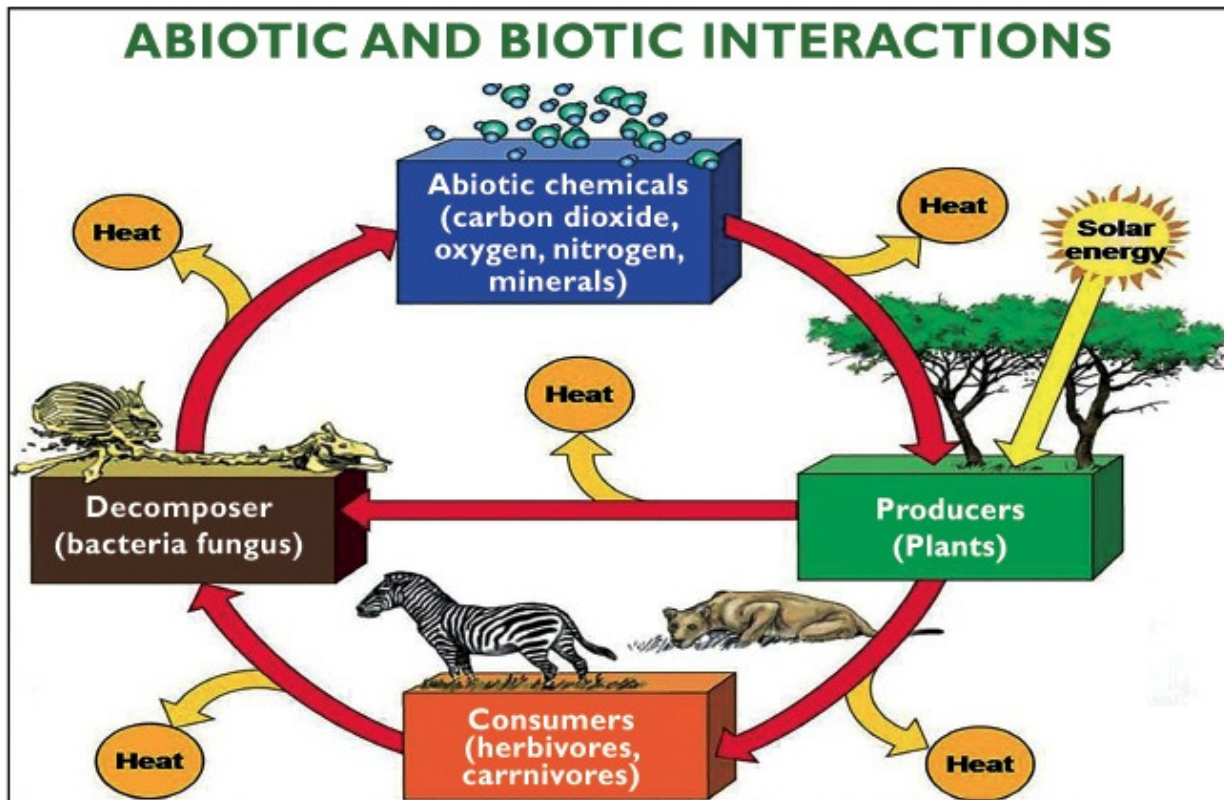


Figure 09. The components of an ecosystem.

2. Origin of Ecosystem Diversity

The diversity of ecosystems observed worldwide is largely influenced by **climatic factors**. Among these, the **distribution of solar energy, temperature, and precipitation** play a crucial role in shaping different **terrestrial and aquatic biomes**.

a. Influence of Climate on Ecosystem Diversity

1. Unequal Distribution of Solar Energy

Due to its **spherical shape**, the Earth receives **solar energy unevenly** across its surface. This unequal distribution is caused by the **angle of incidence** of the Sun's rays:

- **At the equator**, solar rays hit the Earth's surface almost **perpendicularly**, resulting in **high solar flux** (the amount of energy received per unit area). This explains the **high temperatures in tropical regions**.
- **Towards the poles**, solar rays arrive at a **more oblique angle**, spreading over a **larger surface area** and passing through a **thicker layer of atmosphere**. This reduces the amount of **energy received**, leading to **colder temperatures**.

As a result, this **uneven distribution of solar energy** is responsible for the **various climatic zones** across the globe, ranging from **hot tropical regions** to **cold polar areas**, with **temperate zones** in between.

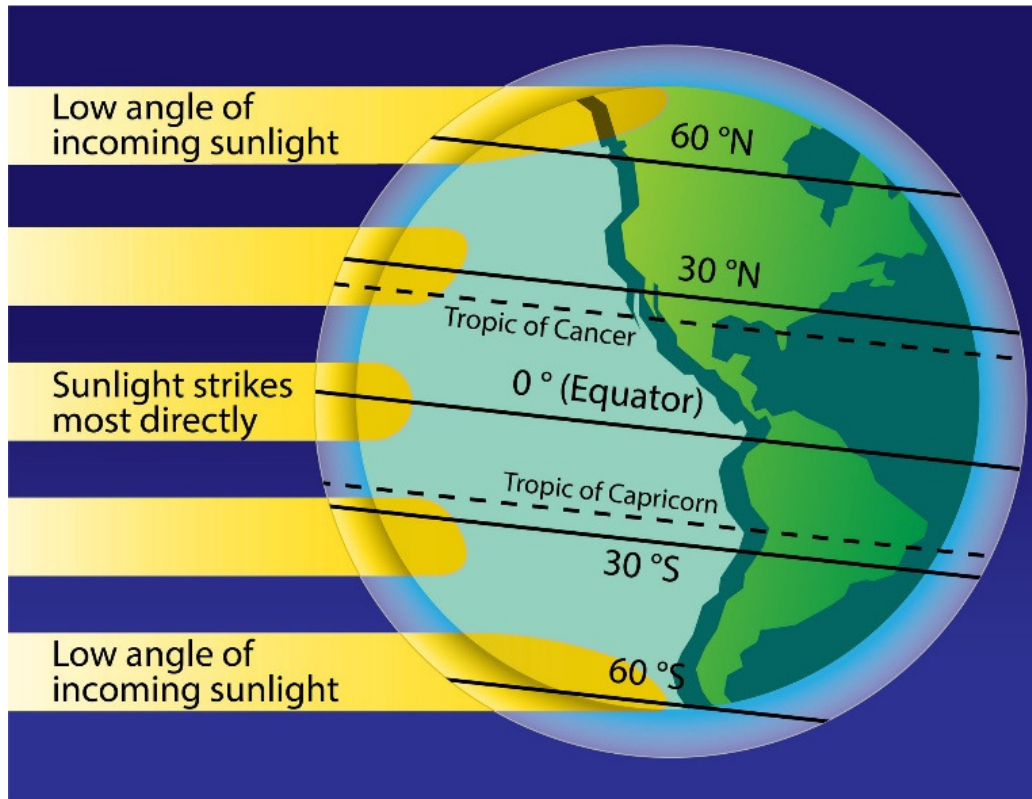


Figure 10. The Earth is unevenly heated because it is a sphere.

