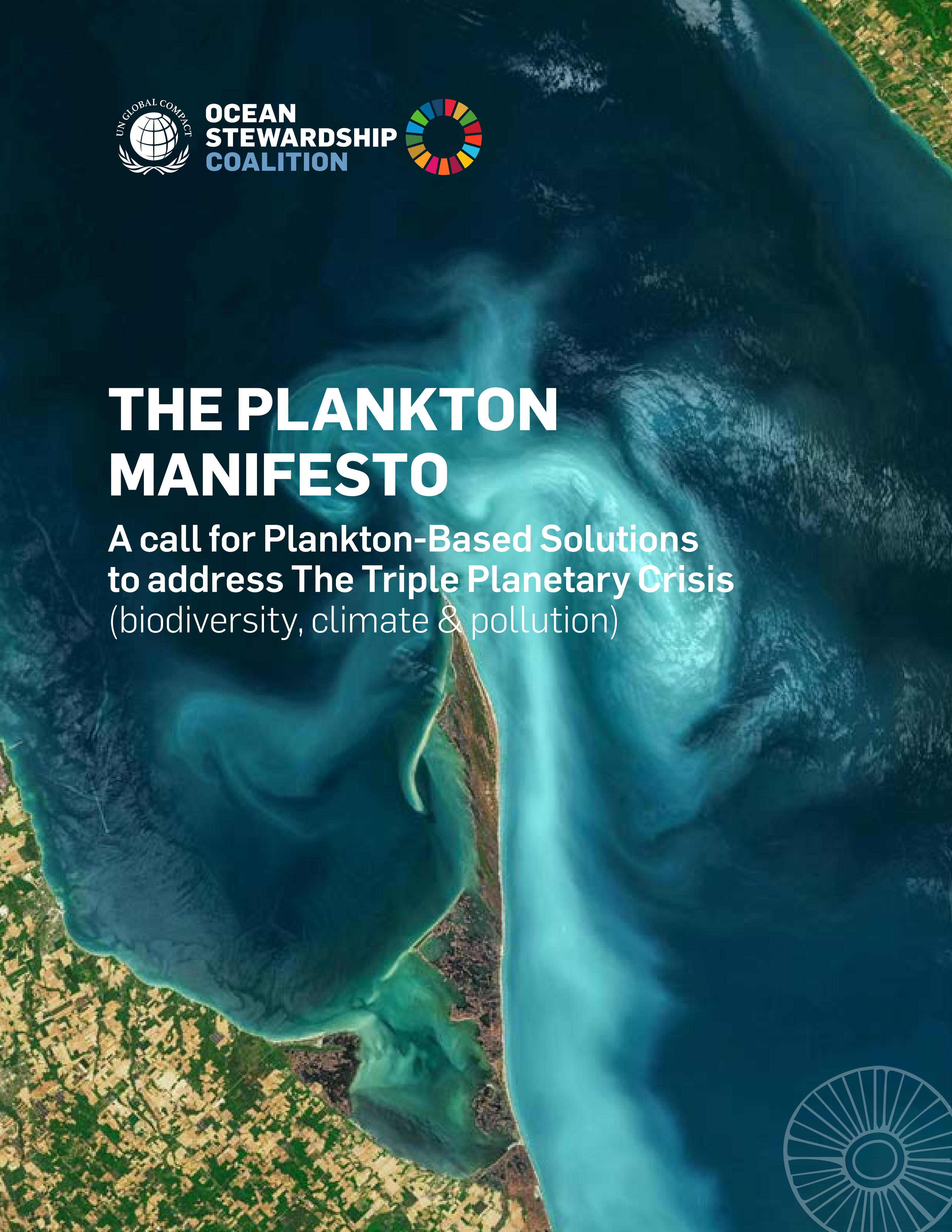


UN GLOBAL COMPACT
OCEAN STEWARDSHIP COALITION

THE PLANKTON MANIFESTO

A call for Plankton-Based Solutions to address The Triple Planetary Crisis
(biodiversity, climate & pollution)

