Chapter II: Biological Diversity – An Overview

II.1. The classification of living organisms and its principles

Classification is a way of organizing information by grouping similar entities together. For centuries, humans have attempted to describe, name, classify, and count species, and there have been various approaches to do so. In his time, Aristotle grouped humans and birds together because they both walk on two legs. Today, classifications are based on the degree of genetic similarity between individuals and group organisms according to their phylogenetic relationships.

Taxonomy is the scientific discipline concerned with naming, describing, and classifying living organisms. This highly formalized science follows the rules established by international codes of nomenclature.

Systematics, on the other hand, aims to study the diversity of organisms and to understand the relationships among living and fossil organisms, that is, their degrees of relatedness. What is now called **biosystematics** represents a modern approach to systematics, drawing on information from various sources—morphology, genetics, biology, behavior, ecology, and so forth.

II.1.1. Levels of organization of the living world

One of the main characteristics of the living world is its complex structure: atoms organize themselves into crystals or molecules; molecules form cells capable of reproducing; cells can aggregate or cooperate to constitute multicellular organisms; individuals (unicellular or multicellular) organize into populations and then into multi-species communities.

All organisms interacting within a specific environment form a **biocenosis**. The functional unit combining abiotic factors (**biotope**) and biotic factors (**biocenosis**) forms an **ecosystem**. All ecosystems interacting and modified by human activity constitute a **landscape** or **ecocomplex**. The entirety of ecosystems within the same biogeographical zone constitutes a **biome**, of which there are roughly a dozen worldwide—tropical forests, tundras, deserts, and so on. The **biosphere** represents the ultimate whole of all living beings.

The elementary unit of the living world is the **individual**, bearer of a specific **genetic heritage**. The set of its genes constitutes its **genotype**. A bacterium contains about 1,000 genes; some fungi, around 10,000; and humans, slightly more than 30,000.

- **Species**: A species comprises all individuals capable of interbreeding and producing fertile offspring.
- **Population**: A population refers to all individuals of the same biological species inhabiting the same environment. It is at this level of organization that **natural selection** takes place. Often, a species is distributed among separate populations, whose existence and dynamics depend on exchanges and replacements among them.

- **Communities or Assemblages**: Multispecific groupings, most often defined on taxonomic bases, constitute communities or assemblages. The **biocenosis** encompasses all populations of plant and animal species living within a given environment.
- **Ecosystem**: The term “ecosystem” was introduced by **Tansley (1935)** to designate an ecological system that combines all living organisms with their physicochemical environment. The **Convention on Biological Diversity (CBD)** defines an ecosystem as a “dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.” This legal definition is essentially consistent with that found in ecological literature.
- **Biosphere** (*sensu stricto*) refers to all living organisms inhabiting the Earth’s surface. However, the biosphere (*sensu lato*) is also defined as the superficial layer of the planet containing living organisms, where life is permanently possible. This space thus includes the **lithosphere** (Earth’s crust), the **hydrosphere** (all oceans and continental waters), and the **atmosphere** (the gaseous envelope of the Earth).

II.1.2. Taxonomic hierarchies

Naturalists around the world use the same general nomenclature system proposed by **Linnaeus** to name and classify species. **Systematics**, which is a hierarchical classification of living organisms according to their genetic or morphological proximity, proposes a hierarchy consisting of seven main ranks:

- Kingdom
- Phylum (or Division)
- Class
- Order
- Family
- Genus
- Species

This nomenclature is based on a **binomial system** that combines the species and the genus. The supra-specific categories serve to indicate the degrees of relatedness between taxa of lower rank and to group them into higher hierarchical levels.

Example:

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Odonata
Family: Calopterygidae
Genus: *Calopteryx*
Species: *haemor rhoidalis*

The criteria used to establish the hierarchy of a taxon include **phenetic hierarchy** and **phylogenetic hierarchy**.

- **Phenetic hierarchy:** A classification method based on the assumption that the degree of similarity between organisms correlates with their degree of kinship. The weakness of this method lies in the fact that many resemblances among living organisms cannot be attributed to common ancestry. These are analogies resulting from **convergent or parallel evolution**, not homologies.
- **Phylogenetic hierarchy:** Based on the formation and evolution of living organisms and their evolutionary relationships.
- **Cladistic classification:** A classification method of living organisms founded on their common ancestry. Cladistics arranges compared characters hierarchically; only species that share the same traits inherited from a **common ancestor** are grouped into a **clade**.