2. The Impact of Solar Flux on Evaporation and Atmospheric Circulation

The **high solar radiation** in regions near the **equator** causes **intense evaporation** of ocean water. This water vapor then **condenses** to form clouds, which are transported by **dominant winds** toward higher latitudes. This phenomenon leads to:

- **An alternation of humid and dry zones:**
 - Near the **equator**, warm and humid air rises, creating areas of **high precipitation** (e.g., **tropical rainforests**).

- As this air moves toward **higher latitudes**, it **cools down** and loses its moisture, leading to the formation of **arid and desert regions**.
- **Large-scale movements of air and water masses:**
 - These **atmospheric currents** influence **global climate patterns** and determine the **distribution of terrestrial biomes** (such as **forests, deserts, savannas, and tundras**).

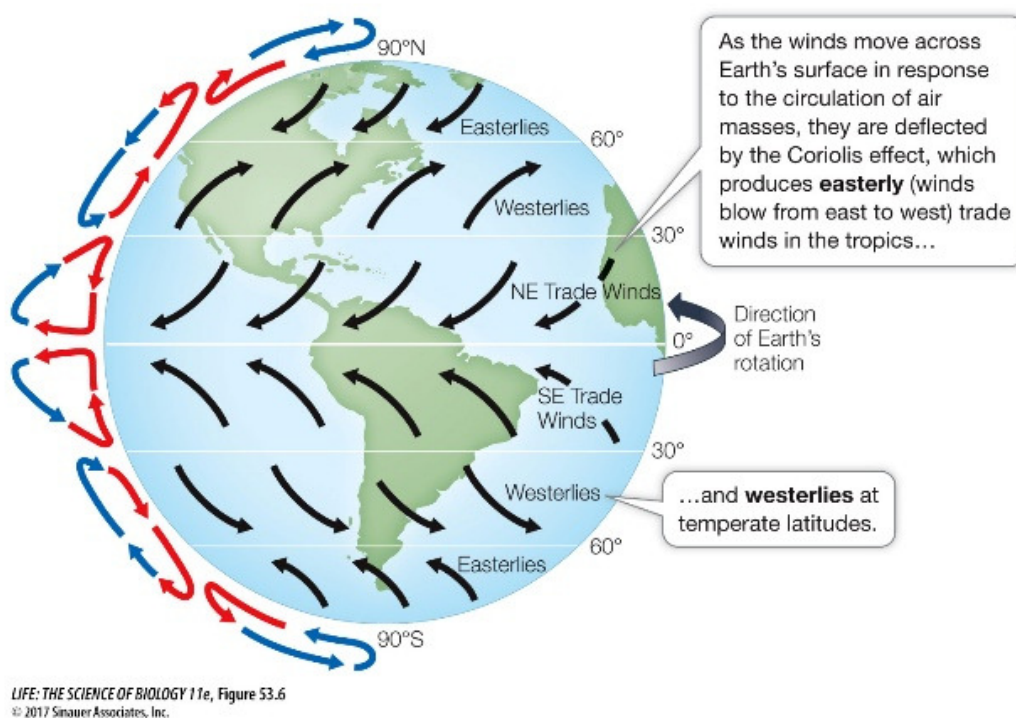


Figure 11. Prevailing Winds Created by Earth's Rotation and Atmospheric Circulation.

3. Definition of Climate Zones

The **variations in temperature and precipitation** caused by these atmospheric and solar phenomena give rise to different **climate zones**, which in turn shape **ecosystem diversity**:

- **Tropical zones** (near the **equator**) are characterized by **high temperatures** and **abundant rainfall**, promoting the growth of **humid tropical forests** and **rich aquatic ecosystems**.
- **Desert zones** (around **30° latitude north and south**) result from **dry, descending air**, which limits precipitation and restricts biodiversity to species adapted to **arid conditions**.
- **Temperate zones** (between the **tropics and polar circles**) experience **seasonal climate variations**, allowing for the development of **diverse ecosystems** such as **temperate forests and grasslands**.
- **Polar zones** are defined by **extremely low temperatures** and **persistent snow cover**, hosting **extreme ecosystems** like the **tundra and polar ice caps**, where only highly specialized species can survive.

The **origin of ecosystem diversity** is largely based on **climatic differences** caused by the **unequal distribution of solar energy**. These variations **directly influence temperature and precipitation**, shaping the diversity of **terrestrial and aquatic biomes**. Understanding these mechanisms is **crucial** for better assessing the **distribution and evolution of ecosystems** in response to **current climate change**.

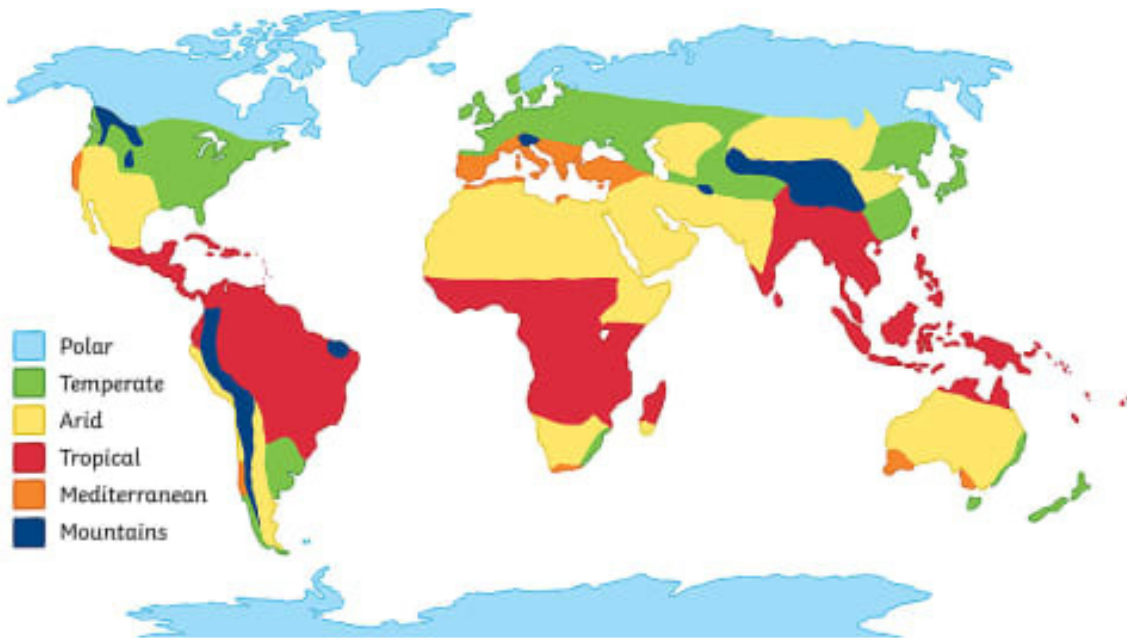


Figure 12. World Climate Zones – Image courtesy of the UK Meteorological Office

b. The Nature of Soils

The **diversity of ecosystems** is influenced by numerous **environmental factors**, among which **soil composition** plays a fundamental role. Soil is much more than just a **physical support** for vegetation; it is a **living and dynamic medium** that provides essential **nutrients** for plant development and, consequently, for the entire **food chain** that depends on it.

