# Chapter 1

# Introduction

## 1.1 Microbial ecology

### 1.1.1 Microbial communities: composition (*who*) & function (*what*)

Microbes are considered to be omnipresent in the various ecosystems on Earth [1]. It was only until recently (2019) that scientists discovered for the first time a place on Earth where no microbial forms of life are present [2]. Extremely low pH, high salt and high temperature had to be at the same place at the same time to stop microbes. However, microbes are not just abundant but exceedingly variant too. Locey and Lennon using a unified scaling law and a lognormal model of biodiversity, estimated microbial diversity at about 1 trillion species [3]. However, despite the extensive studies of the scientific community, less than 1% of the microbial species on Earth have been identified [4].

To tackle their intense diversity, microbes are distinguished by multiple properties. Based on their morphology microbes can be spherical (cocci), rod-shaped (bacilli), arc-shaped (vibrio), and spiral (spirochete) [5]. Based on their metabolic characteristics, microbes are further distinguished. More specifically, according to their *energy source*, a microbe can either oxidate inorganic compounds (**chemotrophs**) or sunlight (**phototrophs**). Similarly, microbes can use $CO_2$ (**autotrophs**) as their *carbon source*, or organic compounds (**heterotrophs**) or both (**mixotrophs**). Finally, based on their *electron source* microbes are distinguished bewtween those using inorgarnic compounds (**lithotrophs**) and those using organic compounds (**organotrophs**) [6]. Microbial taxa combine combinining alternatives of the aforementioned categories shape a range of microbial profile of all the possible combinations; for example **chemolithoautotrophic** bacteria, e.g. nitrifying and sulfur-oxidizing bacteria, as well as **photoautotrophic** bacteria, e.g. purple bacteria and Green sulfur bacteria. Finally, microbia taxa can also be disinguished by their various ecological distributions and activities, and by their distinct genomic structure, expression, and evolution [5].

However, it is not only the number of microbial taxa and their massive biomass that make the study of microbial communities essential; it is mostly their functional potentials. Life on Earth would not be as we know it, if existed at all, if it was not for the microbes and their long contribution on ensuring life-supporting conditions. Nevertheless, these are the *biological machines responsible for planetary biogeochemical cycles* [1]; meaning that biogeochemical cycling to a global extent is powered by the metabolic processes of the microbial taxa [7]. In Figure 1.1 the contirbution of microbial communities in the cycle of $CO_2$ is shown.