The Plankton Manifesto from the **Ocean Stewardship Coalition** of the United Nations Global Compact calling for plankton awareness and stewardship

Why Plankton? Plankton provide planetary-level crucial ecosystem services such as absorbing carbon and excess nutrients, and supporting marine food webs

What is the problem? Under threat, lack of awareness, and lack of data

What is the potential? Leverage new technologies and existing datasets to develop Plankton-Based Solutions to support life on our planet

What is needed? Global stewardship of the Global Ocean commons

Action: Sign up to the manifesto and its 10 recommendations

Terrestrial ecosystems have been studied for centuries, providing a detailed understanding of their biodiversity, function, opportunities for utilization, and vulnerabilities in the face of 21st-century global change. The same cannot be said for life in the 71 percent of Earth's surface covered by water, even though it is a major source of food and provides jobs for billions of people.

Plankton are the diverse collection of organisms that drift in water but are unable to actively swim against currents. Nearly all aquatic ecosystems are sustained by plankton which account for about half of all photosynthesis on Earth. In Earth's deep history, plankton were responsible for the transformation of our planet to one with atmospheric oxygen needed to support complex multicellular organisms such as ourselves. Today, plankton still represent 90% of biomass in the open ocean and are **vital to global carbon** cycling as well as other nutrients whilst being the **first level of the food webs** and playing a critical role in ocean **ecology** and **planetary health**. Plankton also **offer untapped opportunities for innovations in food, medicine, and bio-industries**.

As such, plankton represent an incredibly **powerful solution** to support addressing **the triple planetary crises: biodiversity, climate change and pollution**. Nonetheless, the planetary importance of **plankton remains largely ignored**[1] and is primarily absent from ongoing global discussions related to the **blue economy, blue food, and blue carbon**.

In the meantime, they also represent **underappreciated vulnerabilities** in how our aquatic ecosystems will respond to the onslaught of human activities. Our lack of consideration for plankton is mostly explained by their **incredible diversity, their complexity and their invisible nature** in a complex environment. Still, over the last 10 years, the **emergence of new technologies** (DNA sequencing, AI, satellite imaging…), when used with existing time-series datasets, offers an unprecedented step change in our **capacity to assess, understand and possibly leverage** them to support us in addressing our most pressing challenges.

Through **10 concrete propositions**, this Plankton Manifesto calls for:

- **a deeper understanding, better collaboration, and increased research** on marine and freshwater plankton to better harness their manifold potentials and encourage actions to promote ecosystem protection,

- **initiatives in education** to better understand, utilize, and protect planktonic ecosystems, and the myriad species they support,

- **integrating plankton into international discussions** (national policies & contributions, COP Climate, COP Biodiversity, BBNJ, international food organizations discussions and other UN programs, etc…) to develop programs, define objectives, and activate solutions to help the regeneration of our Global Biodiversity, our Climate & our Environment while providing food and jobs to People.