1. Formation and Composition of Soils

Soil forms over time from the **breakdown of bedrock**, a process driven by **physical, chemical, and biological interactions** known as **weathering**. This process is influenced by:

- **Climate** (temperature, precipitation), which accelerates or slows down **rock erosion**.
- **Biological activity**, particularly that of **microorganisms and plant roots**, which contribute to **mineral decomposition and soil structuring**.
- **Topography and regional geology**, which determine the **type of parent rock** from which the soil originates.

Over time, these processes give rise to a **wide variety of soils**, each with **specific physical and chemical characteristics**, directly influencing the **ecosystems they support**.

2. Influence of Soil Composition on Biodiversity

Each type of soil has a **unique chemical composition and structure**, which affects the **availability of minerals, water, organic matter, and microorganisms**. These factors determine the **types of vegetation** that can grow and, by extension, the **diversity of animal species** that depend on them.

a. Limestone Soils: A Floristic and Pollinator-Friendly Ecosystem

Limestone soils, formed from the **decomposition of rocks rich in calcium carbonate (CaCO₃)**, are generally **alkaline and well-drained**. These conditions favor the growth of **a highly diverse flora**, particularly plant species adapted to **relatively dry and mineral-rich environments**, such as:

- **Wild orchids**,
- **Aromatic plants** (thyme, lavender),
- **Calcareous grasslands**, characteristic of **Mediterranean meadows and karst plateaus**.

This **rich plant diversity** attracts a **wide variety of pollinating insects** (bees, butterflies, bumblebees), which play an essential role in **plant reproduction** and **ecosystem stability**. As a result, **limestone soils contribute significantly to biodiversity conservation** by fostering **complex ecological interactions between plants and pollinators**.

b. Humus: A Fertile and Life-Rich Soil

Humus is a **surface layer of soil** particularly rich in **organic matter**, derived from the **decomposition of leaves, deadwood, and other plant residues** by **soil microorganisms and invertebrates** (bacteria, fungi, earthworms). This type of soil is **highly fertile**, as it gradually releases **essential nutrients** necessary for **plant growth**.

Humus is a **distinctive feature of temperate forests**, where the **seasonal accumulation of organic matter** creates a favorable environment for a **wide range of biodiversity**:

- **A dense and diverse flora** (oaks, beeches, ferns, mosses).
- **An active soil fauna** (earthworms, decomposing insects, mycorrhizal fungi).
- **A rich microbial diversity**, essential for the **transformation of organic matter** and **nutrient cycling**.

This type of soil **plays a crucial role in nutrient recycling**, maintaining **soil fertility** and enabling the **regeneration of forest ecosystems**.

The **nature of soils** directly influences **ecosystem diversity** by determining the **living conditions of plants, microorganisms, and animals**. Whether **limestone-based, humus-rich, or of another type**, soils regulate **species distribution** and shape **ecological interactions**. Understanding their role helps us better grasp **ecosystem dynamics** and adopt **sustainable management practices** to preserve **biodiversity and soil fertility**.

3. Ecosystem Diversity

The **diversity of ecosystems** across the world is the result of **complex interactions** between **geographical, climatic, and edaphic (soil-related) factors**. These parameters influence both the **species composition** of living communities (**biocenosis**) and their **functioning**. The more diverse an ecosystem is, the more **stable and resilient** it becomes in the face of **environmental disturbances**.

3.1. Examples of Correlation Between Environmental Factors and Ecological Diversity

✓ **Tropical Rainforests** (Amazon, Congo, Southeast Asia)
✦ **High solar energy + abundant rainfall + nutrient-rich soils**
→ **Exceptional biodiversity, high primary productivity**, record levels of **plant and animal diversity**.

✓ **Savannas and Temperate Grasslands**
✦ **Moderate sunlight, marked seasonality, rich but shallow soils**
→ **Extensive grasslands**, home to **herbivores and specialized predators** adapted to grazing ecosystems.

✓ **Arid Deserts** (Sahara, Atacama, Arizona)
✦ **Intense solar radiation, low precipitation, sandy and nutrient-poor soils**
→ **Flora and fauna adapted to drought**, such as **cacti, nocturnal reptiles, and mammals capable of storing water**.

- ✓ Arctic and Alpine Tundra
- ✦ Cold temperatures, low precipitation, frozen soils (permafrost)
- Limited biodiversity, low-growing vegetation, and fauna adapted to extreme conditions (reindeer, polar bears, migratory birds).

The **diversity of ecosystems** is shaped by **complex interactions** between **climatic factors** (solar energy, precipitation) and **edaphic factors** (soil composition, nutrient availability). These parameters directly **influence biological productivity** and **species richness** within ecosystems. Each **biome** has **unique characteristics** that determine **its biodiversity and ecological function**.

4. Biomes: Diversity and Characteristics

The planet is home to a **vast variety of ecosystems**, which are grouped into **macro-ecosystems**, also known as **biomes**. These **large ecological units** are defined by their **climatic, geographical, and biological characteristics**. Each biome hosts a **unique set of plant and animal species** adapted to its specific conditions.

4.1. Definition and Classification of Biomes

A **biome** (also called a **macro-ecosystem** or **biotic zone**) is a **large ecological region** characterized by:

- **A specific climate** (temperature, precipitation)
- **Dominant vegetation**
- **Adapted fauna**

Biomes are further **divided into smaller ecosystems**, which exhibit local variations due to **topography, soil type, and human influence**.

The seven major terrestrial biomes are:

- 1 Tundra
- 2 Taiga (Boreal Forest)
- 3 Temperate Deciduous Forest
- 4 Tropical Rainforest
- 5 Savanna
- 6 Steppes and Grasslands
- 7 Desert

Each of these biomes has a **specific biodiversity** and plays a **crucial role in maintaining the planet's ecological balance**.

4.2. Overview of the Main Terrestrial Biomes

1 Tundra ❄️

📍 **Location:** Arctic and subarctic regions (Siberia, Canada, Greenland)

🌡️ **Climate:** Extremely cold (-40°C in winter, 10°C in summer), low sunlight, low precipitation.

