Diversity of global marine plankton

I heard that plankton are tiny, microscopic organisms: how is it possible that they are so important for planet Earth?

Sea Sparkle, or bioluminescent plankton, at the Yacht Port of Zeebrugge, Belgium (June 2010). Photographer: Hans Hillewaert. Creative Commons Attribution-Share Alike 4.0.

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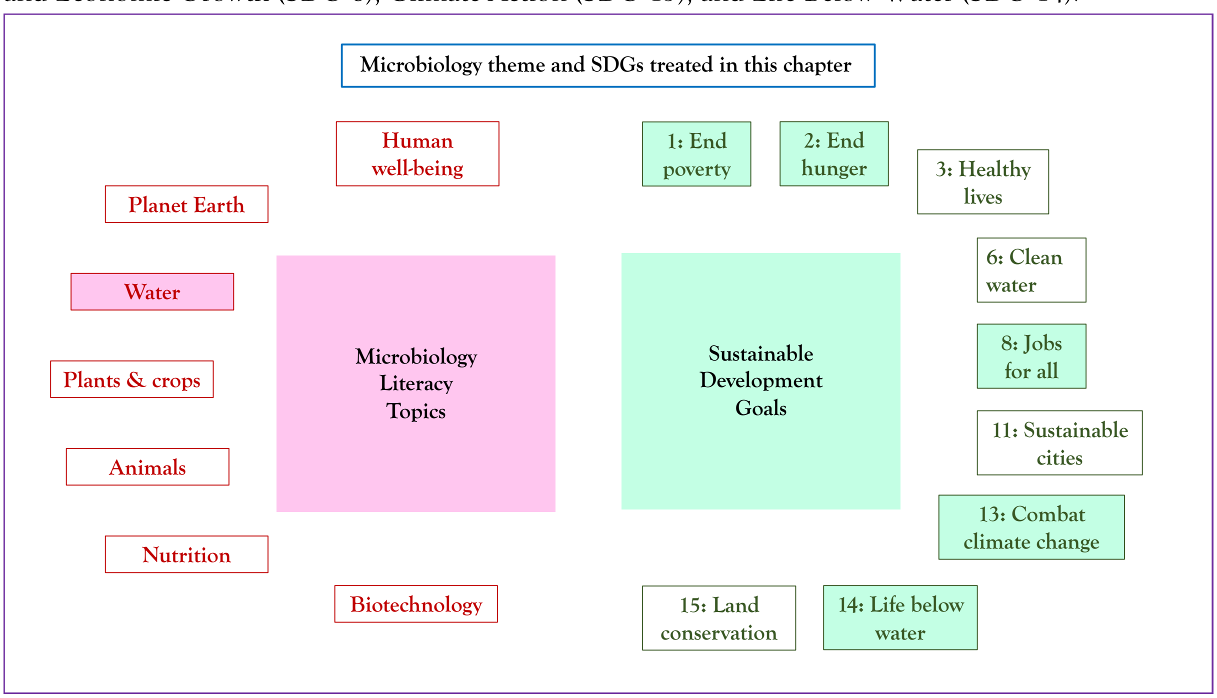
Diversity of global marine plankton

Storyline

Marine plankton consist of a myriad of microscopic organisms, mostly invisible to the human naked eye, floating freely in the water. On their travels throughout the global ocean, transported by currents, many plankton species are good at growing in the hot, tropical oceans, whereas some perform well in cold, nutrient-rich waters. Some can even survive the long and dark winter at the poles to resume growth in spring and summer. One part of them, called phytoplankton, act like terrestrial plants: with the help of sunlight providing energy, they capture carbon dioxide to produce sugars and other organic compounds while releasing oxygen in a process known as photosynthesis. These newly-synthesized biological compounds are used for growth and multiplication – so-called *production*. All sorts of non-photosynthetic microbes feed on phytoplankton and recycle nutrients that will enable further new *production*. As a whole, marine plankton represent the basis of the food web in the surface as well as in deeper waters, since a fraction of this microbial life sinks to the bottom. This sinking process also drives the storage of carbon in the deep ocean, which has a major relevance in the global carbon cycle and climate.