Monophyletic groups (clades): Systematic groups composed of an entire evolutionary lineage, including the first species of that lineage and all its descendants (e.g., the insect clade). Members of the same clade share a set of similar characteristics inherited from the original representative of the clade.

Polyphyletic groups: Groups of species that include unrelated lineages and only a part of their descendants, sharing traits not derived from a common ancestor. Examples include invertebrates, reptiles, and fish. Modern vertebrates, for instance, descended from invertebrates.

Paraphyletic groups: Groups of organisms that show similarities but do not all descend from a common ancestor.

II.1.3. The concept of species

The definition of **species** remains a subject of controversy among scientists. Traditionally, a species is considered as the set of individuals identical to each other and to a **type specimen**. Later, another concept emerged the **biological species concept**, where the criterion of **interfertility** (ability to interbreed and produce fertile offspring) serves as a fundamental element.

The species represents the **basic unit of classification**. Within a given species, subcategories may be identified, such as **subspecies**, **strains**, **varieties**, or **races**, etc.

II.1.4. Ecosystems

An **ecosystem** is a dynamic and adaptive system formed by a set of living organisms (**biocenosis**) interacting within a physicochemical environment (**biotope**).

The functioning of an ecosystem is characterized by:

- **Energy flows**
- **Biogeochemical cycles**
- **Food chains**

These three factors evolve over time and space, forming an essentially **dynamic concept** the ecosystem. The **biosphere** represents the ultimate ecosystem.

II.2. The Inventory of Species

Biological diversity is observed at all levels of organization in the living world from genes to ecosystems. However, it is most often discussed in terms of **species diversity**, after counting the species that occupy a given space over a defined unit of time.

Botanists and zoologists began describing and inventorying living species nearly three centuries ago. **Carl Linnaeus** recorded about **9,000 species** of plants and animals in the mid-18th century. Two and a half centuries later, with over **1.7 million species** described, we know that the **inventory of life** is far from complete.

No one actually knows the exact number of living species on Earth, but estimates range from **7 million to 100 million**.

Some groups are better inventoried than others—for instance, **mammals and birds** (over 95% described). **Insects**, on the other hand, account for more than **two-thirds** of all new species descriptions.

The main sources of new species discoveries include **tropical regions**, **coral reefs**, the **deep sea**, and other environments that are **difficult to access**. other groups such as **bacteria** and **viruses**, scientists find it much more difficult to **characterize species** precisely.