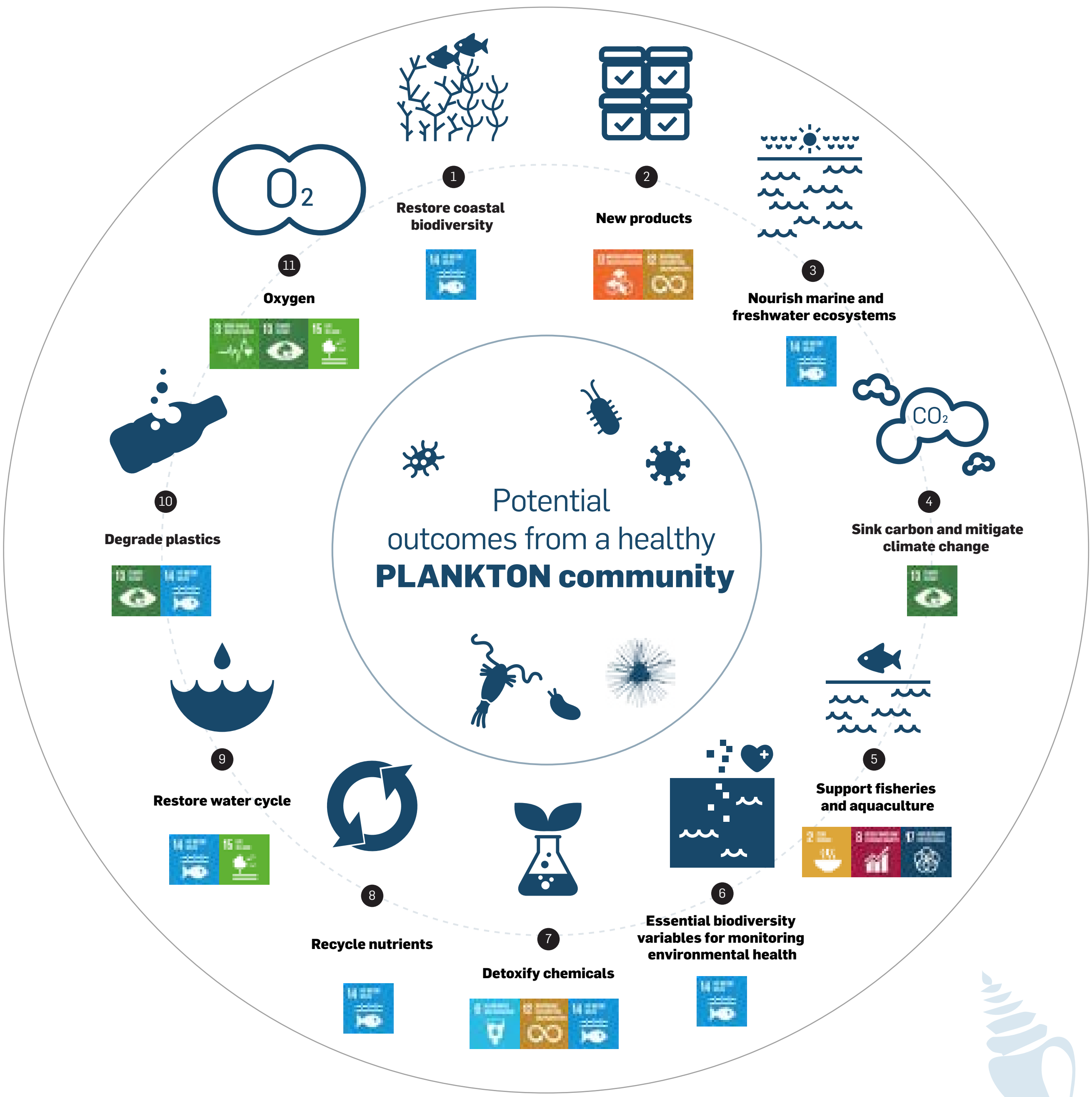
This document is endorsed by:

- **Sanda Ojiambo**, Assistant Secretary-General, United Nations Global Compact

- **Olivier Poivre d'Arvor**, Ambassador for the Poles and Maritime Affairs, Special Envoy of President Macron for UNOC3

- **Peter Thomson**, UN Secretary-General's Special Envoy for the Ocean

PLANKTON-BASED SOLUTIONS TO SUPPORT LIFE ON OUR PLANET:



