Chapter 3: Structure and organization of biocenoses

3.1 Definition

A community (=Biocenosis) is a biological system formed by the populations inhabiting a given biotope at a specific time. Although composed of bacteria, fungi, plants, animals, and other living organisms, it is a relatively uniform grouping in appearance and composition (floristic and faunal). The populations forming such a biotic community live together in an orderly and coordinated manner. Thus, the biocenosis can be subdivided into functional units: producers, consumers, and decomposers.Métabolisme

A biocenosis has a defined organization based on trophic levels. Green plants are the autotrophic producers, and animals are the consumers, which can be classified into first order, second order, etc. Food chains are thus formed, where the question is who eats whom? Other organisms (decomposers) cause these chains to close.

3.2 Qualitative expression of biocenoses (Structure in time and space)

The community has a defined structure. The distribution of organisms is such that it makes the best use of the conditions offered by the abiotic environment. Chorological links (that is, links related to the distribution of species in space) are established between living beings competing for light, food, water, or seeking protection against an unfavorable environmental factor or an enemy. This results in a structuring of the biocenosis in space (strata) and in time (phenophase).

3.2.1 Vertical structure = Vertical stratification of phytocenoses

For animals, the vertical distribution is less rigid:

- ✓ burrowing animals in the soil;
- ✓ walking or crawling animals on the ground;
- ✓ climbing animals;
- ✓ flying animals, etc.

It comprises 4 main layers in the forests: tree, shrub, herbaceous and moss.

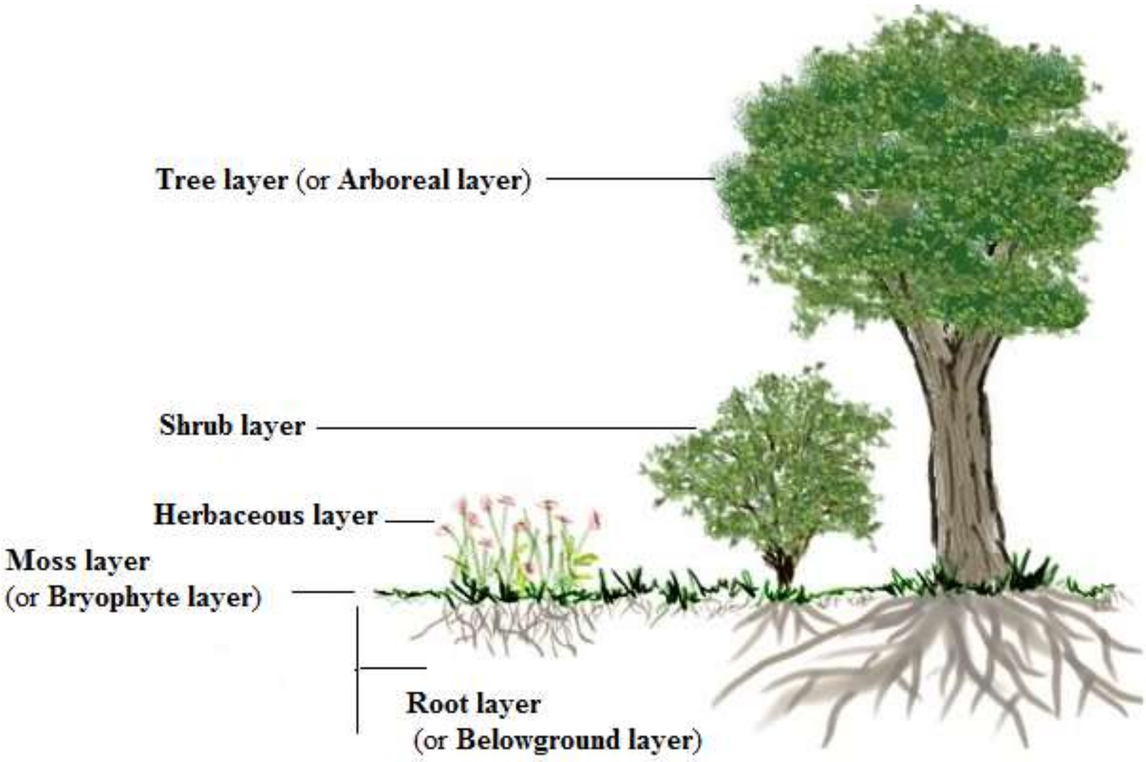

Figure 3.1: Vertical stratification of vegetation in a terrestrial ecosystem, showing tree, shrub, herbaceous, moss and root layers (modified after Odum & Barrett, 2005).

- The moss layer (cryptogamic): occupies the first few decimeters of the surface and is composed of mosses, terrestrial lichens, fungi, and various dwarf plants.

