Chapter IV: Biological diversity and the functioning of ecological systems

Ecologists study three major types of processes involving the living world within ecosystems through:

• trophic dependence relationships among groups of organisms (food chains or trophic networks);

• the role of species in the dynamics of biogeochemical cycles;

• and biological production, that is, the capacity to produce living matter and thus to accumulate energy within an ecosystem.

IV.1. Functions of species in ecosystems

Species differ from one another in the way they use and transform resources, in their impact on the physico-chemical environment, and in their interactions with other species. They are characterized by their ecological niche.

IV.1.1. Keystone species

Some species are more important than others within the network of interactions in ecosystems. A species whose loss would cause significant changes in the structure and functioning of an ecosystem is referred to as a **keystone species**. When a keystone species disappears, an ecosystem may undergo a major decline, even if the species in question had low abundance or productivity. It is not necessarily a large species, but rather one that structures its ecosystem (e.g. keystone predators, keystone mutualists). **Example:** pollinator species (bees).

IV.1.2. Ecosystem engineers

These are organisms that directly or indirectly control the availability of resources for other species by causing changes in the physical state of their environment. **Autogenic engineers** modify the environment through their own physical structure. This is the case for trees and corals which, due to their physical structures, create habitats for other species. **Allogenic engineers** modify the environment by transforming its structure. Thus, beavers, by cutting trees to build dams, alter the hydrology and ecology of rivers. Other examples of allogenic engineers include termites, ants, and earthworms, which dig and mix soils, modify their organic and mineral composition, as well as nutrient cycling and drainage.

IV.1.3. Functional groups

Functional groups are defined as sets of species that exert a similar effect on a given process or respond in a similar way to changes in external constraints. For example, they may include all species that exploit the same category of food resources, or all species involved in major biogeochemical cycles (nitrogen, carbon, etc.).

IV.1.4. Rare species

In every ecosystem, there are rare species that are observed only occasionally. The term *rare* generally refers to species that meet at least one of the following two characteristics: low population size and a relatively restricted geographic distribution. The causes of species rarity, aside from anthropogenic influences, can be summarized as follows:

- Large body size, which requires a large home range;
- Specific edaphic and climatic requirements;
- Interannual variability in abiotic factors;
- Species that are on the verge of extinction.

Iv.1.5. Hypotheses concerning the role of species in ecosystem functioning

To understand the contribution of species to matter and energy flows, scientists have compared different ecosystems. These comparisons show that species may display functional similarities. **Example:** phytoplankton and photosynthetic plants perform the same function in two different ecosystems, aquatic and terrestrial. Several hypotheses have been proposed to explain the relationship between the nature of species and species richness.

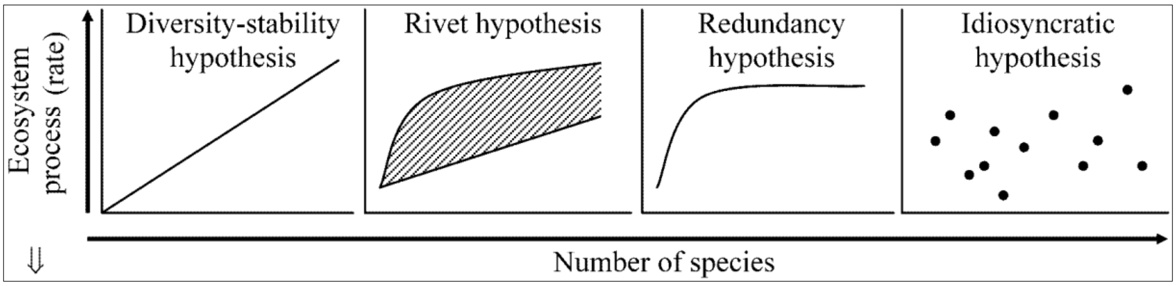

Figure 8: Example of a few hypotheses concerning the relationships between diversity and ecosystem function.

IV.1.5.1. The Diversity–Stability hypothesis

According to this hypothesis, energy flow within trophic networks is better maintained when there is a high number of interspecific interactions. If some links are broken following the disappearance of one or more species, other links can be established and substitute for those that have been lost. The corollary is that the ecological functions of different species overlap, so that if one species disappears, the function it performed can be compensated for by others.

IV.1.5.2. The "Rivet" hypothesis

According to another metaphor developed by Paul Ehrlich, biodiversity is compared to the rivets of an airplane. Losing a few rivets has no immediate consequence for the airplane or its passengers; however, beyond a certain number of missing rivets, the remaining ones also begin to fail under mechanical stress. The airplane then loses its balance and breaks apart in mid-air. Biodiversity is therefore of fundamental importance, as the consequences become catastrophic beyond a certain level of decline.