🌿 **Vegetation:** Mosses, lichens, small shrubs adapted to cold conditions (no trees).

🐾 **Fauna:** Reindeer, polar bears, arctic foxes, migratory birds.

🔄 **Adaptations:** Short plant life cycles, animals with thick fat layers and insulating fur.

2 Taiga (Boreal Forest) 🌲

- 📍 **Location:** Northern Hemisphere (Canada, Scandinavia, Russia).
- 🌡️ **Climate:** Long, cold winters; short, mild summers; moderate precipitation.
- 🌿 **Vegetation:** Conifers (firs, pines, spruces), nutrient-poor soils.
- 🐾 **Fauna:** Wolves, brown bears, lynxes, elks, rodents.
- 🔗 **Adaptations:** Evergreen trees to withstand the cold; animals with thick fur.

3 Temperate Deciduous Forest 🍁

- 📍 **Location:** Europe, North America, East Asia.
- 🌡️ **Climate:** Four distinct seasons, abundant precipitation.
- 🌿 **Vegetation:** Oaks, beeches, maples; diverse deciduous trees.
- 🐾 **Fauna:** Deer, foxes, squirrels, migratory birds.
- 🔗 **Adaptations:** Trees shed leaves in winter; fauna adapted to seasonal changes.

4 Tropical Rainforest 🌴

- 📍 **Location:** Amazon, Equatorial Africa, Southeast Asia.
- 🌡️ **Climate:** High temperatures year-round, abundant rainfall (>2000 mm/year).
- 🌿 **Vegetation:** Exceptional biodiversity, dense canopy, nutrient-poor soils.
- 🐾 **Fauna:** Tropical birds, jaguars, primates, reptiles.
- 🔗 **Adaptations:** Fast-growing plants, specialized fauna (camouflage, mimicry).

5 Savanna 🌿

- 📍 **Location:** Africa, South America, Australia.
- 🌡️ **Climate:** Distinct wet and dry seasons, high temperatures.

- ✿ **Vegetation:** Tall grasses, scattered trees (baobabs, acacias).
- **Fauna:** Antelopes, lions, giraffes, elephants.
- 📄 **Adaptations:** Migratory animals following rainfall, drought-resistant plants.

6 Steppes and Grasslands 🌾

- 📍 **Location:** North America (prairies), Eastern Europe and Central Asia (steppes).
- 🌡️ **Climate:** Variable temperatures, moderate precipitation.
- ✿ **Vegetation:** Short grasses, few trees.
- 🐾 **Fauna:** Bison, antelopes, rodents, wolves.
- 📄 **Adaptations:** Fertile soils ideal for agriculture, burrowing animals.

7 Desert 🏜️

- 📍 **Location:** Sahara, Atacama, Arabian Desert, Australian Desert.
- 🌡️ **Climate:** Extreme temperatures (hot days, cold nights), very low precipitation.
- ✿ **Vegetation:** Cacti, xerophytic plants with reduced leaves.
- 🐾 **Fauna:** Camels, snakes, scorpions, nocturnal rodents.
- 📄 **Adaptations:** Water-storing plants, nocturnal animals avoiding heat.

4.3. Importance of Biomes in Global Balance

🔗 Biodiversity and Ecosystems

Each **biome** supports a **unique set of plant and animal species** adapted to its **specific conditions**. Their **biological diversity** is **essential** for **ecosystem stability** and **resilience to climate change**.

🌐 Role in Biogeochemical Cycles

Biomes play a **key role** in regulating **global natural cycles**:

- **Tropical forests** → **Massive CO₂ absorption**, climate regulation.
- **Oceans & tundras** → **Carbon storage**.
- **Grasslands & savannas** → **Soil fertility and water regulation**.

⚠️ Threats and Conservation

Today, **biomes face numerous human-induced threats**:

- **Deforestation** (Amazon rainforest).
- **Climate change** (permafrost melting in tundra).
- **Urbanization & intensive farming** (desertification of grasslands).

🔗 **Conservation efforts** are **crucial** to protect these vital ecosystems through:

- **Natural reserves & national parks**
- **Sustainable development policies**

Biomes are **macro-ecosystems** that structure the **planet's ecological diversity**. They are determined by **climatic and edaphic (soil-related) factors**, directly influencing **vegetation and fauna**. Their **preservation** is **crucial** for maintaining **ecological balance** and combating **climate change**. 🌍🌿

