ALBERT CALBET

Plankton in a Changing World

The Impact of Global Change on Marine Ecosystems

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About the Book

"Plankton in a Changing World: The Impact of Global Change on Marine Ecosystems" is a detailed and accessible examination of the crucial role plankton play in the world's ocean and the significant challenges they face due to global environmental changes. This book complements "The Wonders of Marine Plankton," which explored, in a casual and entertaining way, the intricate details of plankton ecology and their peculiarities and surprising characteristics. In "Plankton in a Changing World" the focus is on how global changes impact these essential organisms and, in turn, the broader marine ecosystems they sustain. While this book stands on its own, familiarity with "The Wonders of Marine Plankton" can enhance understanding of some chapters, making the complex interactions and impacts even clearer.

The book opens with an introduction to plankton, providing a comprehensive overview of the various types of plankton and their ecological importance. It covers everything from the foundational phytoplankton, which are key to oceanic primary production, to the complex interactions within planktonic communities. These initial chapters set the stage by explaining the diverse world of marine plankton and their critical functions in ocean ecosystems.

Following this, the book explores the distribution and habitats of plankton, emphasizing the variability in biomass across different ecosystems and the unique strategies plankton use for dispersal and survival. This section highlights the dynamic and often patchy nature of plankton distribution, shaped by both biological interactions and physical oceanographic processes.

At the heart of the book, we find an in-depth analysis of the impacts of global environmental change on marine plankton. With increasing ocean temperatures, acidification, and altered nutrient dynamics, plankton face numerous challenges. The book examines these issues, discussing the effects of global warming, the role of plankton in the ocean's biological pump, and the consequences of smaller plankton in warmer ocean.

Human activities and their effects on plankton are also addressed, including pollution, overfishing, and the introduction of classic and emerging pollutants. These chapters highlight the complex interplay between human-induced changes and plankton dynamics, emphasizing the need for sustainable practices to preserve these vital components of marine ecosystems.

The book concludes with case studies and regional perspectives, offering insights into plankton in various climatic zones, from polar regions to tropical waters. This section provides a global viewpoint on the diverse responses of plankton to environmental changes, illustrating the different challenges and adaptations in various regions.

Finally, the future directions section brings together the key themes of the book, discussing the importance of public awareness and education in promoting plankton conservation. It also outlines emerging trends and future research directions, emphasizing the need for advanced methodologies and technological innovations in studying and monitoring plankton.

"Plankton in a Changing World" is an essential read for anyone interested in marine life and environmental science. While it is designed to be accessible to the general public, the depth and coverage of information make it a valuable resource for marine biologists, ecologists, and environmental scientists seeking to understand the critical role of plankton in marine ecosystems and the profound impacts of global change on these tiny but mighty organisms.

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About the Author

Albert Calbet is a marine researcher at the Institute of Marine Sciences, CSIC, in Barcelona, Spain, specialized in the ecology and ecophysiology of micro- and mesozooplankton. His work has significantly advanced our understanding of the role of microzooplankton in marine food webs. Albert earned his Ph.D. in Marine Sciences in 1993 from the Institute of Marine Sciences (ICM), CSIC, followed by postdoctoral research at the University of Hawaii at Manoa. At ICM, he has held various positions, including Deputy Director.

Albert has published over 130 peer-reviewed articles, authored several books and book chapters, and actively participated in scientific conferences worldwide. He has also been involved in teaching and mentoring students at the Ph.D., Master's, and undergraduate levels. His research has been supported by prestigious institutions, and he has served as a reviewer for funding agencies and on the editorial boards of high-impact scientific journals. Dedicated to science outreach, he manages several web pages and engages with the public through social media, outreach articles, conferences and books.

Part I

Introduction to Plankton Ecology and Major Groups

1

An Introduction to the World of Marine Plankton

The whole of the world's ecosystems are based on the healthy ocean and if that part of the planet becomes dysfunctional and goes wrong, then the whole of life on this planet will suffer
—Sir David Attenborough.