- The herbaceous layer (5 to 80 cm): of mixed composition, it includes tree seedlings, understory herbaceous plants, and is mainly composed of grasses, flowering plants, ferns, as well as small woody subshrubs such as heathers, cranberries, blueberries, rhododendrons, etc.

- The shrub layer (1 m to 10 m): made up of shrubs and small trees. It is often subdivided into a strict shrub layer (shrubs 3 to 10 m tall) and a subshrub layer consisting of either woody plants that rarely exceed this height (holly, rowan, yew, boxwood, etc.) or young trees.

- Above 10 meters in height, the plants belong to the tree layer.

In tropical forest ecosystems, this stratification is sometimes more difficult to discern, either because the canopy is too dense to allow for true stratification, or because the abundance of lianas or epiphytes distorts the perception of stratification.

Note: Underground stratification: this corresponds to the layering in depth of the root system of the different individuals constituting a plant stand. Thus, it corresponds to the inverted image of the aboveground layer.

3.2.1 Horizontal structure of phytocoenoses

The horizontal structure of phytocoenoses refers to the spatial distribution of plant individuals across the ground surface. In a strict sense, it corresponds to the density and relative abundance of the different plant species within the phytocoenosis. This structure is rarely uniform and generally exhibits varying degrees of spatial heterogeneity, resulting from environmental gradients, species interactions, and disturbances.

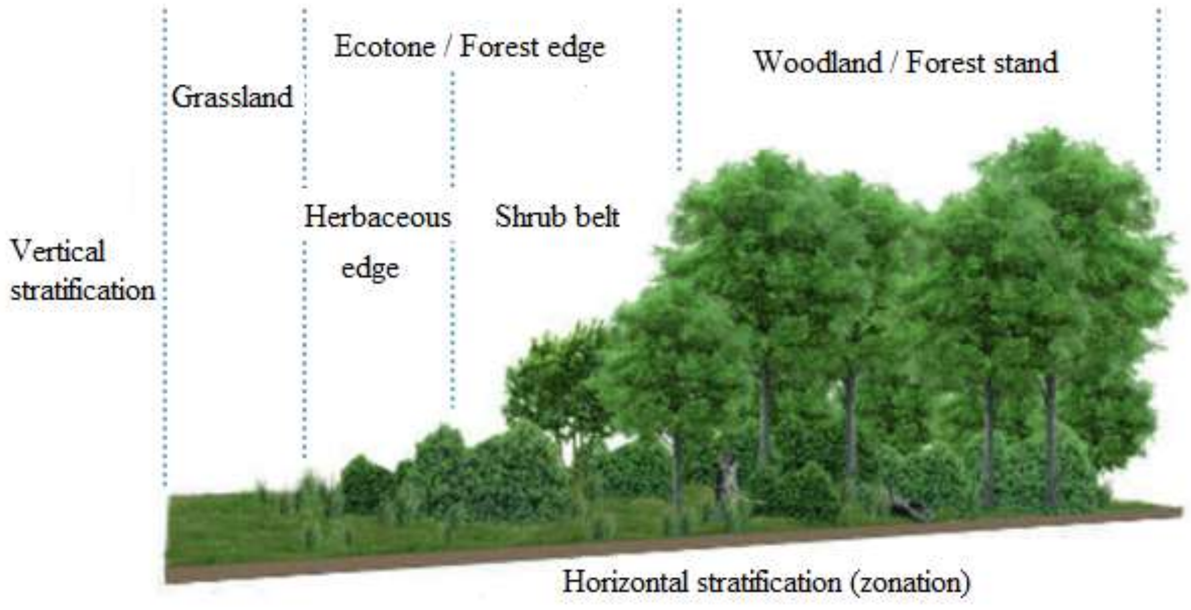

Figure 3.2: Horizontal and vertical vegetation stratification along a grassland-forest gradient, showing the herbaceous fringe (ourlet), shrub mantle (manteau) and woodland core (modified after Ramade, 2009).

3.2.2 The biological spectrum of plant communities

This characterizes the relative proportion (%) of the various biological forms, including:

- ✓ Phanerophytic (e.g., rainforests);
- ✓ Hemicryptophytic (e.g., temperate and boreal forests);
- ✓ Chamaephytic (e.g., tundra);
- ✓ Therophytic (e.g., deserts).