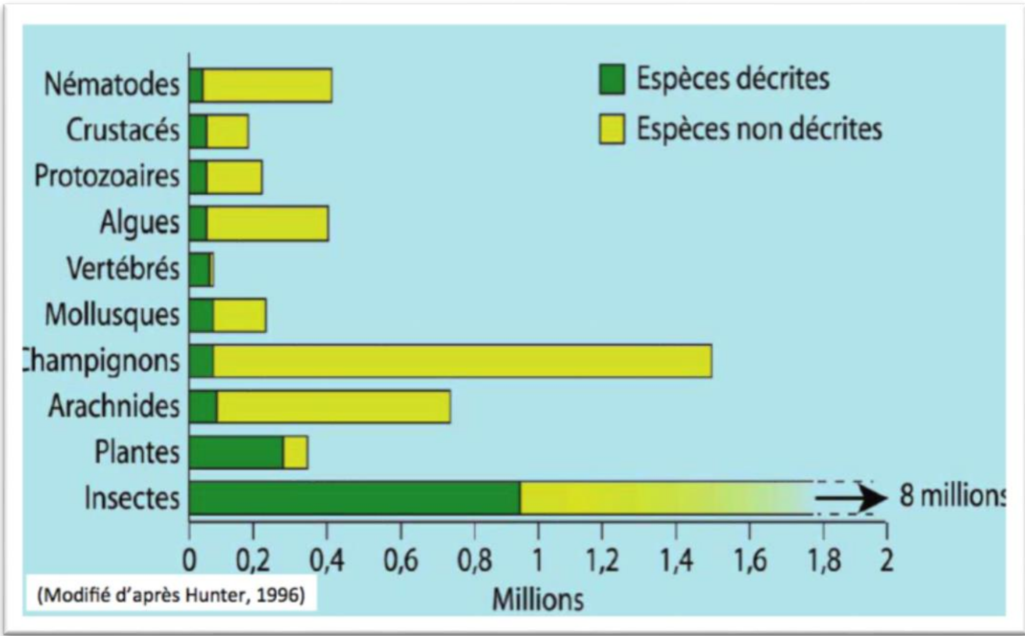

Figure 1: Approximate number of recorded and estimated species.

II.3. Measuring Biological Diversity

There can be **no single, objective measure** of biodiversity, but only **relative measures** reflecting specific trends, uses, or applications. Therefore, it is more appropriate to speak of **biodiversity indices** rather than true indicators.

Biodiversity has **two main components**:

- **Taxonomic richness** (the number of taxa), and
- **Evenness** (the relative abundance of taxa).

II.3.1. Measuring taxonomic richness

- **Absolute measure:** The number of taxa recorded increases with the **sampling effort**.
- **Relative measure:** Expresses the relationship between **richness and area**, obtained by **standardizing the sampling effort**.

II.3.2 Some examples of biological indices

II.3.2.1 Alpha (α) diversity indices

II.3.2.1.1 Ecological indices of composition

The classical diversity indices include those of **Shannon** and **Simpson**, as well as **species richness**. They can be estimated from inventory data, although estimating richness is particularly challenging and has been the subject of extensive literature.

II.3.2.1.1.1 Species richness

Richness (S) is the number of species present in the considered taxon. It is conceptually the simplest measure but practically the most difficult to estimate in highly diverse systems, even with considerable sampling efforts. It is the simplest and most widely used index.

II.3.2.1.1.2 Mean species richness

Mean richness (Sm) is the average number of species present in the samples of a studied community. Mean richness provides valuable information about the **homogeneity (or heterogeneity)** of the spatial distribution of species within the studied community. It represents the **average number of species (Sm)** per sample and is calculated as the ratio between the total number of species recorded in each survey and the total number of surveys carried out.

II.3.2.1.1.3 Frequency of occurrence (C or Fo)

The **frequency of occurrence**, also called **frequency of appearance**, is the ratio (expressed as a percentage) between the number of surveys containing the studied species and the total number of surveys conducted. It is calculated using the following formula:

$$C = (Pi/P)\ x100$$

Where:

Pi = number of surveys containing the studied species

P = total number of surveys conducted

According to the value of **C**, species can be classified as follows:

Omnipresent species if C = 100%
Constant species if 75% ≤ C < 100%
Regular species if 50% ≤ C < 75%
Accessory species if 25% ≤ C < 50%
Accidental species if 5% ≤ C < 25%
Rare species if C < 5%

II.3.2.1.1.4 Centisimal Frequency (F or AR)

The **centisimal frequency (F)** is calculated according to the following formula:

$$F = (ni\ /\ N)x100$$

Where:

F% = centisimal frequency
ni = total number of individuals of the considered species
N = total number of individuals of all species combined

According to the relative abundance value of a species, individuals can be classified as follows:

If F > 75% → the species is **very abundant ;**

If 50% < F ≤ 75% → the species is **abundant ;**

If 25% < F ≤ 50% → the species is **common ;**

If 5% < F ≤ 25% → the species is **rare ;**

If F ≤ 5% → the species is **very rare.**

II.3.2.1.2 Ecological indices of structure

II.3.2.1.2.1 Shannon-Weaver Diversity Index (H')

Diversity takes into account not only the **number of species** but also the **distribution of individuals among species**. The **Shannon-Wiener index** is one of the two main diversity indices developed.