I. INTRODUCTION

A. THE NEED FOR A MANIFESTO

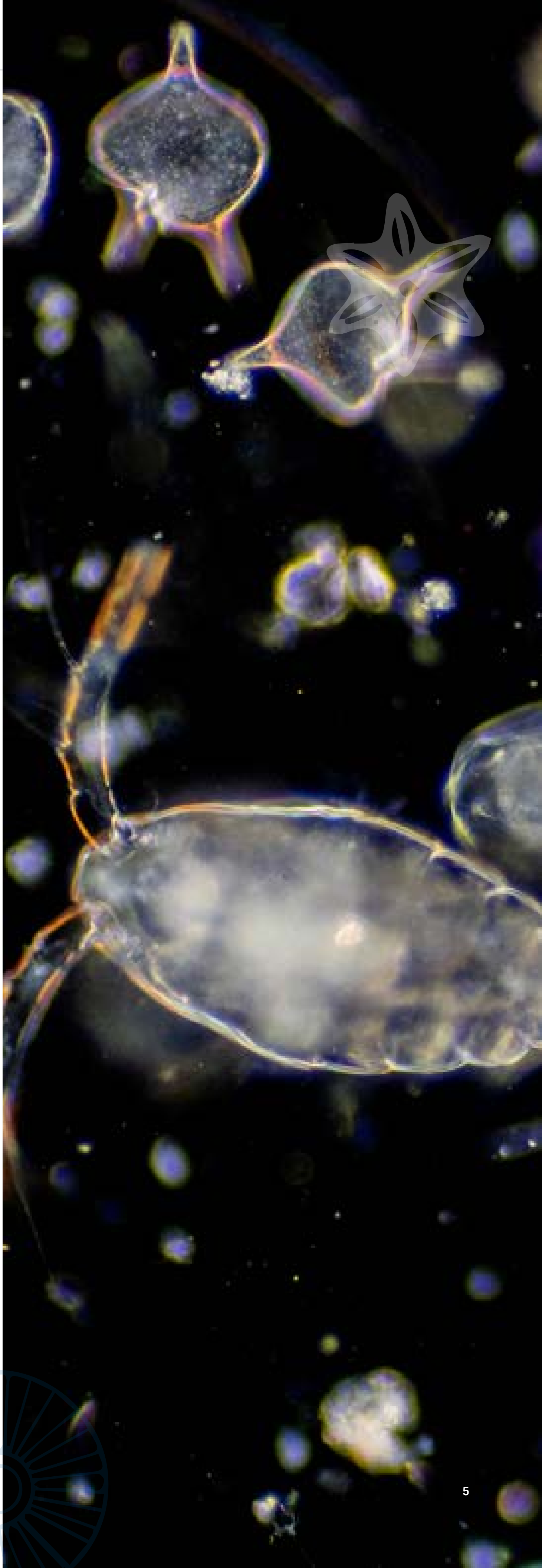
Despite their exceptional biodiversity and the critical roles they play in the global ecosystem (see "plankton essentials" below), plankton remain almost entirely **absent** from ongoing **international discussions** related to the blue economy, blue food, blue carbon, national biodiversity strategies, and COPs. Few plankton-related global programs are led by leading **public agencies, research programs and international NGOs**, as the **focus** in aquatic sciences is typically placed on **visible** and more traditionally deemed "**charismatic**" organisms such as mammals, fish, corals, and more recently seaweed, or to health concerns related to water-borne pathogens. This lack of consideration of plankton may in part be due to significant knowledge gaps, limited market applications, and the complexity of planktonic ecosystems.

This **Plankton Manifesto** outlines how a more comprehensive understanding of these organisms contributes to developing strategies to tackle **the triple planetary crises** of **climate change**, **pollution**, and **biodiversity loss**, and to achieve multiple **UN Sustainable Development Goals** way beyond SDG 14: Life Below Water. It defines a **vision** for supporting our planet's largely invisible ecosystems, explores the **opportunities** and **benefits** for both the **public** and **private** sectors, and outlines the **challenges** and **barriers** to global action on plankton.