The capacity of an ecosystem to absorb changes in species richness decreases progressively as species disappear, even if ecosystem performance appears unchanged at first. According to this hypothesis, each species plays a role in the ecosystem, and each extinction gradually weakens the integrity of the system. Beyond a certain threshold, a significant alteration of ecosystem functioning occurs.

IV.1.5.3. The "Drivers and passengers" hypothesis

This hypothesis is an alternative to the previous one and is based on the principle that not all species play an equivalent role. Many species are considered redundant (*passengers*), whereas only a few (*drivers*) play an essential role in maintaining the integrity of the ecosystem. These species, which have a greater ecological function than others, include for example ecosystem engineers or keystone species. It is their presence or absence that determines the stability of an ecological function.

IV.1.5.4. The Idiosyncratic hypothesis

A final hypothesis considers the possibility that there is no consistent relationship between species composition and ecosystem functions. These functions change when biological diversity changes, but the magnitude and direction of these changes are not predictable, because the role of each species is not fixed and may vary from one environment to another.

IV.2. Species diversity and biological production

Species-poor environments such as deserts or tundra exhibit low biological production. Species-rich environments such as tropical or humid forests show high biological production. In contrast to these two examples, agricultural systems characterized by monoculture display high biological production. High productivity is therefore not necessarily associated with high biological diversity.

Three general conclusions emerge from various experimental studies aimed at understanding the relationship between species richness and ecosystem productivity:

- Greater species richness provides a form of insurance, which can be described as a compensation system;
- Functional types and biological traits are more important factors for biological production than species richness itself;
- Interactions among species can generate positive or negative feedback effects, whose responses are very complex to understand.

IV.3. Biological diversity and ecosystem stability

The concept of stability is often debated, but it is based on the idea that an ecosystem has a structure and a mode of functioning that persist over time. The terms **persistence** or **permanence** are sometimes used to describe ecological systems that maintain themselves over time without notable changes. The term **resilience** (or **homeostasis**), on the other hand, refers to the capacity of an ecosystem to recover its original structure after having undergone a disturbance.

Biological diversity helps maintain the stability and persistence of ecosystems and leads to biological diversification.

IV.4. Role of biological diversity in biogeochemical cycles

Ecosystem productivity is closely dependent on the availability of nutrient resources, which control primary production at the base of trophic chains. The circulation of nutrients is governed jointly by chemical processes and by the biological components of ecosystems (their presence and use).

IV.4.1. Biological nitrogen fixation

Biological nitrogen fixation is the main mechanism through which nitrogen is introduced into the biosphere. In marine environments, only **cyanobacteria** have the ability to use dinitrogen (N_2) to meet their metabolic needs. In terrestrial environments, there are two main groups of nitrogen-fixing bacteria associated with higher plants:

- the large group of **Rhizobium**, associated with legumes (families Papilionaceae, Mimosaceae, Caesalpiniaceae);

- **Frankia**, filamentous, spore-forming bacteria (actinomycetes) associated with trees and shrubs of the genera *Alnus*, *Casuarina*, etc.

The bacterium **Nitrobacter** alone is believed to carry out the nitrification function in soils.

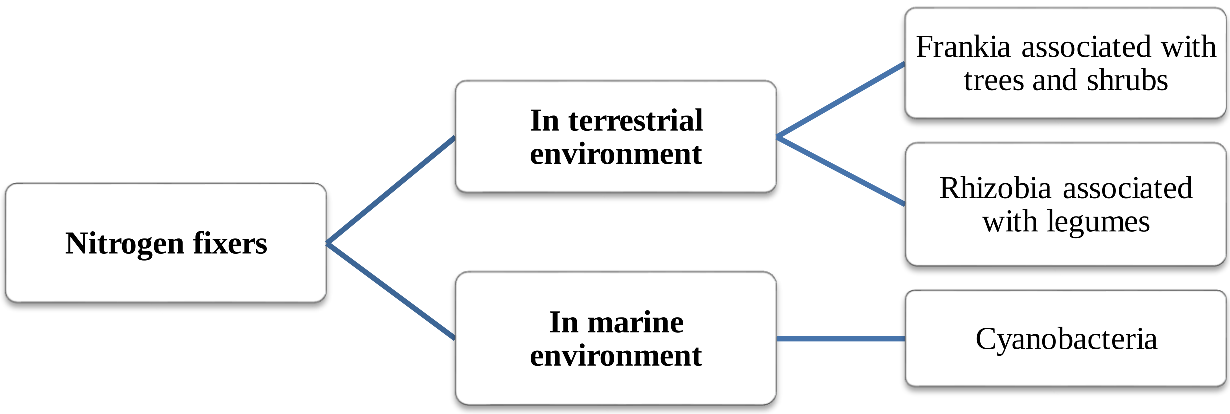

Figure 9: Nitrogen fixation by bacteria in terrestrial and marine environments.