The Microbiology and Societal Context

This chapter covers biodiversity in marine microbial communities, their traits, their adaptation and evolution, and their roles in biogeochemical cycles. Additionally, their interaction within ecological systems, such as their function in food webs, and the impact of harmful algal blooms. These topics contribute to achieving key SDGs including No Poverty (SDG 1), Zero Hunger (SDG 2), Decent Work and Economic Growth (SDG 8), Climate Action (SDG 13), and Life Below Water (SDG 14).



Diversity of global marine plankton: the microbiology

1. ***What is plankton?*** Plankton are a diverse group of microscopic organisms that drift around on water currents (https://oceanservice.noaa.gov/facts/plankton.html). Unlike seaweed attached to rocks, or animals like finfish, shellfish and jellyfish, that move independently of water currents, plankton simply drift wherever the water flows.

2. ***In terms of abundance and biomass, marine life is mainly microbial.*** When we think of marine organisms, our minds immediately picture fish or large marine mammals, such as whales or dolphins. However, the most abundant marine forms correspond to the microscopic organisms forming the plankton. Just one drop of seawater can contain millions of them! In fact, if we collect all marine life forms, 50% to 70% of the resulting weight would correspond to plankton.

3. ***Plankton are also extremely diverse.*** In terms of size, marine plankton span from 0.0001 to 1 millimeter, which is equivalent to the size range between a mouse and a large city. Throughout this size spectrum, a multitude of structural shapes and materials are featured (Fig. 1). Materials include mainly calcium carbonate, silica ('glass') and organic polymers that are used for making hard shells. Shapes and sizes can be further extended through the formation of chains or colonies that hold numerous individual cells sticking together. Their diversity manifests also in the different functions that they perform: primary producers or photosynthesizers (phytoplankton or microalgae), phagotrophs or consumers (zoo- and bacterioplankton), nitrogen fixers ('natural fertilizers'), symbionts and/or parasites. Because of their functional diversity, global distribution, high collective biomass and total abundance, plankton have an enormous influence on the ocean's life and even on planetary cycles of chemical elements.

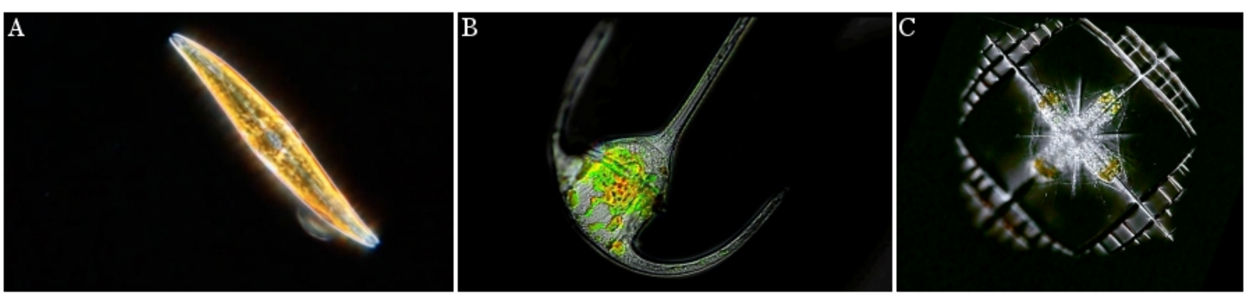


Figure 1: Examples of marine phytoplankton groups. Pictures have an illustrative purpose and their scale is arbitrary. Source: http://planktonchronicles.org. (A) Pennate diatom. Photo: C. y N. Sardet, S. Mirshak, CNRS, Parafilms. (B) Dinoflagellate. Photo: Ulysse and C. Sardet, CNRS. (C) Acantharia, from the genus Lithoptera. Non-photosynthetic protist with microalgae endosymbionts. Photo: C. Sardet, J. Decelle, CNRS.