B. TARGET AUDIENCE & CONTRIBUTORS

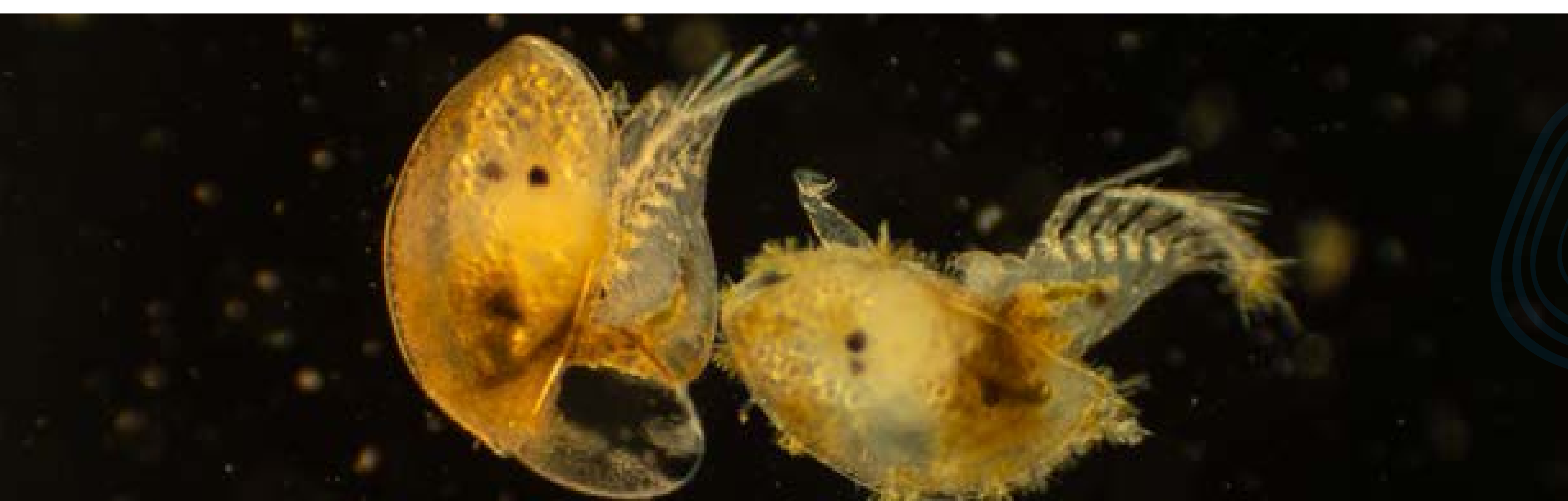
The Plankton Manifesto is intended to be a **catalyst for action** for all kinds of **policymakers**. It seeks to deliver a concise yet comprehensive, scientifically grounded message to the international community, spanning **governments**, **UN agencies**, **NGOs**, **multilateral financial institutions**, **ocean organizations**, and **the private sector**.

This manifesto was initiated by the **Ocean Stewardship Coalition** of the United Nations Global Compact and led by Vincent Doumeizel based on the successful experience of the Seaweed Manifesto. It is the result of a collaboration among a diverse and global community of some of the **most recognized plankton** experts brought together for the very first time. The selected core editorial team is composed of individuals coming from academia, business, and international specialized agencies. The document synthesizes inputs from participants, group discussions, and relevant scientific reports and materials. **The content may not necessarily reflect the position of all participating and cited organizations**.