The **Shannon index**, also called the **Shannon-Weaver** or **Shannon-Wiener** index, is the simplest and most widely used in its category. It is calculated using the following equation:

$$H' = - \sum_{n=1}^{S} pi \, x log2 \, (pi)$$

Where:

S = total number of species
pi = (ni / N), the proportion of taxon *i* in the sample
ni = relative frequency of species *j* in the sampling unit
N = sum of the specific relative frequencies

Table 1: Example of Shannon-Weaver Index Calculation

Espèces de la station	Fréquence spécifique (n_i)	$p_i = n_i/N$	$\log_2 p_i$	$-p_i \log_2 p_i$
Marrubium vulgare L.	4	4/23 = 0.1739	-2.5236	0.4389
Olea europea L.	2	2/23 = 0.0870	-3.5236	0.3064
Pistacia atlantica Desf.	1	1/23 = 0.0435	-4.5236	0.1967
Ruta chalepensis L.	1	1/23 = 0.0435	-4.5236	0.1967
Asphodelus microcarpus Sal. & Viv.	4	4/23 = 0.1739	-2.5236	0.4389
Thymus ciliatus Desf.	1	1/23 = 0.0435	-4.5236	0.1967
Silybum marianum L.	10	1/10 = 0.4348	-1.2016	0.5224
N (effectif total)	23			
S (richesse spécifique)	7			
Indice de Shanon ($\sum -p_i \log_2 p_i$)	**2.2966**			

The higher the value of the **H' index**, the greater the diversity. Before discussing fluctuations in H' values, it is necessary to mention **H'max**, or the **maximum diversity value**, which serves as an important reference in evaluating H'.

From the previous equation, the maximum diversity value can be calculated as follows:

$$H'max = log2 \, (S)$$

H'max is directly related to the value of **species richness (S)**. When richness is high, the Shannon-Wiener diversity index reaches its maximum value, represented by **H'max**.

II.3.2.1.2.2 Pielou's Evenness Index (J)

Evenness represents the regularity in the distribution of species an important component of diversity. It is derived from the Shannon index using the following formula:

$$J = H'/H'max$$

The value of **J** ranges between **0 and 1**.

The relative abundance structure of species determines **evenness** or the **dominance component** of diversity.

Given a phytocoenosis composed of **S species**, diversity is higher when all species are well represented (high evenness, low dominance) than when a small number of species (T) are very common and the rest (S–T) are present but rare (low evenness, high dominance).

Evaluating evenness is useful for detecting changes in community structure and has sometimes proven effective for identifying **anthropogenic impacts**.

Evenness, or **equirepartition**, measures the balance within a community:

It is **maximal** when all taxa have identical abundances.
It is **minimal** when nearly all individuals are concentrated in a single taxon.

II.3.2.1.2.3 Dominance Index (D)

This group of indices considers the **measured frequency of species**. They give greater weight to the most frequent species than to total species richness and are therefore more sensitive to dominant species. The dominance index **D** is calculated as follows:

$$D = \sum_i \left(\frac{ni}{n}\right) x \left(\frac{ni}{n}\right)$$

Where:

ni = number of individuals of taxon *i*
n = total number of individuals
The dominance index ranges between **0 and 1**:
D = 0 → all taxa are equally represented
D = 1 → one taxon completely dominates the community

II.3.2.2 Study of β-Diversity

II.3.2.2.1 Jaccard Similarity Index

This index quantifies the **similarity between habitats**. Similarity increases with the value of the index. It is calculated using data from stations (surveys, inventories, transects) based on a species-by-survey matrix.

$$PJ = ca+b-cx\ 100$$

Where:

a = number of species in list A (survey A)
b = number of species in list B (survey B)
c = number of species common to both surveys A and B

II.3.3 Types of Diversity

II.3.3.1 Alpha Diversity (α)

Alpha diversity refers to **local diversity**, measured within a defined ecosystem. It represents the **species richness** within a local ecosystem.

II.3.3.2 Beta Diversity (β)

Beta diversity (**between-site diversity**) compares species diversity **between ecosystems** or along **environmental gradients**. It reflects how alpha diversity changes from one ecosystem to another within a region.

II.3.3.3 Gamma Diversity (γ)

Gamma diversity (**regional diversity**) corresponds to **species richness** at a regional or geographic scale.