IV.4.2. Mineralization of organic matter

Prokaryotes play a fundamental role in biogeochemical cycles by decomposing detrital organic matter, thereby releasing inorganic elements that can be used to synthesize new organic molecules.

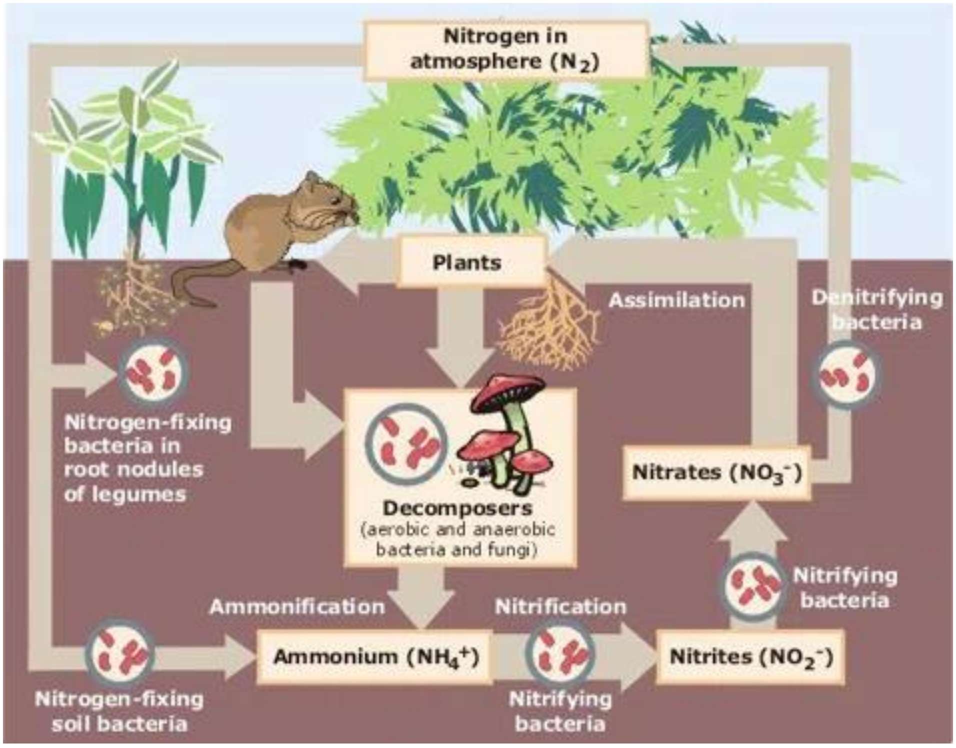

Figure 10: Simplified representation of nitrogen transformation under bacterial control.

IV.4.3. Long-term storage of mineral elements

Biogeochemical cycles involving living organisms also lead to the accumulation of significant sedimentary formations, resulting in the long-term storage of certain elements that remain outside biogeochemical cycles for often very long periods. The most representative example is fossil fuels (lignite, coal, petroleum, etc.), which result from an interruption of the remineralization processes of plants and animals.

IV.4.4. Recycling and transport of nutrients by consumers

Due to their mobility, consumers can also transport nutrients to different parts of the ecosystem. **Example:** Pacific salmon (*Oncorhynchus kisutch*), which return to spawn and die in the upper reaches of rivers after growing in the ocean.

IV.5. Role of biological communities

While certain species play a decisive role in ecosystem functioning, communities as a whole represent another level of integration within the hierarchy of the living world and also perform important functions.

IV.5.1. Importance of microorganisms in the structure and functioning of pelagic trophic networks in aquatic environments

Traditionally, the trophic chain was viewed as linear, but we now know that microorganisms can significantly control the main flows of energy and nutrients. A large portion of primary production (sometimes over 50%) is diverted into the **microbial loop**, through which nutrients are rapidly remineralized and reintegrated into the pool of dissolved inorganic substances. Through this rapid recycling and remineralization process, the microbial loop ensures a continuous renewal of the nutrients necessary for phytoplankton growth.