Marine plankton, those tiny organisms drifting in the ocean and seas, form the foundation of aquatic ecosystems. Despite their small size, they play a colossal role in maintaining the health and functionality of marine environments. Plankton are broadly categorized into groups such as virioplankton, bacterioplankton, microzooplankton, phytoplankton, mixoplankton, zooplankton, and ichthyoplankton. Each group is home to a multitude of species, each contributing uniquely to the marine ecosystem. In this chapter, I will present a brief summary of the major groups and functions of plankton, which will be further elaborated upon in the following chapters.

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Phytoplankton: The Ocean's Primary Producers

Phytoplankton are the primary producers in the marine food web, akin to terrestrial plants. Through photosynthesis, they convert sunlight into energy, producing oxygen and organic materials that sustain nearly all marine life. Despite their lower biomass compared to terrestrial plants (1 vs 450–470 Gt C, respectively), phytoplankton produce roughly the same amount of oxygen as terrestrial plants. However, most of this oxygen is readily consumed by marine organisms, and only a very small fraction, if any, reaches the atmosphere. Phytoplankton group includes various types of algae, with diatoms (Fig. 1.1) and dinoflagellates being among the most prominent. Phytoplankton are integral to the carbon cycle; they absorb carbon dioxide during photosynthesis, helping to mitigate the greenhouse effect and regulate the global climate. When they die, some of their carbon sinks to the ocean floor, effectively sequestering it and reducing atmospheric carbon dioxide levels. Additionally, phytoplankton serve as a primary food source for zooplankton, thus sustaining a complex and diverse marine food web. Their abundance and productivity also influence the distribution and health of fish populations, which are vital for global fisheries. Moreover, phytoplankton affect nutrient cycling by transforming inorganic nutrients into organic matter that other organisms can use, playing a pivotal role in maintaining the balance of marine ecosystems. Through their various functions, phytoplankton support biodiversity, contribute to biogeochemical cycles, and influence the health and stability of the entire oceanic environment.

Zooplankton: The Ocean's Primary Consumers

Zooplankton, the animal-like counterparts of phytoplankton, are critical as primary consumers in the oceanic food web. They feed on phytoplankton (and bacteria, smaller zooplankton, etc.) and, in turn, provide nourishment for larger marine animals, including fish, whales, and seabirds. Zooplankton encompass a diverse range of organisms, from microscopic protozoans to larger forms like jellyfish and krill. Protozoans include a varied array of groups, including ciliates, flagellates, dinoflagellates,