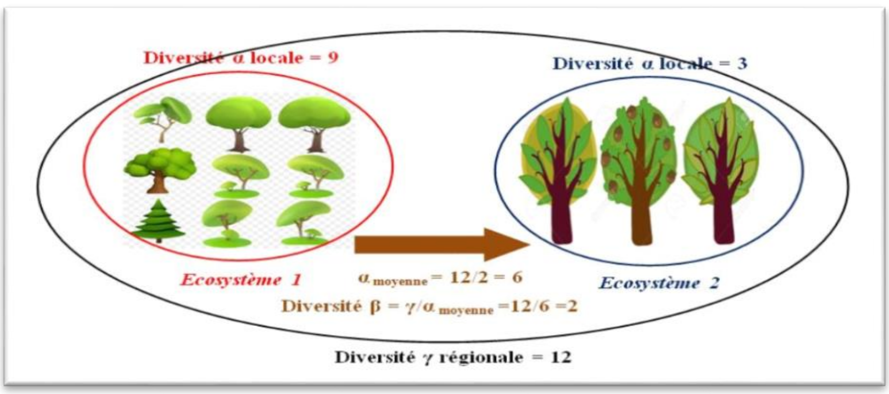

Figure 2: Example of the calculation of α, β, and γ diversity.

II.4 Geographical distribution of biological diversity

Biogeography refers to the distribution of diversity across regions, continents, and the biosphere a result of evolutionary processes. This discipline helps explain diversity patterns responsible for the distribution of living organisms, influenced by factors such as **climate, altitude, longitude, latitude, and topography**.

Biological diversity is **not evenly distributed** across the planet. In marine environments, all known major phyla are represented 15 are exclusively marine, while only one group, the **Onychophora**, is strictly terrestrial.

II.4.1 Gradients of spatial distribution

Gradients are the factors that explain the spatial distribution of species. Studying gradients helps better understand the organization of biological diversity.

II.4.1.1 Latitudinal Gradients

A major biogeographic pattern is the **decrease in species diversity with latitude**. This trend is observed among **protists, marine invertebrates, fish, birds, mammals, and plants**, and is primarily influenced by **sunlight** and **annual precipitation**.

Species richness increases **from the poles toward the equator** for most taxonomic groups.
Few groups, such as **soil nematodes**, show an opposite trend, with greater specific richness at higher latitudes.

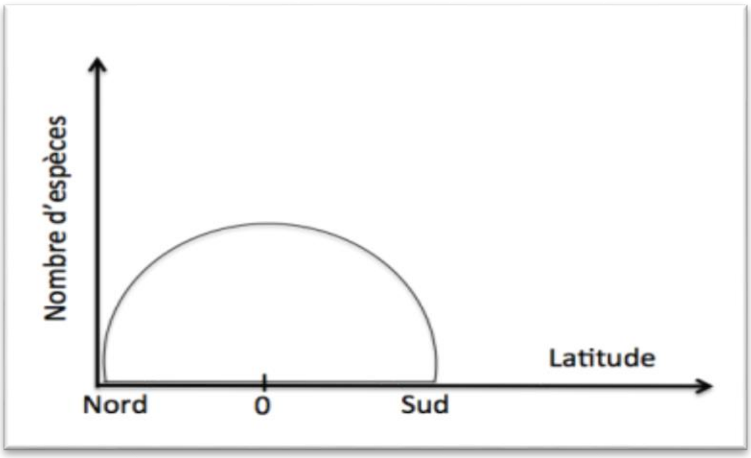

Figure 3: Schematic curve showing species richness distribution (amphibians, reptiles) across latitudes.

II.4.1.2 Longitudinal gradients

In marine environments, a well-established longitudinal gradient is observed in **coral diversity**.

The **highest species richness** occurs in the **Indonesian archipelago**, decreasing westward irregularly across the Indian Ocean (with exceptions in the Red Sea for certain groups) and reaching its lowest levels in the **Caribbean**.

II.4.1.3 Altitudinal gradients

Temperature and **rainfall** are the main physical factors shaping this gradient. For some taxa, species richness decreases with altitude; for others, richness follows a **bell-shaped curve**.