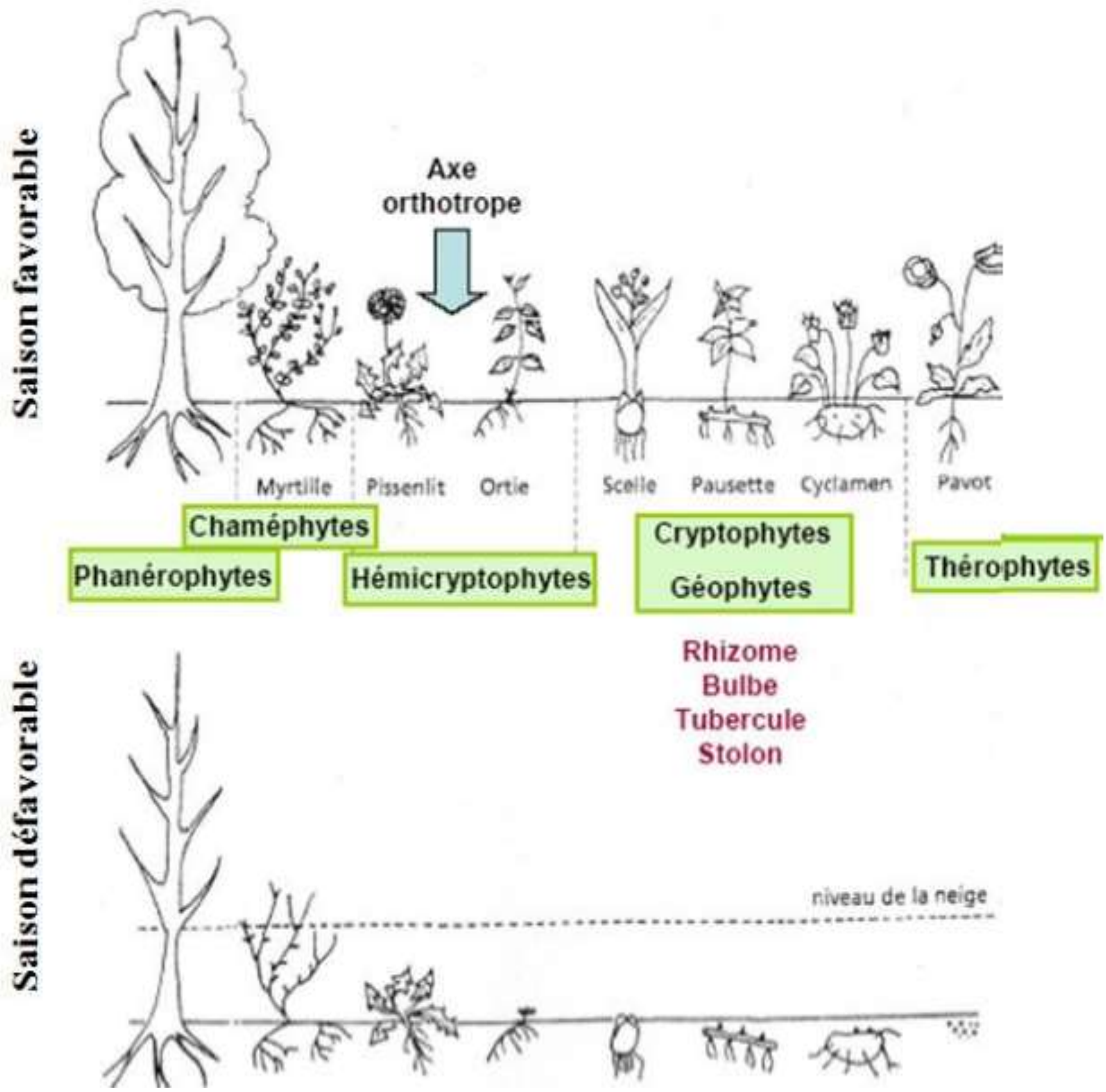

Figure 3.3. Different biological life forms according to Raunkiaer's classification based on plant survival strategies during the unfavorable (winter) season.

3.4 Quantitative expression

To describe the composition of a biocenosis, a set of descriptors is used that takes into account the numerical importance of plant and animal species. By counting (density) within each plant or animal community the total number of species that compose it, as well as the population sizes of each species, it is possible to describe the structure of the biocenosis through parameters such as species richness, abundance, dominance, diversity, etc.

This variability of living organisms present in a given environment reflects biodiversity, which is expressed at different levels of biological organization:

- **Genetic diversity**: variability of genes within a species
- **Species diversity**: variety of species in an ecosystem
- **Ecosystem diversity**: diversity of natural habitats

In terrestrial ecosystems, particularly in Mediterranean and semi-arid zones such as those found in Algeria, biodiversity constitutes a fundamental indicator of ecological stability, soil fertility, and the functioning of agroecosystems.

To quantify this biodiversity, ecologists use biodiversity indices.

3.4.1 Species Richness

Species richness (S) is a measure of the biodiversity of all or part of an ecosystem; it refers to the total number of species present in a given sample or environment. It is a way of assessing changes in biodiversity induced by the expansion of a highly competitive species.

Example: In an agroecosystem, we count 35 earthworms, 20 beetles, 50 mites, and 70 nematodes.
Therefore, species richness **S = 4 species**.

However, this measure does not take into account the relative abundance of species.