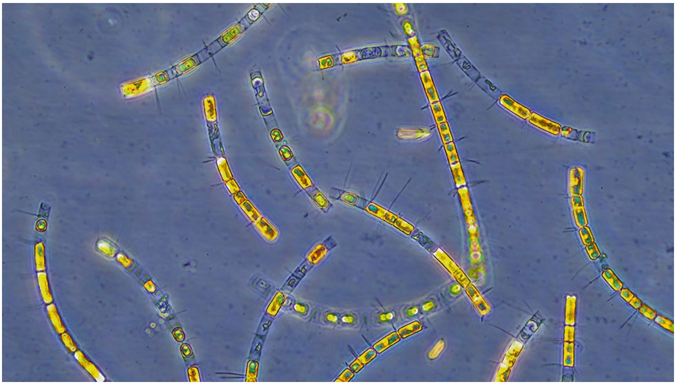

Fig. 1.1 Marine diatoms (*Chaetoceros pseudocurvisetus*). © Albert Calbet

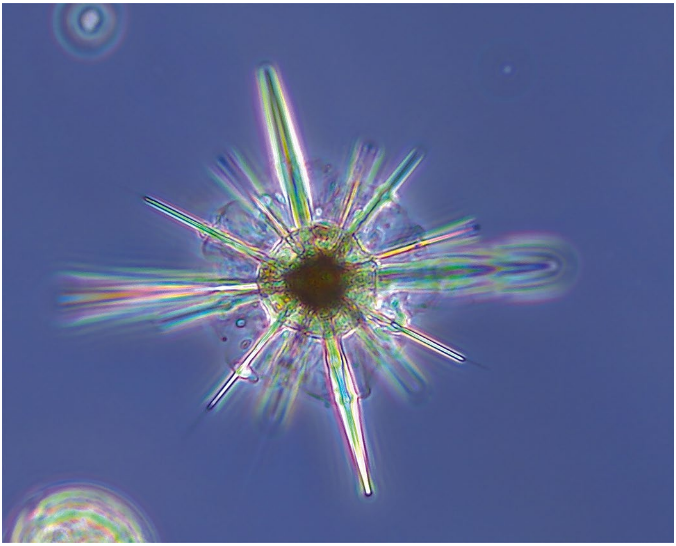

Fig. 1.2 Acantharian (Radiolaria). © Albert Calbet

foraminifera, and radiolarians, among others. Some of them have naked bodies, while others possess protective shells. For instance, foraminifera and radiolarians (Fig. 1.2) have intricate calcium carbonate or silica shells that contribute to ocean sediment after they die. These organisms are key indicators of environmental changes and past climatic conditions.

Fig. 1.3 The marine copepod *Calanus minor*. © Albert Calbet

Protozoans and some small metazoans are known as microzooplankton and they play a key role as primary consumers, feeding on phytoplankton and bacterioplankton, transferring energy and organic matter up the food web. They are also vital in the microbial loop, consuming bacteria and recycling nutrients, thus maintaining balance in the ecosystem.

Among zooplankton, copepods (Fig. 1.3) and krill are particularly abundant and ecologically significant. Copepods, often referred to as the "insects of the sea," are crucial for many fish species and are the most abundant metazoans on Earth. Krill, small shrimp-like crustaceans, are vital in polar regions, forming dense swarms that serve as a primary food source for larger marine animals, including whales, penguins, fish, etc.

The Interplay Between Phytoplankton and Zooplankton

The interaction between phytoplankton and zooplankton is a delicate balance that supports the entire marine ecosystem. This dynamic relationship ensures the flow of energy and nutrients through the food web.

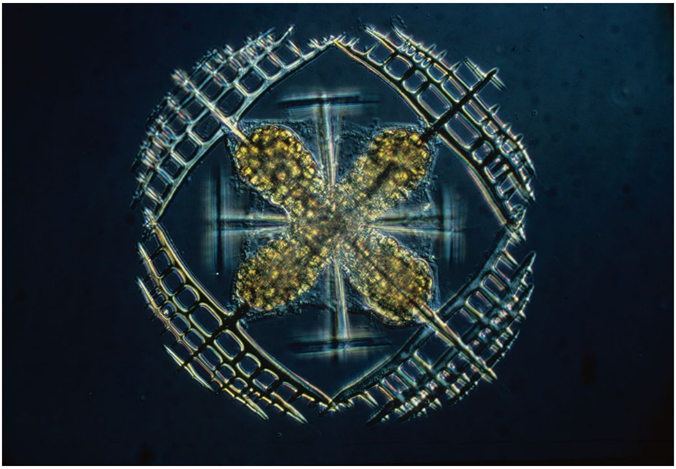

Fig. 1.4 The mixotrophic acantharian *Lithoptera* sp. © C. Carré

Phytoplankton absorb carbon dioxide during photosynthesis, acting as a significant carbon sink and playing a vital role in regulating the Earth's climate. When zooplankton consume phytoplankton, the carbon is transferred up the food web and eventually sequestered in the deep ocean as these organisms evacuate fecal pellets or die and sink to the seabed. This process, known as the biological pump (Chap. 18), is essential for mitigating the impacts of climate change.

Mixoplankton: The Dual Nature of Plankton

Mixoplankton (Fig. 1.4), alike the terrestrial carnivorous plants, are fascinating organisms that combine characteristics of both phytoplankton and zooplankton. They can photosynthesize like plants but also consume other plankton as animals do. This dual capability allows them to adapt to varying environmental conditions, making them important players in nutrient cycling and energy transfer in the ocean. Their flexible feeding strategies help maintain the stability and resilience of marine ecosystems.