4. ***Different methods are used to study plankton.*** Early explorers were aware of peculiar phenomena that took place in the surface ocean, such as patches of *marine dust* (large colonies of blooming microalgae) or *sea sparkle* (bioluminescent plankton; see image above). Gradually, it

became clear that all kinds of tiny pigmented creatures drifted around the world and were responsible for sustaining marine life the same way plants do on land.

The study of plankton became more rigorous with the design of plankton nets for their sampling (Fig. 2) and the use of microscopy for their observation (Fig. 1). These tools are still commonly used on dedicated cruises onboard scientific vessels, in addition to more sophisticated techniques. For example, relatively new technologies confer scientists the ability to "read" the DNA from the microbial community living in a seawater sample. This approach provides a kind of fingerprint of the microbial species and their genes, and therefore an answer to the questions "Which marine microbes are out there?" and "What functions can they perform?". For decades now, we have also been able to monitor plankton from space through the use of satellites, taking advantage of the fact that phytoplankton blooms affect the color of the ocean (Fig. 3).

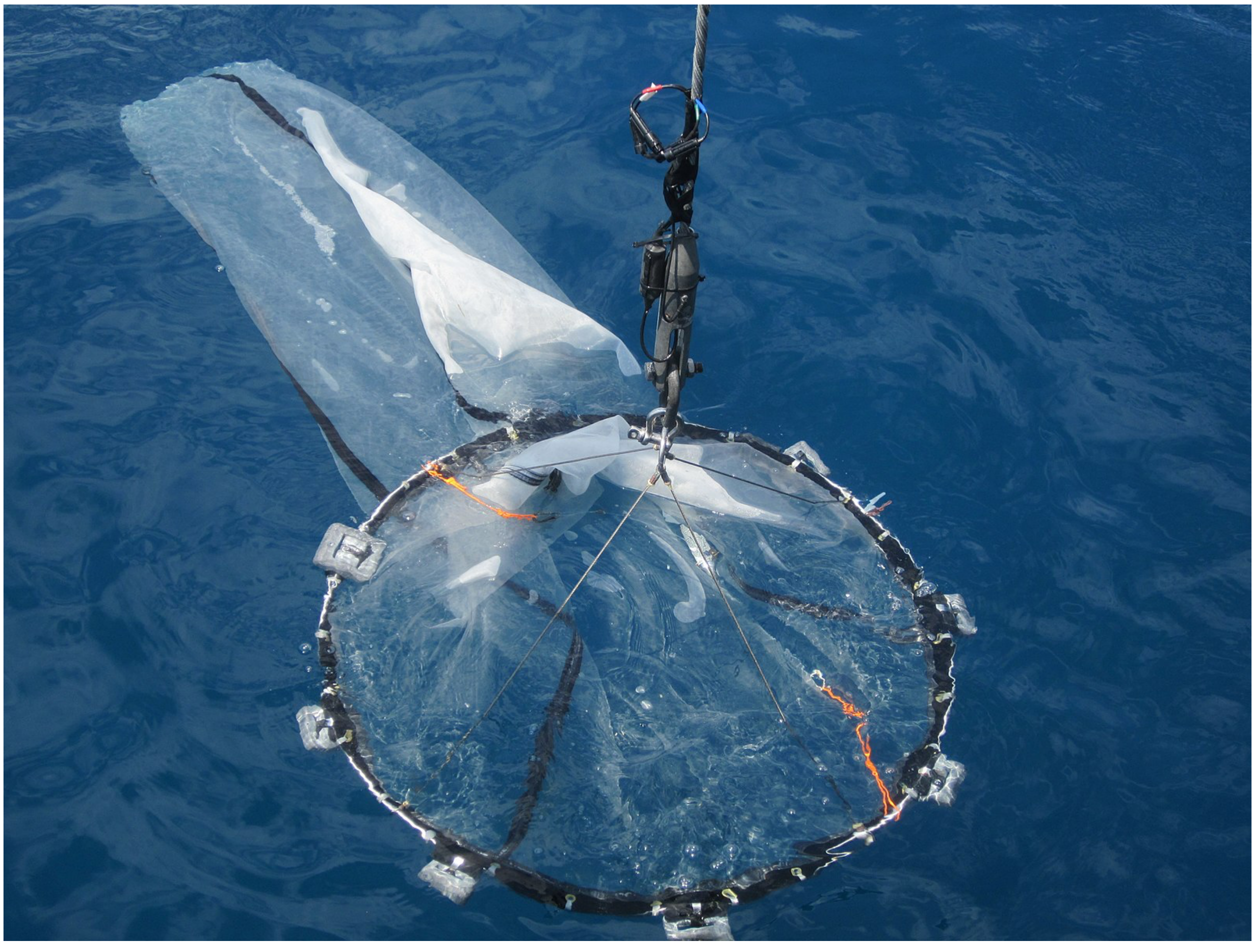


Figure 2: Example of a plankton net. The net has a mesh with many holes that are small enough to collect the plankton. The net is dragged through the water and it funnels and filters the sea water. While the seawater escapes through the walls of the net, the plankton is captured in the net and flows into a receptacle. Credit: Michael Wing, NOAA Teacher at Sea Program, NOAA NMS R/V FULMAR. Source: https://www.flickr.com/photos/noaaphotolib/27554974624/