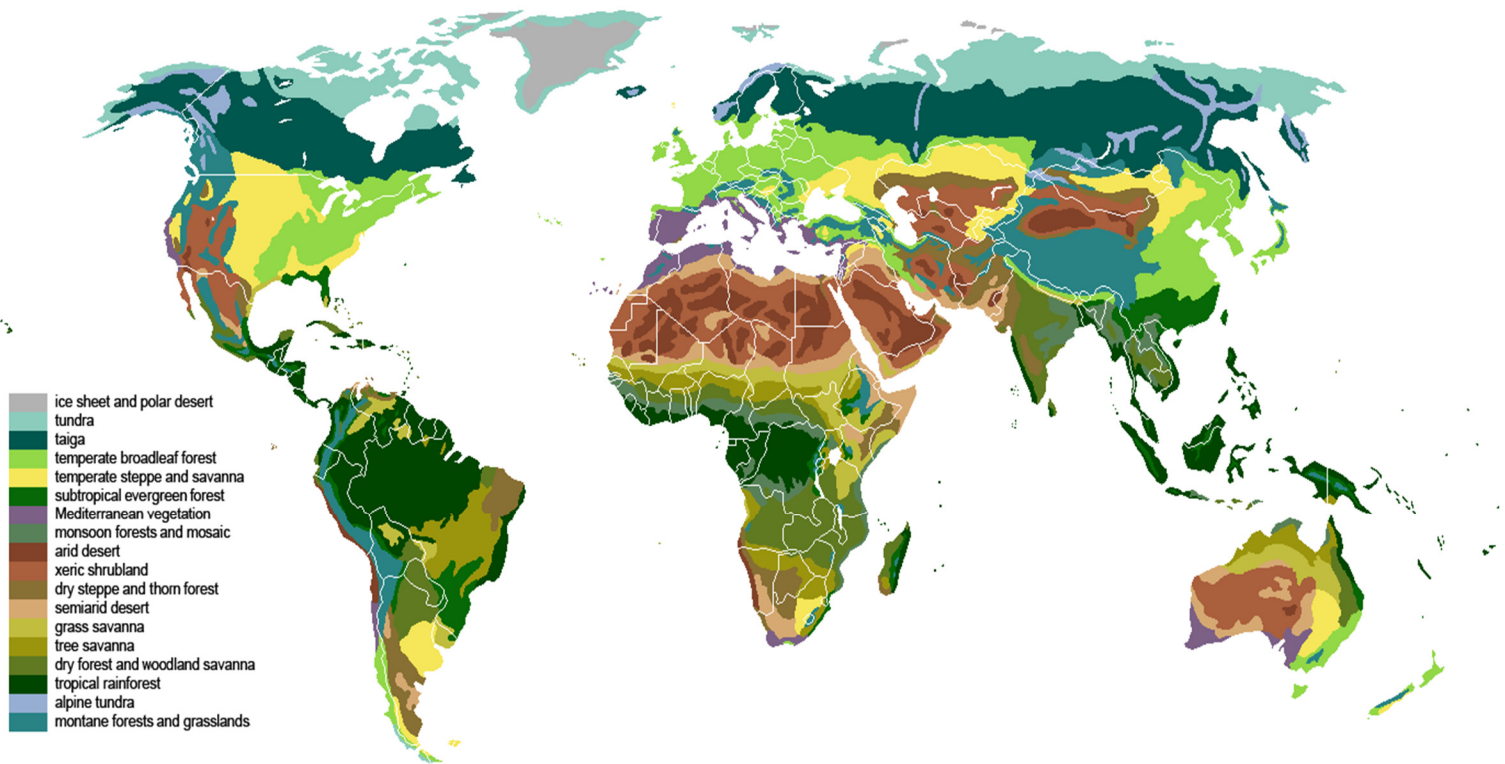


Figure 13. The terrestrial biomes, according to the WWF.

COURSE 05: POPULATION GENETICS.

I. Definition, Objectives, and Applications

Genetics, initiated by Gregor Mendel and traditionally known as Mendelian genetics, aims to understand the determination and transmission of traits by analyzing the offspring of a controlled cross between individuals with different genotypes.

After the discovery of DNA as the genetic information carrier, molecular genetics has continued to investigate the precise mechanisms of trait determination, expression, and transmission.

To fully understand the determination and transmission of traits, it is also necessary to study individuals in natural conditions, where they are genetically unique and free to reproduce with any other individual of the same species. This branch of genetics, which considers individuals in interaction with their environment, is **population genetics**.

A) Definitions and Objectives

Population genetics studies the genetic variability within and between populations with three main objectives:

1. To measure genetic variability, also known as genetic diversity, by analyzing the frequency of different alleles of the same gene.
2. To understand how genetic variability is transmitted from one generation to the next.
3. To understand how and why genetic variability evolves over generations.

While Mendelian genetics relies on controlled crosses conducted by an experimenter, population genetics examines the proportions of genotypes within a group of individuals

resulting from uncontrolled matings between numerous parents. It is, therefore, an application of the fundamental principles of Mendelian genetics at the population level.

B) What is a Population?

A population is defined as a group of individuals of the same species that have the potential to interact with one another during reproduction.

Examples:

- Elephants in an African national park
- Oak trees in a forested area
- Individuals of an intestinal parasite species living within a single host

II. Genetic Variability in Natural Populations

One of the fundamental characteristics of living organisms is the variability of individual phenotypes. Within a species, no two individuals share exactly the same phenotypic traits—each individual is unique. Some of these variations are expressed at the phenotypic level (e.g., morphology, physiology, behavior), while others remain "hidden" and require specialized techniques to be detected (such as protein variability or DNA sequence variations).

Phenotypic variations (**P**) arise partly due to environmental factors (**E**) (e.g., diet, climate, interactions with other species) and partly due to genetic differences among individuals (**G**), which can be inherited by offspring.

A) Determinants of Variation: The Concept of Polymorphism

Population genetics primarily focuses on genetic variability within populations, referred to as **polymorphism**. This includes variations in traits such as color, shape, and DNA sequences that exist in multiple allelic forms.

In contrast, **monomorphic** genes do not exhibit variability, meaning only one allele is present within the population.

1) Epigenetic Determinism

When trait variability has no genetic basis—that is, it does not result from changes in DNA sequences—it is classified as **epigenetic variability**. This type of variability often arises from environmental influences on phenotypic expression, such as temperature, diet, or the physicochemical conditions of the environment.

2) Genetic Determinism

A trait's variability is considered **genetically determined** when it results, at least in part, from the presence of multiple allelic forms within a population.

In some cases, phenotypic variability is caused by variations in a single gene—this is known as **monogenic determinism**. This does not necessarily mean that the trait is controlled by only one gene, but rather that a variation in a single gene is sufficient to induce a phenotypic change. Such traits are called **Mendelian traits**, and approximately 5,000 Mendelian traits have been identified in humans.

In other cases, trait variability is influenced by multiple genes, each with several alleles—this is referred to as **polygenic determinism**. It applies to **quantitative traits**, such as height and weight, which can be measured. The genetic analysis of these traits falls under **quantitative genetics**, which separates gene effects into:

- **Additive effects (A)**
- **Dominance effects (D)**
- **Epistasis or gene interaction effects (I)**

This relationship is expressed as:

$$G = A + D + I$$

B) Scope and Methods for Studying Genetic Variability

Historically, the study of genetic variation in natural populations focused on traits that were **easily observable**, such as morphology and color. However, advancements in **biochemistry, cytogenetics, and molecular biology** have allowed researchers to analyze genetic variability at a much finer scale, even at the **DNA sequence level**, including non-coding regions.

Types of Genetic Polymorphism:

1. **Morphological polymorphism**
2. **Protein polymorphism**
3. **Enzymatic polymorphism**
4. **Immunological polymorphism**
5. **Chromosomal polymorphism**
6. **DNA polymorphism**

III. Allelic and Genotypic Frequencies

When a population is **polymorphic** for a given trait, it is possible to calculate the frequency of observed phenotypes.

For example, in a population of N individuals, where N_n have a black body and N_b have a white body, the phenotypic frequencies for body color in the population are:

- **Frequency of the black phenotype:** $f[n] = \frac{N_n}{N}$
- **Frequency of the white phenotype:** $f[b] = \frac{N_b}{N}$

If this trait is controlled by an **autosomal gene** with two alleles **A** and **a**, where **a** is **recessive** and responsible for the white color, then the **AA** and **Aa** genotypes correspond to the black phenotype, while the **aa** genotype corresponds to the white phenotype. However, phenotypic frequencies alone only provide information about the frequency of the **aa** genotype, as individuals with black coloration could be either **AA** or **Aa**. Thus, **allelic frequencies cannot be directly calculated.**

If body color is determined by two **autosomal codominant** alleles, A_1 and A_2 , leading to **three phenotypes** (black, yellow, and white), then the three possible genotypes (A_1A_1 , A_1A_2 , A_2A_2) can be **directly distinguished** through their phenotypic expression (black, yellow, and white, respectively). In this case, the phenotypic composition of the population corresponds to its genotypic composition. If N_n , N_j , and N_b represent the number of individuals with black, yellow, and white phenotypes, respectively, then genotypic frequencies can be easily calculated as follows:

- **Frequency of genotype A_1A_1 :** $f(A_1A_1) = \frac{N_n}{N} = D$

- **Frequency of genotype A_1A_2 :** $f(A_1A_2) = \frac{N_j}{N} = H$

- **Frequency of genotype A_2A_2 :** $f(A_2A_2) = \frac{N_b}{N} = R$

Thus, for a given **locus**, a population is fully described if the frequency of each genetic category is known. In the case of a **biallelic system** (A and a), the genetic structure of a population with N individuals is fully determined if the counts of the three genotypes (N_{AA} , N_{Aa} , and N_{aa}) are known, with:

$$N = N_{AA} + N_{Aa} + N_{aa} = N_{\{AA\}} + N_{\{Aa\}} + N_{\{aa\}}$$

From these counts, **genotypic frequencies** can be calculated.