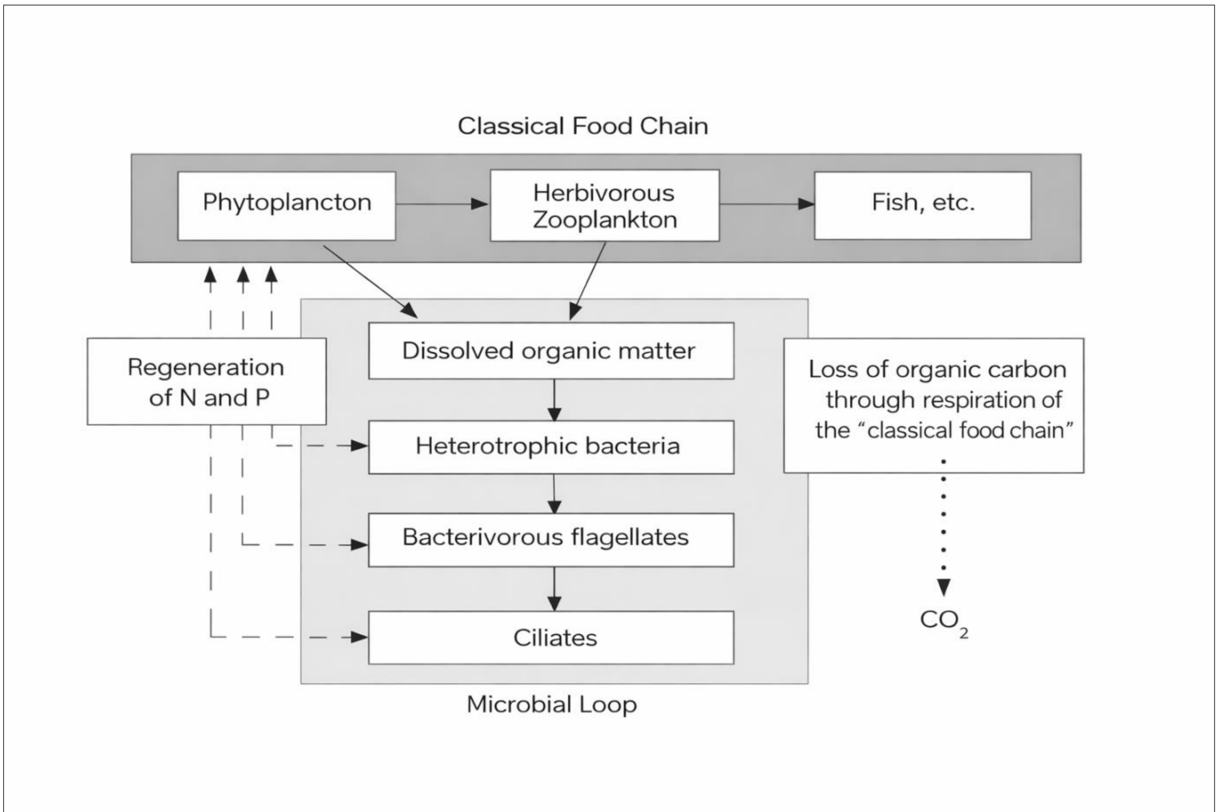

Figure 11: The microbial loop in a lake environment.

IV.5.2. Riparian vegetation and river functioning

Riparian wooded formations (*riparian forests*) play multiple roles in ecological functioning:

- **Bank stabilization:** The roots of many trees (willows, alders, etc.) or shrubs form a biological mesh that retains sediments and slows bank erosion.
- **Flood prevention:** Vegetation affects water flow. The above-ground parts of grasses, shrubs, and bushes reduce current velocity and slow flood propagation.
- **Habitat creation and diversification:** Tree trunks and deadwood from riparian zones were long considered obstacles to water flow and potential hazards to riverside activities and structures. However, coarse woody debris (*large woody debris*) plays a key role in the ecological balance of rivers by promoting habitat creation and diversification. The succession of waterfalls and calmer pools (*pools*) created by debris forms microenvironments favorable to the establishment of numerous species and generates heterogeneity that allows their coexistence.
- **Temporary habitat:** Riparian vegetation provides temporary habitat for reproduction, feeding, or refuge for many terrestrial animals (amphibians, birds, mammals).
- **Source of organic matter:** Riparian zones are a source of allochthonous organic matter (leaves, stems, animals) for the river. These inputs are decomposed by microorganisms in the water (fungi, bacteria, etc.). The quality of these inputs varies with the composition of the vegetation.
- **Denitrification and pollution mitigation:** Through their root systems, riparian trees and shrubs also influence nutrient cycles and contribute to the removal of diffuse agricultural pollutants.

IV.5.3. Role of soil communities

One of the essential functions of soil organisms is their participation in the recycling of nutrients contained in organic matter.

Example: Mycorrhizae are symbiotic associations between plant roots and certain soil fungi. The mycelium colonizes the exterior of the root without penetrating the cells. Mycorrhizae enhance the absorption of mineral nutrients by roots, thereby improving the nutrition of most plant species.