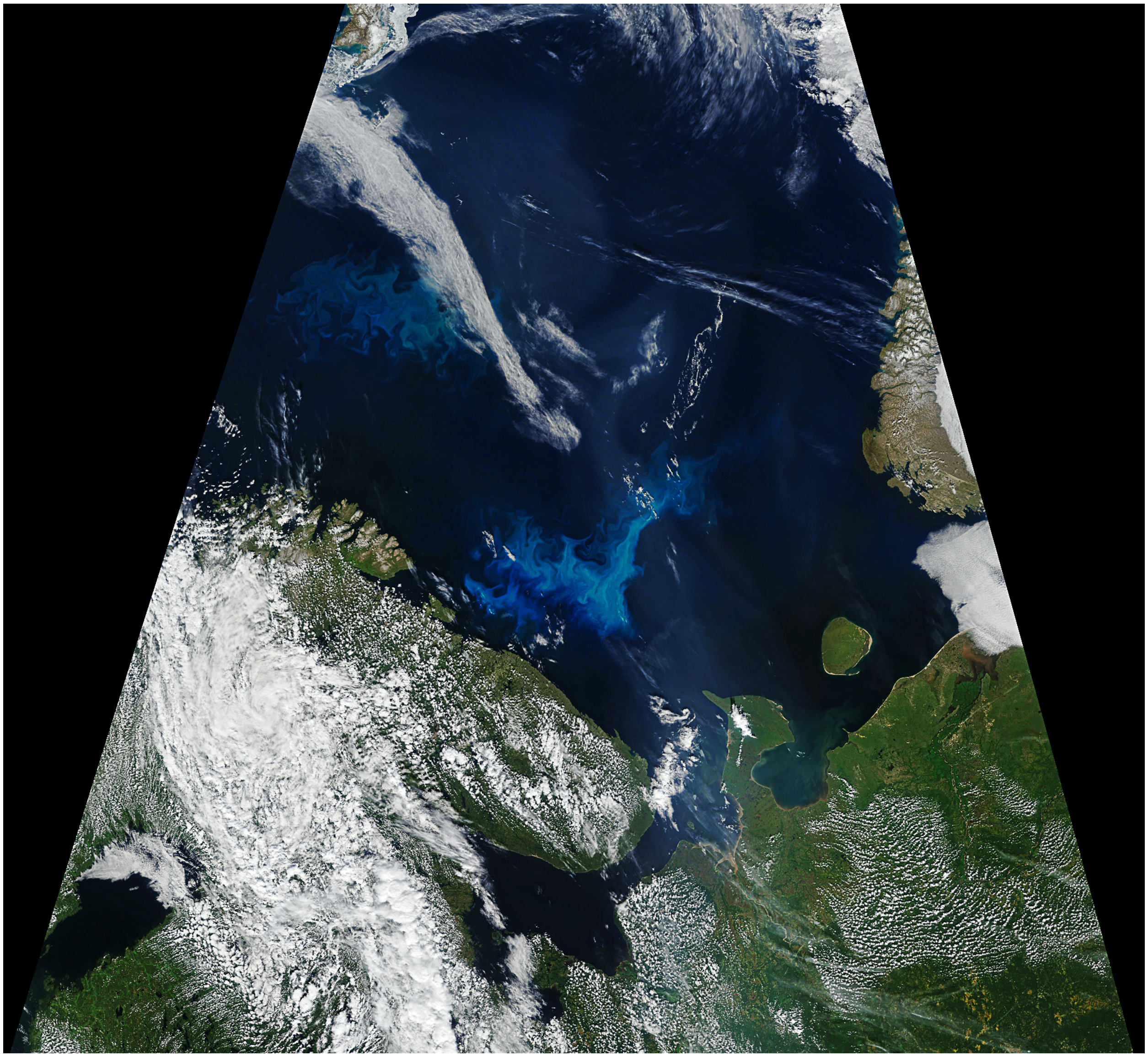


Figure 3: Satellite image of a phytoplankton bloom in the Arctic Ocean during the summer 2020. The Arctic Ocean is one of the regions most affected by climate change. Source: https://earthobservatory.nasa.gov/images/147049/phytoplankton-surge-in-arctic-waters

5. **The majority of plankton are harmless to human health, although there are some that produce toxic compounds.** In general, marine microbes do not represent a risk to human health. The exception comes from a relatively small number of marine microalgae that produce what we know as phycotoxins, compounds that poison one or more members of the marine food web. These compounds may have been selected throughout evolution to fight against grazing.

Phycotoxin-producing algae do not normally cause problems for larger animals, but sometimes their populations increase dramatically, producing a so-called algal bloom, also commonly known as 'red tide'. In this case, phycotoxin levels also rise dramatically to dangerous levels. Sometimes, phycotoxins can accumulate along the food chain and intoxicate and even kill fish, seabirds and large marine mammals. If they accumulate in mussels and clams that are then collected and consumed by humans, they can also poison people and make them sick in different ways.

Scientists still cannot fully predict the occurrence of algal blooms, although some preliminary evidence suggests that they have been increasing in magnitude and frequency over the past decades, potentially because of human-driven change of the ocean. The rise in seawater temperature, and the higher availability of nutrients washed from land (e.g. fertilizers and wastewater) could make harmful algal blooms more likely. In any case, these phenomena are carefully monitored by countries around the world to avoid human poisoning.

6. **Planktonic organisms distribute and grow in today's ocean according to traits that have evolved over millions of years and still evolve.** The presence of planktonic traces in fossil records across geological sediments made scientists realize that these organisms had populated Earth for a long time and could drive biogeochemical processes at a global scale. Scientific evidence suggests that photosynthetic microorganisms have been around for at least 2.4 billion years, and that during the first 1.9 billion years or so they were the only photosynthetic organisms on Earth. Over that very long period of time, they were responsible for adding oxygen to the atmosphere and therefore causing a major shift in the planet's chemistry (because oxygen *oxidizes* other elements) and biology (higher oxygen concentrations were key for the development of multicellular life forms like animals and plants).

Different microbial species have evolved over time through complex processes of genome and cellular modifications. Exchange of genetic material through the uptake of foreign DNA, viral infections or cellular interactions represents a central mechanism by which diversity is generated among microbes. Endosymbiosis, or the stable symbiosis between a microbe that has been engulfed by another microbe at some point of evolutionary history, has also played a major role in the emergence of new species, particularly among phytoplankton.