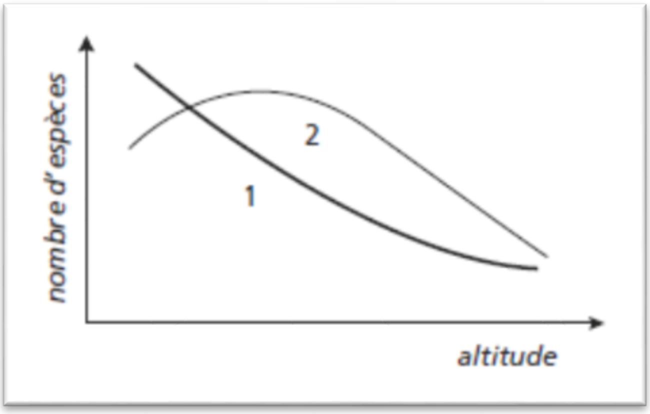

Figure 4: Changes in species richness with altitude.
1: Gradual decrease observed in bats of Manu National Park (Peru);
2: Dome-shaped distribution observed in terrestrial birds of South America.

II.4.1.4 Depth

In general, **biological diversity** is higher in **benthic environments** than in **pelagic ones**, and higher in **coastal** than **open-ocean** habitats.

II.4.2 Species–Area relationships

The **species–area relationship** can be explained as follows: As area increases, **habitat diversity** also tends to increase. Communities are thus richer in species when habitats are more diverse.

According to the **MacArthur and Wilson (1967) theory of island biogeography**, the number of species observed on an island results from a **dynamic equilibrium** between **natural extinction** and **immigration** from a richer continental source.

II.4.3 Ecological organization: The Biomes

The number of recognized **biomes** depends on the chosen resolution, ranging from **10 to 100** according to different authors. **Vegetation** serves as the primary basis for delimiting these biomes.

II.4.4 Taxonomic organization: Biogeographical regions

Based on historical knowledge and current distribution patterns, six major regions corresponding to the main continental plates are recognized:

- **Afrotropical (Africa)**
- **Neotropical (South America)** — tropical regions
- **Indo-Malayan (Oriental)**
- **Nearctic (North America)**
- **Palearctic (Eurasia)** — temperate and cold zones
- **Australian (Australia)**

Additionally, the **Pacific Islands** and **Antarctica** are recognized as separate regions.

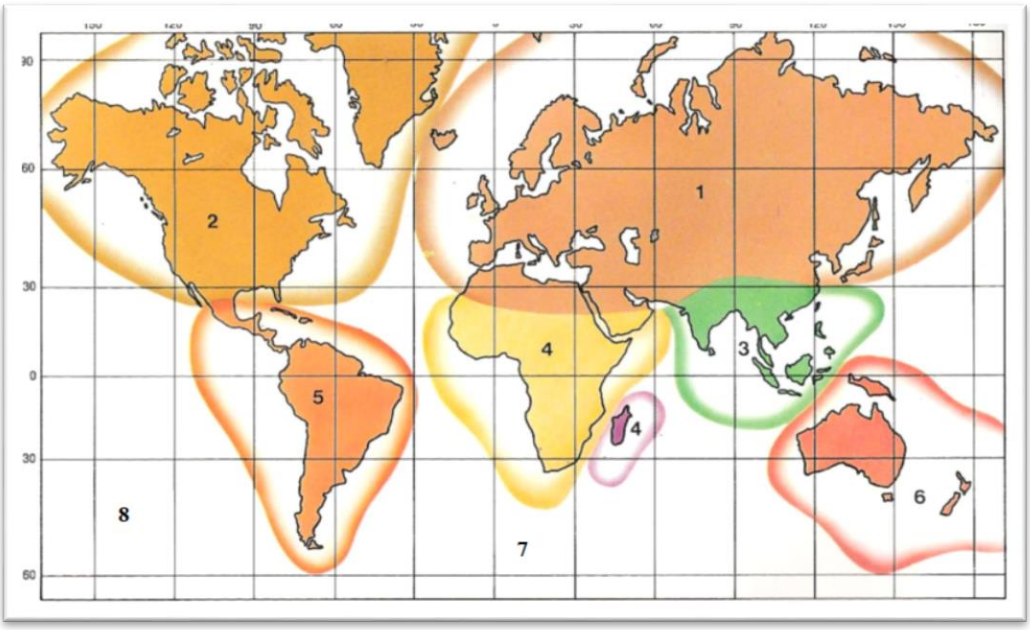

Figure 5: Map of the world's major biogeographical regions.
1: Palearctic (PA) 2: Nearctic (NA) 3: Oriental (OL) 4: Afrotropical (AT) 5: Neotropical (NT) 6: Australian (AU) 7: Antarctic (ANT) 8: Pacific Islands (PAC)

II.4.5 Areas of High Diversity : The Hotspots

Because conservation has a cost, efforts must focus where diversity is greatest. A 1988 study by **Norman Myers** showed that **44% of all vascular plants** (over 130,000 species) and **35% of vertebrates** (excluding fish, about 10,000 species) are concentrated in **high-diversity areas covering only 1.4% of Earth's surface**.