Calculating Allelic Frequencies

Allelic frequencies represent the proportion of different alleles present in the population for a given locus. In a **diploid** population of N individuals, the **total number of alleles at the locus is $2N$** .

- **AA individuals** carry **two A alleles**.
- **Aa individuals** carry **one A allele and one a allele**.
- **aa individuals** carry **two a alleles**.

The total number of **A alleles** in the population is:
 $2N_{AA} + N_{Aa}$

Thus, the frequencies **p** (A allele) and **q** (a allele) are given by:

$$f(A) = p = \frac{2N_{AA} + N_{Aa}}{2N}$$

$$f(a) = q = \frac{2N_{aa} + N_{Aa}}{2N}$$

with the condition that:

$$p + q = 1$$

Alternatively, if **D** and **R** are the frequencies of homozygous genotypes (**AA** and **aa**), and **H** is the frequency of heterozygous individuals (**Aa**), the allelic frequencies can also be expressed as:

$$f(A) = p = D + \frac{H}{2} \quad f(a) = q = R + \frac{H}{2}$$

These **allelic frequencies** also represent the **probability** that a randomly selected gamete (from a male or female) carries the **A** or **a** allele.

It is important to note that **allelic frequencies contain less information than genotypic frequencies**, as they **do not indicate how alleles are paired within individual genotypes**.

IV. Hardy-Weinberg Population

In an **infinitely large** population where individuals reproduce **randomly** (panmixia), and in the absence of **migration, mutation, or natural selection**, the **allelic and genotypic frequencies** remain **constant** across generations. This is known as the **Hardy-Weinberg principle**.

For a **gene with two alleles (A and a)** with frequencies **p = f(A)** and **q = f(a)** (**q = 1 - p**), the Hardy-Weinberg equation predicts the expected **genotypic frequencies**:

Frequency of AA = p^2 \text{Frequency of AA} = p^2
 Frequency of Aa = $2pq$ \text{Frequency of Aa} = $2pq$ Frequency of aa = q^2 \text{Frequency of aa} = q^2

Hardy-Weinberg Equilibrium Conditions

If the population remains **panmictic**:

- The genotype frequencies remain **p^2 , $2pq$, and q^2** across generations (**Hardy-Weinberg equilibrium**).
- The allelic frequencies remain **p and q** .
- The relationship between allelic and genotypic frequencies remains **$(p + q)^2 = p^2 + 2pq + q^2 = 1$** (**Panmictic relation**).

Genetic Drift and Variation in Small Populations

While the **Hardy-Weinberg principle** applies at the **species level**, small populations often experience **random variations in allele frequencies over time and space**, known as **genetic drift**.

Main Factors Affecting Allelic Frequencies in Small Populations:

1. **Migrations:** Reduce or homogenize differences in allele frequencies between populations.
2. **Natural Selection:** Amplifies differences in allele frequencies by favoring certain alleles over others.

V. Applications of the Hardy-Weinberg law

A. Classical Calculations of Genotypic and Allelic Frequencies

1. Biallelic Autosomal Loci (Dominant and Recessive Autosomal Alleles)

- Determining genotypic frequencies for alleles with dominance and recessivity relationships requires a structured approach. A dominant phenotype could have either of two genotypes, **AA** or **Aa**, but there is no way to distinguish between the number of homozygotes and heterozygotes in our sample. The only phenotype with a definitively known genotype is the recessive (**aa**).

- If the population is in equilibrium, we can estimate **q** through q^2 . Then, the frequency of the dominant allele is: $p=1-q$ or $p=1-q^2$ $p = 1 - q \quad \text{or} \quad p = 1 - \sqrt{q^2}$

2. Biallelic Autosomal Loci (Codominant Autosomal Alleles)

- In the presence of codominant alleles in a two-allele system, each genotype has a distinct phenotype. The number of each allele in homozygous and heterozygous conditions can be counted in a sample of individuals from the population and expressed as a percentage of the total number of alleles in the sample.

- If the sample is representative of the total population, we can estimate the allelic frequencies present in the gene pool.

B. Applications in Human Populations

- In humans, population genetics (including the Hardy-Weinberg law) is used in medical and anthropological studies. For example, in the case of a rare and severe genetic disease, recent advancements in treatment have allowed patients to survive into adulthood. Consequently, they can reproduce and transmit the deleterious allele

to their offspring. This raises the question of how medical advancements will alter allelic frequencies in the general population and what the consequences of these changes will be on the disease frequency over X generations.

- Other classic applications include:
 - Cost-benefit analysis when implementing a genetic screening test by first calculating the frequency of the concerned disease in the population.
 - Estimating the frequency of heterozygotes in the general population for autosomal recessive diseases.

1. Calculation of Heterozygote Frequency

- The Hardy-Weinberg law allows for the estimation of heterozygote frequency in a population. The frequency of a recessive trait can be easily determined by counting individuals expressing it in a population sample. Using this information and the Hardy-Weinberg law, we can then calculate allelic and genotypic frequencies.

- **Cystic fibrosis**, an autosomal recessive trait, has an incidence of $1/2500 = 0.0004$ in populations of Northern European origin. Individuals affected by this disease are easily identifiable in the population due to their symptoms. Since it is a recessive trait, individuals with cystic fibrosis must be homozygous. Their frequency in the population is represented by q^2 , assuming that mating occurred randomly in the previous generation.

The frequency of the recessive allele in the population is then:

$$q = \sqrt{q^2} = \sqrt{0.0004} = 0.02$$

Since $p + q = 1$, the value of p is:

$$p = 1 - q = 1 - 0.02 = 0.98$$

According to the Hardy-Weinberg equation, the frequency of heterozygotes is $2pq$:

$2pq=2(0.98)(0.02)=0.04$ or 4% or $1/25$
 $2pq = 2(0.98)(0.02) = 0.04$ \text{ or } 4%
 \text{ or } $1/25$

Thus, the proportion of heterozygotes for the **cystic fibrosis allele** in the population is relatively high, while the frequency of **homozygous recessives** is only **0.04%**.