3.4.2 Species Abundance

This is another parameter used to describe the structure of a community. Density, that is, the number of individuals of each species present per unit area, is commonly used to estimate abundance. The use of biomass and/or dry weight per unit area provides a more accurate estimate of abundance when comparing communities composed of species of very different sizes.

The relative abundance (**Pi**) of a species is given by:

$$Pi = \frac{ni}{N}$$

Where:

- **n_i**: number of individuals of species *i*
- **N**: total number of individuals of all species combined

3.4.3 Dominance

Dominance expresses the area covered by the species studied. This dominance is expressed numerically using the Braun-Blanquet scale:

5: species covering more than 3/4 of the area;
4: species covering more than 3/4 to 1/2 of the area;
3: species covering more than 1/2 to 1/4 of the area;
2: species covering more than 1/4 to 1/20 of the area;
1: Species covering less than 1/20 of the surface area.

Simpson proposed a dominance concentration coefficient (C) as a measure of dominance, expressed as follows:

$$C=\sum_{i=1}^{S}[\frac{ni}{N}]^2$$

Or S is the total number of species present in the population, nor the number of individuals of species of rank i and N the total number of individuals.

3.4.4 Main Biodiversity Indices

Several diversity indices are used to provide a quantitative expression of the structure of the communities under study. The introduction of the concept of species diversity by ecologists aimed to account for the unequal distribution of individuals among species.

Among the indices developed to estimate this diversity, the Shannon index (Ish) remains the most widely used and shows clear superiority over others, such as the Margalef index (Daget, 1979).

3.4.4.1 Shannon–Weaver Index (H')

The Shannon index represents an amount of information about the community structure of a given sample and the way individuals are distributed among different species. A low diversity index indicates a young community with high reproductive potential, dominated by one or a few species, whereas a high index characterizes mature populations with a complex species composition (Iltis, 1974) and relatively high community stability.

The Shannon–Weaver index is the most commonly used and is recommended by several authors (Gray et al., 1992). The Shannon index measures the heterogeneity of a biological community by taking into account:

- species richness
- species abundance

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i$$

As a guideline :

- **H' > 3** : high diversity
- **1 < H' < 3** : moderate diversity
- **H' < 1** : low diversity

The Shannon index expresses diversity by considering both the number of species and the abundance of individuals within each species. Thus, a community dominated by a single species will have a lower index value compared to a community in which all species have similar abundances.

3.4.4.2 Simpson Index (D)

The Simpson index measures the probability that two individuals randomly selected from a sample belong to the same species.

$$D = \sum_{i=1}^{S} P_i^2$$

It is often expressed as 1−D

- If the value of **1 − D** is close to **0**: low diversity;
- If the value of **1 − D** is close to **1**: high diversity;
- A strong dominance of a single species results in low diversity.

3.4.4.3 Pielou's Evenness Index (J)

Pielou's evenness index (J), also called regularity, measures the degree to which individuals are distributed among the different species in a community while taking species richness into account. It corresponds to the ratio between the observed diversity (**H'**) and the theoretical maximum diversity (**H'max**). Its value ranges from **0** (dominance of a single species) to **1** (equal distribution of individuals among species) (Blondel, 1979).

It measures the distribution of individuals among species while accounting for species richness:

$$J = \frac{H'}{H'_{\max}} = \frac{H'}{\log_2 S}$$

Where:

- **H'** is the Shannon diversity index
- **S** is species richness
- **$\log_2(S)$** is the maximum value that **H'** can reach when all species have the same abundance

The maximum diversity **H′max** depends directly on the number of species **S**. Therefore, evenness is standardized by species richness.

- When **J ≈ 0**: strong dominance
- When **J ≈ 1**: homogeneous distribution

3.4.4.4 Margalef Index (R)

The Margalef index (R) is one of the most commonly used indices in ecology to assess the species richness of a biological community while taking into account the size of the studied sample. Unlike diversity indices such as Shannon or Simpson, which incorporate both species richness and relative abundance, the Margalef index mainly focuses on the number of species present in a given environment, adjusted by the total number of individuals recorded.

The Margalef index expresses species richness as a function of the total number of individuals observed in a sample. It is particularly useful for comparing species diversity between different natural environments or among several study sites with varying sample sizes.

$$R = \frac{S - 1}{\ln N}$$

Where:

- **S**: total number of species recorded in the sample (species richness)
- **N**: total number of individuals of all species combined
- **ln**: natural logarithm

In general:

- **R** < **2**: low species richness
- **2** < **R** < **5**: moderate species richness
- **R** > **5**: high species richness

The Margalef index increases with:

- an increase in the number of species (**S**)
- the biological complexity of the environment

It decreases when:

- a single species strongly dominates
- species richness is low
- ecological conditions become restrictive (water stress, anthropogenic disturbances, salinity, etc.)