These regions are called **biodiversity hotspots** areas remarkable for their species richness, and therefore **priorities for conservation**.

The young NGO **Conservation International**, founded in 1987, identified a number of global hotspots to **focus conservation resources** efficiently. Today, **34 hotspots** are officially recognized.

Most of these sites are located in **tropical regions**, five are in the **Mediterranean Basin**, and nine are **islands**.

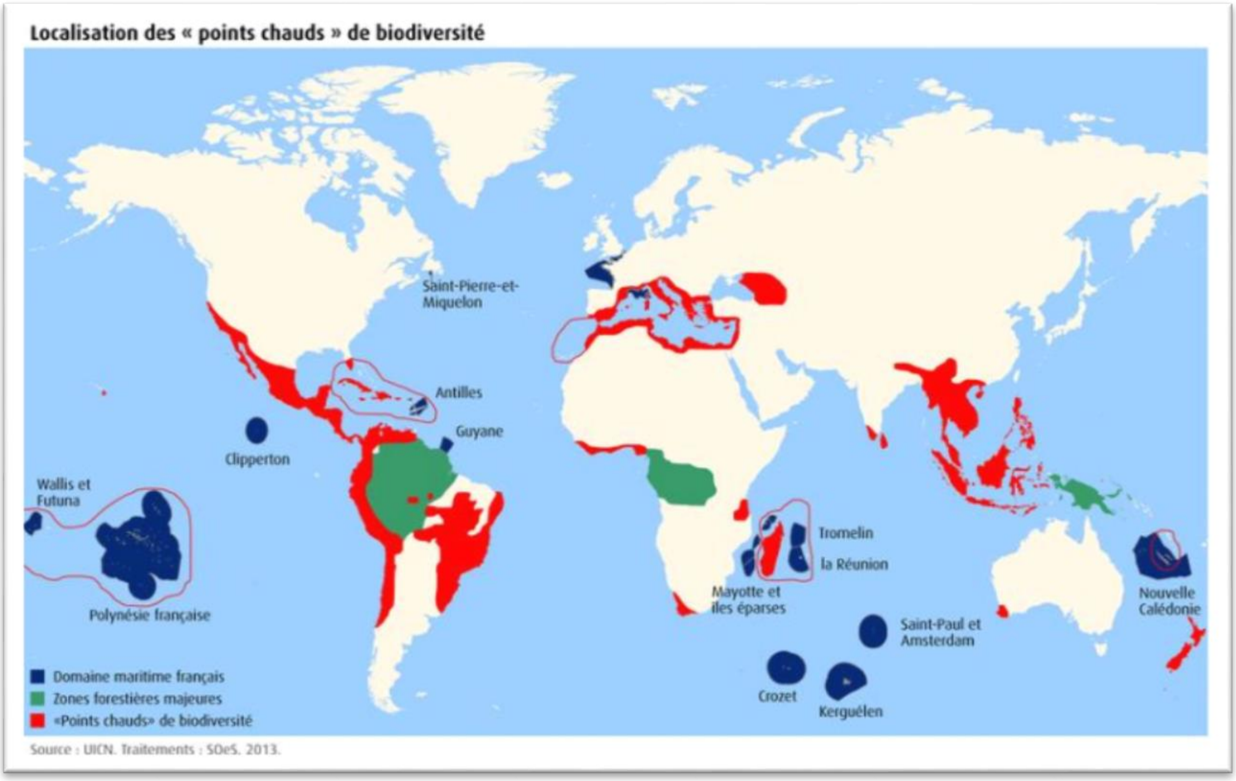

Figure 6: The 34 biodiversity hotspots and their percentage of global biological diversity.