Virioplankton and Bacterioplankton: The Microscopic Recyclers

Virioplankton, viruses that inhabit marine environments, are incredibly abundant and play a crucial role in controlling microbial populations and recycling nutrients. By lysing their host cells, they release organic matter back into the environment, making it available for other microorganisms. This process, known as the "viral shunt," helps regulate the microbial loop, an essential component of the ocean's nutrient cycle. Virioplankton also influence genetic diversity and evolution through horizontal gene transfer.

Bacterioplankton, prokaryotic plankton, are pivotal in decomposing and recycling organic matter. These microorganisms break down organic compounds from dead plants and animals, converting them into inorganic nutrients that can be reused by other organisms, particularly phytoplankton. Their metabolic activities help maintain the balance of nutrients in marine ecosystems, supporting the productivity and health of the ocean.

Ichthyoplankton: The Future of Fish Populations

Ichthyoplankton, the planktonic stages of fish, include eggs and larvae critical for replenishing fish populations. These early life stages are highly dependent on suitable planktonic food sources, such as some large phytoplankton and zooplankton, for growth and development. The survival and success of fish larvae are influenced by various factors, including water temperature, salinity, and the abundance of predators and prey. Understanding ichthyoplankton dynamics is crucial for fisheries management and the conservation of fish stocks.

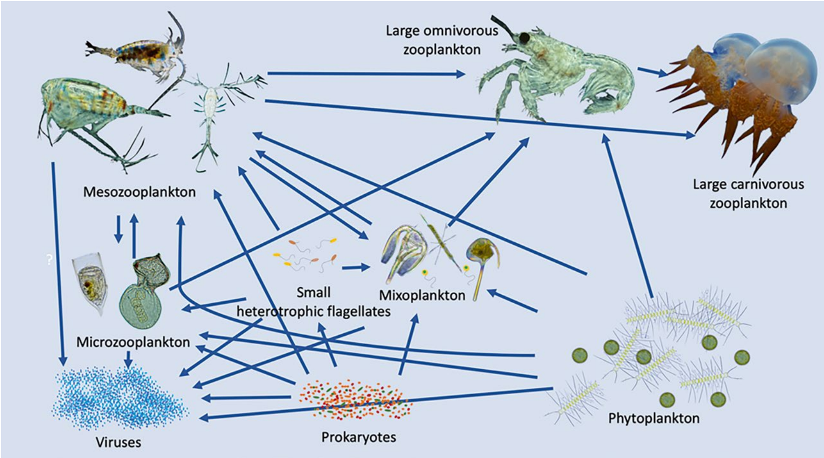

Fig. 1.5 Representation of the marine planktonic food web. © Albert Calbet

The Complex and Dynamic Marine Planktonic Food Web

The marine planktonic food web (Fig. 1.5) is a complex and dynamic system supporting a vast array of marine life. Phytoplankton produce organic matter through photosynthesis, which is consumed mostly by bacterioplankton, microzooplankton, and copepods. These, in turn, are preyed upon by larger zooplankton such as krill and jellyfish. Mixoplankton add complexity by functioning as both primary producers and consumers. Virioplankton control microbial populations that recycle nutrients, while ichthyoplankton rely on these interactions for their development and growth.

This food web is constantly influenced by environmental factors such as temperature, nutrient availability, and light conditions. Seasonal changes, climate variations, and human activities impact plankton abundance and distribution, affecting the entire food web.

2

Plankton Size Classification

Plankton come in all shapes and sizes, from microscopic creatures invisible to the naked eye to giants larger than a beach ball. But how do we categorize this incredible range? In the previous chapter we have seen a classification of plankton based mostly on their function and trophic modes. But scientists have developed also a system known as size classification to understand the ecological roles and challenges faced by these fascinating drifters.