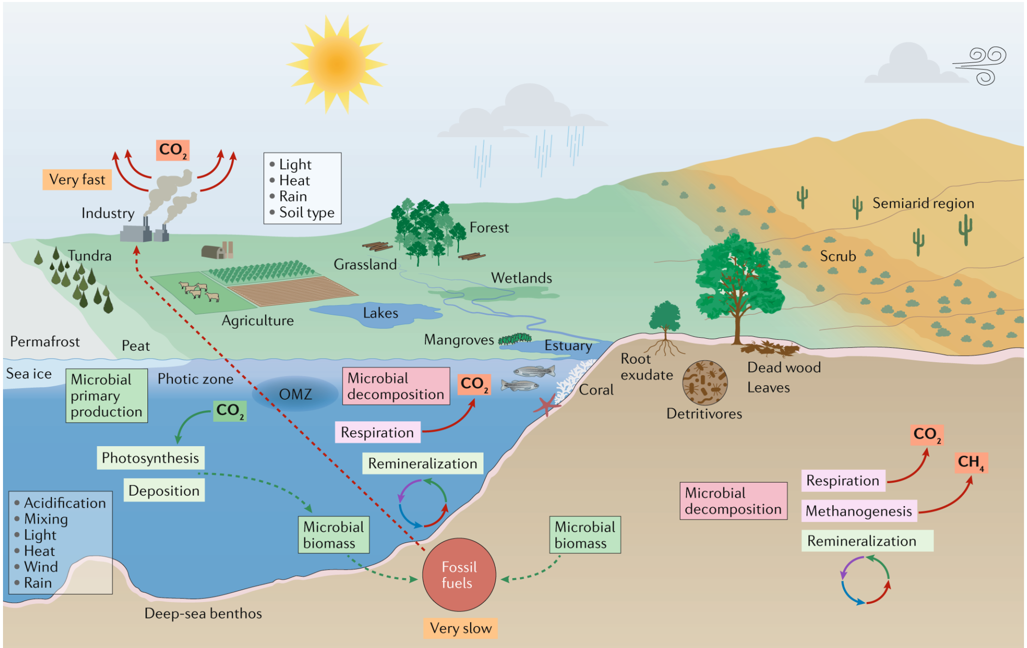


FIGURE 1.1: Marine microbial communities contribute to $CO_2$ sequestration, nutrients recycle and thus to the release of $CO_2$ to the atmosphere. Soil microbial communities decomposers organic matter and release nutrients in the soil from [8] doi: 10.1038/s41579-019-0222-5, under Creative Commons Attribution 4.0 International License

The biological fluxes of most of the major elements for any biological macromolecule (carbon, hydrogen, oxygen, nitrogen and sulfur) are driven largely by microbially catalyzed, thermodynamically constrained redox reactions [1]. Phosphorus tha last of the 6 fundamental elements for life, is also included in the metabolic pathways catalyzed by microbes. Thus, microbial communities consisting of hundreds or even thousands of metabolically diverse strains and species [9], and their functions determine the fitness of most organisms on Earth. In case of human health, specific microbial enzymatic pathways and molecules necessary for health promotion have been well known. Some of these "beneficial factors" are already known for probiotics and species in the human microbiome [10].

Microbial ecology studies the interactions:

- between microbial taxa and their environment
- among the various microbial taxa present is a community
- between microbial taxa and their host [4]

Microbial ecologists also investigate the role of microbial taxa in biogeochemical cycles [1] and their interaction with anthropogenic effects e.g. pollution and climate change [8].

Even though HTS has allowed a massive extension of our knowledge in specific enzymatic reactions that regulate these pathways the rules that determine the assembly, function, and evolution of these microbial communities remain unclear. Thus, both in case of environmental and human the underlying mechanisms for how microbial assemblages work and affect their environmnet, remain to be discovered. Understanding the underlying governing principles is central to microbial ecology [11] and crucial for designing microbial consortia for biotechnological [12] or medical applications [13].

Studies such as the one of Louca et al. have opened new frontiers in our understanding on microbial assemblages. After building metabolic functional groups and assigning more than 30,000 marine species to these groups, Louca et al. showed that the distribution of these functional groups were influenced by environmental conditions to a great extent, shaping *metabolic niches*. At the same time though, the taxonomic composition within individual functional groups were not affected by such environmental condintions [7].

### 1.1.2 Microbial interactions: unravelling the microbiome (*how*)

Microbial interactions play a fundamental role in deciphering the underlying mechanisms that govern ecosystem functioning. Co-occurrence networks have been widely used for inferring microbial associations or/and interactions from metagenomic data. However, spurious associations and tool-dependence confine the network inference.

(from Karoline's [14]) mutualism: a win–win relationship that is known as mutualism cross-feeding (also known as syntrophy), in which two species exchange metabolic products to the benefit of both

In commensalistic relationships, one partner benefits without helping or harming the other. Commensalism is often found in biodegradation, in which commensals cross-feed on compounds that are produced by other community members (for example, in cellulose degradation)

competition between microorganism (a loss–loss relationship) On the basis of these observations, Gause formulated his law of competitive exclusion, which states that two species with similar niches exclude each other

Amensalism — in which one partner is harmed without any advantage to the other — occurs, for example, when metabolic by-products of a microbial species alter the environment to the detriment of other microorganisms (for example, lactobacilli lowering the pH of the surrounding environment). I

### 1.1.3 Reverse ecology: ransforming ecology into a high-throughput field

(from Roie Levy and Elhanan Borenstein [15]) Reverse Ecology—an emerging new frontier in Evolutionary Systems Biology—aims to extract this information and to obtain novel insights into an organism's ecology. The Reverse Ecology framework facilitates the translation of high-throughput genomic data into large-scale ecological data, and has the potential to transform ecology into a high-throughput field