- In general, in a **two-allele system**, the frequencies of the three genotypes can be estimated as long as the Hardy-Weinberg assumptions hold and one of the two allelic frequencies is known.

It is important to note that the proportion of **heterozygotes increases rapidly** in the population when **p** and **q** move away from **0** and **1**. These observations confirm our conclusion that when a trait like **cystic fibrosis** is rare, the **majority of individuals carrying the allele are heterozygotes**.

In populations where the frequencies of **p** and **q** range between **0.37** and **0.67**, heterozygotes are found in **greater proportions** than either of the homozygous genotypes.

2. Calculation of Frequencies for Multiple Alleles

- More than two alleles are often found at a given locus in a population. Human blood groups are an example.

• The **I (isoagglutinin) locus** has three alleles: **I^A**, **I^B**, and **I^O**, resulting in six possible genotypes (**I^AI^A**, **I^BI^B**, **I^OI^O**, **I^AI^B**, **I^AI^O**, **I^BI^O**). It should be noted that **I^A** and **I^B** are **codominant alleles**, and both are dominant over **I^O**. As a result, **homozygous I^AI^A individuals** and **heterozygous I^AI^O individuals** are **indistinguishable** in terms of phenotype. The same applies to **I^BI^B** and **I^BI^O individuals**. **Phenotypic analysis thus allows the identification of only four combinations**.

By introducing another variable into the **Hardy-Weinberg equation**, we can calculate **genotypic and allelic frequencies** for this example involving three alleles. Let **p**, **q**, and **r** represent the allelic frequencies of **I^A**, **I^B**, and **I^O**, respectively. The formula becomes:

$$p+q+r=1 \quad p + q + r = 1$$

The **genotypic frequencies** are given by:

$$(p+q+r)^2 = p^2 + 2pq + 2pr + q^2 + 2qr + r^2 = 1 \quad (p + q + r)^2 = p^2 + 2pq + 2pr + q^2 + 2qr + r^2 = 1$$

If the frequencies of blood groups in a population are known, it is possible to determine the frequencies of the three **ABO system alleles**. For example, in a sampled population, the frequencies of different blood groups are:

- **0.53** for blood type A
- **0.13** for blood type B
- **0.26** for blood type O

Thus,

$$r^2 = 0.26 \Rightarrow r = \sqrt{0.26} \Rightarrow r = 0.51 \quad r^2 = 0.26 \quad \Rightarrow \quad r = \sqrt{0.26} \quad \Rightarrow \quad r = 0.51$$

Using **r**, we can then estimate the frequencies of **I^A** and **I^B**. The **I^A** allele is present in two genotypes: **I^AI^A** and **I^AI^O**, leading to the same phenotype. The frequency of **I^AI^A** is represented by **p²**, and that of **I^AI^O** by **2pr**. The combined frequencies of blood types **A** and **O** are given by:

$$p^2 + 2pr + r^2 = 0.53 + 0.26 \quad p^2 + 2pr + r^2 = 0.53 + 0.26$$

Factoring the left-hand side and summing the right-hand terms, we obtain:

$$(p+r)^2 = 0.79 \Rightarrow p+r = \sqrt{0.79} \Rightarrow p = 0.89 - r \quad (p+r)^2 = 0.79 \quad \Rightarrow \quad p+r = \sqrt{0.79} \quad \Rightarrow \quad p = 0.89 - r$$

Substituting **r = 0.51**:

$$p = 0.89 - 0.51 = 0.38 \quad p = 0.89 - 0.51 = 0.38$$

Having estimated **p** and **r** (the frequencies of **I^A** and **I^O**), we can now determine the frequency of **I^B**:

$$p+q+r=1 \Rightarrow q=1-p-r \quad p + q + r = 1 \quad \Rightarrow \quad q = 1 - p - r$$

$$q = 1 - 0.38 - 0.51 = 0.11 \quad q = 1 - 0.38 - 0.51 = 0.11$$

3. Calculation of Frequencies for Sex-Linked Traits

- The **Hardy-Weinberg law** can be used to calculate allelic and genotypic frequencies for sex-linked traits, but it must be remembered that in **XY sex determination systems**, the **homogametic sex (XX)** will have two copies of an allele carried on the **X chromosome**, while the **heterogametic sex (XY)** will have only one. Thus, in mammals, where **females are XX and males are XY**, the frequency of the **X-linked allele in the gene pool** and the frequency of **males expressing X-linked traits** will be the same. Since each **male has only one sex-linked allele**, the frequency of a **sex-linked trait among males** is a **direct measure of the allele frequency in the population**, assuming that these allele frequencies are also representative of females. The probability that a female has the same allele on both X chromosomes will be q^2 , where q is the frequency of that allele.

- As an example, consider the **recessive allele on an X-linked locus responsible for color blindness**. This condition affects **8% of males**. The frequency of the **allele responsible for color blindness** is therefore **0.08**, meaning **8% of X chromosomes in the population** carry this allele. The remaining **92%** carry the dominant allele. If we assume that **p is the frequency of the normal allele** and **q is the frequency of the allele responsible for color blindness**, then **$p = 0.92$** and **$q = 0.08$** .

- The frequency of **females expressing the disease** (having two **X chromosomes carrying the color blindness allele**) is:

$$q^2 = (0.08)^2 = 0.0064$$

- The frequency of **carrier females (heterozygous, not affected)** is:

$$2pq = 2(0.08)(0.92) = 0.1472$$

This means that **14.7% of females carry the allele for color blindness** and can pass it on to their offspring, even though they **do not exhibit the phenotype** themselves.

VI. NATURAL SELECTION AND VARIATIONS IN ALLELE FREQUENCIES

- We have seen that the **Hardy-Weinberg law** allows us to estimate allele and genotype frequencies for a given locus in populations where **random mating, absence of selection, and absence of mutation** hold true.

- In reality, it is difficult to find **natural populations** where all these assumptions apply to all genes. In nature, populations are **dynamic**, and **changes in population size and gene pools** are frequent.

- The Hardy-Weinberg law also helps analyze populations that differ from the **ideal population**.

A. Natural Selection

- One of the assumptions of the **Hardy-Weinberg law** is that individuals of all **genotypes have the same survival rates and reproductive success**. If this condition is not met, **allele frequencies will not remain constant** from one generation to the next.

- To illustrate this, let's consider a **population of 100 individuals**, where the **frequency of allele A is 0.5** and the **frequency of allele a is 0.5**. Assuming that in the previous generation, individuals **mated randomly**, the expected **genotypic frequencies** among the present generation's zygotes would be:

$(0.5)^2 = 0.25$ for AA, $2(0.5)(0.5) = 0.5$ for Aa, $(0.5)^2 = 0.25$ for aa. $(0.5)^2 = 0.25$ \quad $\text{for } AA$, $\quad 2(0.5)(0.5) = 0.5$ \quad $\text{for } Aa$, $\quad (0.5)^2 = 0.25$ \quad $\text{for } aa$.