A Historical Perspective

The concept of size classification for plankton emerged from early scientific explorations of the aquatic world. In the 1880s, German biologist Victor Hensen conducted pioneering studies on marine life. Using nets with varying mesh sizes (Fig. 2.1), Hensen captured different groups of plankton, laying the groundwork for today's size-based classification system (Fig. 2.2). Over time, scientists have refined this system, resulting in a spectrum that encompasses the entire range of planktonic life.

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Fig. 2.1 Plankton net. This particular net is a double WP2, modified to hold a plastic bag instead of a cod end. This modification, combined with a very slow towing speed, allows for the collection of very fragile organisms. © Albert Calbet

The Size Categories

Megaplankton: The largest size in the classification, encompassing organisms exceeding 20 cm. These giants include jellyfish and some colonial animals that can stretch for meters, such as salps and siphonophores. Megaplankton are relatively rare and play specialized roles in the marine ecosystem.

Macroplankton: Ranging from 2 to 20 cm, this category features a wider variety of organisms, including krill and other large crustaceans.

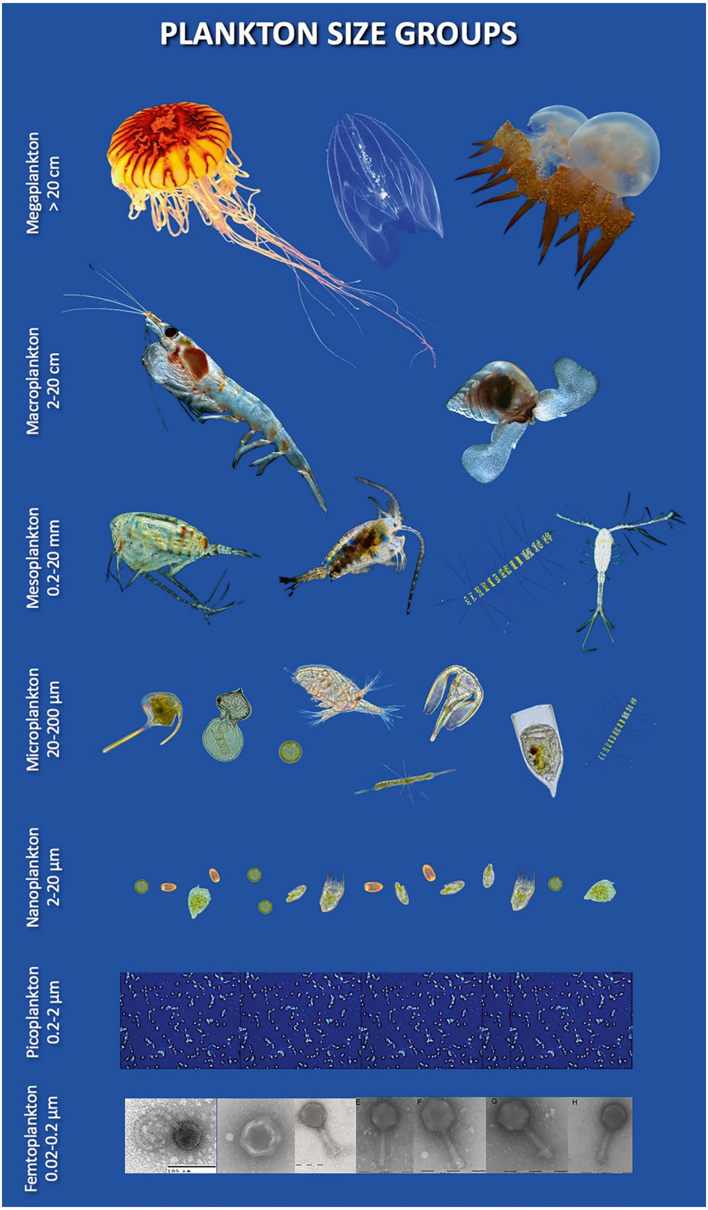

Fig. 2.2 The classification system for plankton based on size was first published by Sieburth et al. in 1978. The image, assembled from various sources and authors: A. Calbet, R. Hopcroft, D. Vaqué, E. Lara, Y.M. Castillo