In parallel, multiple strategies have been selected to survive and outcompete other species. Small phytoplankton cells are favored in warmer, nutrient-poor waters near the tropics, while large-sized species tend to dominate in polar waters. Dormant or inactive stages constitute an important mechanism to survive over long periods of inadequate conditions, for instance during the polar night. Hard shells are likely a defense against predation, while internal vacuoles allow nutrient storage and can therefore confer an advantage in periods of resource scarcity. Diversity among microbial plankton is enormous, and it represents the pool of genes and species from which new communities will be selected in future environmental scenarios.

7. Because they are sensitive to environmental variation, marine plankton are expected to respond in several ways to the global change driven by human activities. Over the past two centuries, human activities have injected huge amounts of carbon dioxide (CO_2) into the atmosphere and the ocean. The accumulation of CO_2 in the atmosphere causes the planet to warm through an exacerbated greenhouse effect, while the fraction that dissolves in water turns the ocean more acidic through a series of chemical reactions. Increasing the temperature of the planet not only makes the surface ocean warmer, it also makes it less prone to mix with nutrient-rich waters that are below. As a consequence, and combined with pollution and expansion of low-oxygen waters, marine plankton are experiencing a suite of environmental stressors that will affect their metabolism, push them to grow in other regions, shift their growing period and eventually drive extinctions and replacements with microbial species better adapted for the new conditions (Fig. 4). This reshuffling of microbial plankton communities might have cascade effects on trophic interactions and ecosystem functioning, potentially causing the marine ecosystem to readjust to a different state as the one we know today.

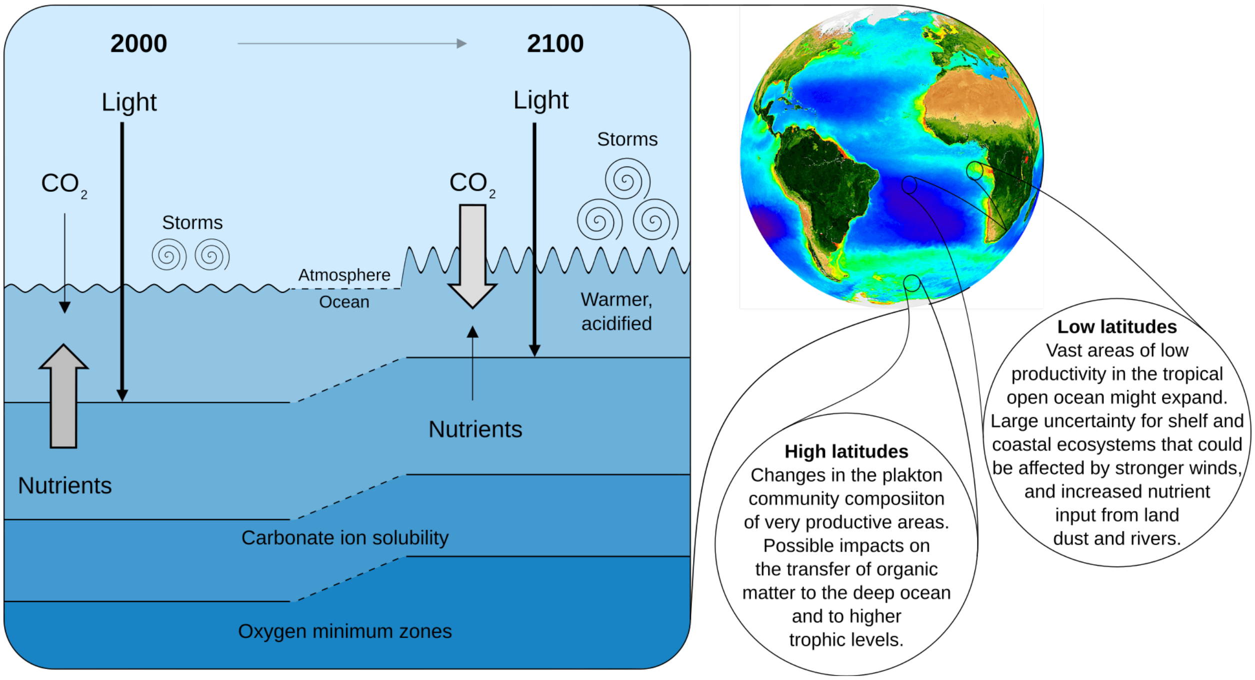


Figure 4: Projected changes in the ocean throughout the 21st century. The left panel outlines the predicted trends for this century in physical and chemical aspects of the ocean. The right panel summarizes the most likely responses of marine plankton at high and low latitudes, both in coastal environments and in the open ocean (modified from IPCC report).