Given that the **population consists of 100 individuals**, we have:

- **25 individuals with genotype AA**
- **50 individuals with genotype Aa**
- **25 individuals with genotype aa**

• Now, let's assume that individuals of different **genotypes have different survival rates**:

- All **25 individuals with genotype AA survive**
- **90% (45 out of 50) of individuals with genotype Aa survive**
- **80% (20 out of 25) of individuals with genotype aa survive**

• When the **surviving individuals reproduce**, each contributes **two gametes** to the **new gene pool**, giving a total of:

$$2(25)+2(45)+2(20)=180 \text{ gametes. } 2(25) + 2(45) + 2(20) = 180 \text{ \textit{gametes}}.$$

• What are the **allele frequencies** in the **surviving population**?

- **50 A alleles** come from **AA individuals**
- **45 A alleles** come from **Aa individuals**
- Thus, the frequency of **allele A** is: $(50+45)/180=0.53$. $(50 + 45) / 180$

$$= 0.53.$$

- **45 a alleles** come from **Aa individuals**
- **40 a alleles** come from **aa individuals**

○ Thus, the frequency of **allele a** is: $(45+40)/180=0.47$. $(45 + 40) / 180$

$$= 0.47.$$

• **Allele frequencies have changed** compared to the initial frequencies. The frequency of **allele A has increased**, while the frequency of **allele a has decreased**.

• The **difference in survival or reproductive success** (or both) between different genotypes is called **natural selection**.

• **Natural selection** is the **main force driving changes in allele frequencies** in **large populations** and is **one of the most important factors in evolutionary change**.

B. Genetic Drift and Random Variations in Frequency

- **Genetic drift** occurs when the number of **reproducing individuals** is too small to allow all alleles in the **gene pool** to be passed to the next generation while maintaining their frequencies. **Drift** is defined as the **change in allele frequencies due to random sampling of gametes**.

- To illustrate this, let's consider a **diploid population** with **sexual reproduction**, consisting of **25 male and 25 female individuals**. Even if individuals reproduce as **25 separate couples** (which is unlikely in a real population) to produce **25 offspring**, the number of gametes forming the **next generation's gene pool** will be only **50**. It is highly unlikely that such a **small number of gametes** will **perfectly reflect** the genetic structure of the **parental population**.

- As a result, **some alleles** may be **overrepresented or underrepresented** in the gamete pool, leading to **random changes in allele frequencies** from one generation to the next.

- If we consider a **single locus** with **two alleles, A and a**, **genetic drift** can eventually lead to the **loss of one allele** and the **fixation of the other**, meaning one allele becomes the **only** representative of this gene in the **population's gene pool**.

- A simple **correlation** describes the **probability of allele fixation or loss**. The probability that an allele is **fixed by drift** is equal to its **initial frequency in the population**.

- If $p = f(A) = 0.8$, the probability that **A is fixed** is **0.8 (80%)**, and the probability that **A is lost** by drift is $(1 - 0.8) = 0.2$ (**20%**).

C. Effects of Mutations

- **Mutation** is a **spontaneous or induced modification** of the genetic information encoded in a cell's **genetic material**. When **chromosomes replicate**, various errors can occur: **substitution, insertion, deletion, or transposition of nucleotides** in DNA.

- **Mutation is the ultimate source of genetic variation**, although most **new mutations**, when they become **homozygous** (meaning both parents contribute identical alleles at the same chromosome locus), tend to be **harmful** in normal environments.

- A balance between **recurrent mutation and loss by selection** helps maintain **harmful alleles** at **very low frequencies**.

- **Radiation or mutagenic chemical agents**, which **increase mutation rates**, can have **serious long-term consequences** for a population.

Non-Recurrent Mutations

- If a mutation is **unique or very rare**, the probability of it **disappearing** is very high due to **sampling fluctuations**.

- A **single mutation** that does not provide a **selective advantage** to the mutant **cannot have a lasting effect** in a population.

Recurrent Mutations

- If a mutation is **recurrent**, it is referred to as **mutation pressure**.

- Let's consider a gene **A** with **two alleles, A₁ and A₂**, with initial frequencies **p₀ and q₀** at time **t₀**:

$$A_1 \xrightarrow{\mu} A_2 \quad A_2 \xrightarrow{\nu} A_1$$

Frequencies:

- $A_1 \rightarrow A_2$ by mutation: μp_0
- $A_2 \rightarrow A_1$ by mutation: νq_0
- In reality, ν is usually much lower than μ , meaning A_1 tends to decrease in favor of A_2 .
- To maintain **equilibrium**, another mechanism—**selection**—must intervene.

D. Inbreeding

• Two people are **related** when they share at least one **verifiable common ancestor**. Individuals born from a union between **relatives** are considered **inbred**. By extension, the term can also refer to the **union itself**.

• The **inbreeding coefficient** is defined as the probability that, at a given **autosomal locus**, an individual has **two alleles that are identical by descent**, meaning they originate from the **replication of an allele** inherited from a **common ancestor** of both parents.

• An inbred individual who is **homozygous at a locus** due to inbreeding is called **autozygous**. The **inbreeding coefficient** is thus the probability that an individual is **autozygous at a given locus**.

Consequences of Inbreeding at the Population Level

In **highly inbred populations**, how do **allelic and genotypic frequencies** change?

- F_i = Average inbreeding coefficient in a **non-random mating population**
- F_i = Mean of the inbreeding coefficients of different couples in **generation**

i

For a **biallelic locus** with two alleles **A₁** and **A₂**, at parental frequencies **p** and **q**, and an average inbreeding coefficient **F** in the parent generation:

At the **next generation**:

$$f(A_1A_1) = Fp + (1-F)p^2 \quad f(A_2A_2) = Fq + (1-F)q^2$$

$$f(A_1A_2) = Fpq + (1-F)2pq$$

Or:

$$f(A_1A_1) = p^2 + Fp(1-p) \quad f(A_2A_2) = q^2 + Fq(1-q)$$

$$f(A_1A_2) = 2pq - 2Fpq$$

• **Inbreeding increases the frequency of homozygotes and decreases the frequency of heterozygotes (genotypic frequencies).**

• **However, allelic frequencies remain unchanged.**

Example:

$$f(A_1) = (p^2 + Fp(1-p)) + \frac{1}{2}(2pq - 2Fpq) = p^2 + Fpq + pq - Fpq = p^2 + pq = p(p+q) = p$$

Thus: **Inbreeding does not deteriorate the gene pool in a large population but increases morbidity for autosomal recessive diseases.**

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