Relevance for Sustainable Development Goals and Grand Challenges

The diversity of global marine plankton relates to several SDGs, including:

- **Goal 1. No Poverty:** The health of marine ecosystems impacts global food security (fish stocks, harmful algal blooms) and the economical activities (e.g. tourism) of communities dependent on marine habitats and resources.
- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Plankton sustain food webs in the ocean and therefore allow the development of fisheries that nurture an important fraction of the global human population. Global warming can potentially reduce marine primary productivity (phytoplankton growth), which could then be reflected in a lower fish catch. Global warming might also increase the likelihood of harmful algal blooms and the poisoning of shellfish. These are relevant reasons for studying the impact of global change on marine plankton.
- **Goal 8. Decent Work and Economic Growth**: The health of marine ecosystems supports fisheries and marine-related industries, which are crucial for employment and well-being in coastal regions.

- **Goal 13 Climate Action:** Due to their role in the carbon cycle, plankton are a component of the climate system. They can mitigate climate change by reducing the atmospheric CO2 levels.
- **Goal 14. Life below water.** The conservation of the oceans is one of the axes of this goal. Current trends indicate that the physics and chemistry of the oceans are changing, and with them the drifting microbial communities at the base of the food chain. Ocean warming and acidification, combined with pollution transported by continental runoff, are large-scale processes that threaten the conservation of the oceanic ecosystem as we know it. Large efforts will be required to reverse these trends and to monitor the overall process.

Potential Implications for Decisions

National policies relating to marine plankton diversity

- Environmental pollution
- Eutrophication/algal blooms/toxic algal blooms preventing use of surface water bodies, fisheries, tourism, etc.
- Greenhouse gas production and global warming,

Pupil Participation

1. Break the ice. Imagine you are a plankton scientist. What would be your preferred approach to study them? Choose between oceanographic cruises, satellite imagery or cultures in the laboratory!
2. Class discussion of the issues associated with marine plankton diversity.
3. Pupil stakeholder awareness
   a. Marine plankton diversity is related to the SDGs. Which of these connections are most important to you personally/as a class?
   b. Can you think of anything that might be done to reduce the negative consequences of human activities on the ocean and therefore the plankton?

The Evidence Base, Further Reading and Teaching Aids

Ocean and Climate scientific sheets
https://ocean-climate.org/en/presentation-of-the-ocean-and-climate-scientific-items/
Plankton Chronicles. https://planktonchronicles.org/en/
What are phytoplankton? https://oceanservice.noaa.gov/facts/phyto.html
Falkowski, P. Ocean Science: The power of plankton. Nature 483, S17–S20 (2012). https://doi.org/10.1038/483S17a
Plankton The superstars of the ocean and the tool to follow them. International Union for Conservation of Nature (IUCN). https://digital.iucn.org/marine/plankton-and-the-mapmaker-tool/

Glossary

- **Nutrients:** In aquatic biology, the term refers mainly to chemical compounds based on nitrogen and phosphorus that are needed by phytoplankton to grow.
- **Abundance:** In ecology, this term refers to the number of individuals in a given population.
- **Biomass:** The total weight of organisms
- **Global change:** large-scale processes of ecosystem change that are happening on Earth, such as climate change or biodiversity loss, and that are driven by human activity and its by-products.
- **Photosynthesis:** the process by which phytoplankton and land plants use sunlight to synthesize foods from carbon dioxide and water.
- **Bioluminescence:** the ability of a few plankton species and other organisms to emit their own light through a series of chemical reactions. Researchers have not yet discovered all the reasons why some plankton are bioluminescent.