CORE EDITORIAL TEAM

Last name/First name	Affiliation	Country
Abreu André	Tara Ocean Foundation	**France**
Biswas Haimanti	CSIR-NIO	**India**
Bonnefond Hubert	DareWin Evolution - Inria	**France**
Bowler Chris	ENS CNRS	**France**
Cadoret Jean-Paul	Algama / EABA	**France**
Casati Roberto	CNRS / EHESS	**France**
Cawley Grace	Scripps	**USA**
Cumming Jane Fiona	Article 13	**UK**
Dai Minhan	Xiamen University	**China**
De Vargas Colomban	CNRS	**France**
Duarte Carlos	KAUST	**Saudi Arabia**
Falkowski Paul	Rutgers University	**USA**
Fernandez Camila	CNRS and University of Conception	**Chile & France**
Flynn Kevin	Plymouth Marine Laboratory	**UK**
Guidi Lionel	CNRS	**France**
Hallegraeff Gustaaf	Tasmania University	**Australia**
Hamasaki Koji	Tokyo University	**Japan**
Hoffmann Pierre-Alain	Kyanos	**France**
Iudicone Daniele	Zoological Station Napoli	**Italy**
Johns David	CPR Survey, Marine Biological Association	**UK**
Knoll Andrew	Harvard University	**USA**
Lin Xin	Xiamen University	**China**
Lopes Rubens M.	University of São Paulo	**Brazil**
Makhalanyane Thulani	Stellenbosch University	**South Africa**
McQuatters-Gollop Abigail	University of Plymouth	**UK**
Meyers Bettina	Alfred-Wegnener Institute	**Germany**
Milo Ron	Weizmann Institute	**Israel**
Mitra Aditee	Cardiff University	**UK**
Ogata Hiroyuki	Kyoto University	**Japan**
Probert Ian	Sorbonne University	**France**
Rocke Emma	University of Cape Town	**South Africa**
Sow Bamol Ali	Zinguichor University	**Senegal**
Stulgis Maris	Directorate-General for Maritime Affairs and Fisheries	**European Commission**
Takeyama Haruko	Waseda University	**Japan**
Tett Paul	SAMS	**UK**
Thukral Monica	Scripps Institution of Oceanography	**USA**
Tiffer-Sotomayor Ruth	World Bank	**Costa Rica**
Vincent Flora	EMBL	**Germany**
Wang Guihua Samuel	Xiamen University	**China**



II. A BUILDING BLOCK FOR SUSTAINING OUR PLANET

10 PLANKTON ESSENTIALS

Striking facts about plankton

Earth's oxygen factory

Marine planktonic primary producers (phyto & mixoplankton) perform the same amount of photosynthesis as all land vegetation and so are responsible for about half of the oxygen and biomass production on our planet.

Terraformed the planet

Since the onset of life on Earth, the biological activity of plankton has transformed the atmosphere, oceans, and lithosphere of the planet, and plankton remain key actors in major planetary biogeochemical cycles. They contribute to the water cycle and fix as much nitrogen in the ocean as leguminous plants on land. Sedimented plankton have created the Alps and the building material for the Giza Pyramids and the Hagia Sophia… as well as the chalk we use at school!

Masters of carbon capture

Plankton are far and away the major primary producers in the oceans, converting dissolved CO_2 in seawater into biomass that supports virtually all marine life. Plankton fix between 30 and 50 billion metric tons of carbon annually. Part of this biomass sinks and is buried in seafloor sediments, sequestering carbon over long time scales and thereby contributing to climate regulation. Over long time intervals, this process generates oil reserves, currently being burned by humans a million times faster than new oil can form.

Major role in evolution

Since early in our planet's history, changes in plankton composition and productivity have fueled evolutionary innovations among animals, including the Cambrian Explosion ca. 540-510 million years ago when the major groups of animals alive today first diversified. The planktonic realm remains one of the richest ecosystems on the planet in terms of biodiversity.

Tiny yet mighty

Plankton account for around 90% of biomass in theopen ocean. In a liter of seawater, there can be trillions of planktonic life forms. If you were to align all of the microalgae in the world's oceans, you would end up with a 7cm x 30cm plank stretching 386,000 km from the Earth to the Moon (Bob Anderson, Bigelow Algal Culture Collection, US). Copepods (small planktonic crustaceans) are the most abundant animal zooplankton and outnumber every other group of multicellular animals on Earth. Every night they participate in the largest animal migration on Earth.

Outstanding diversity

Plankton are organisms that are incapable of moving against water currents and there may be 1000's of individuals in a drop of water. Many plankton groups have no simple parallels in terrestrial ecology. The largest biome on Earth ranges from microscopic entities (<100 nm) to the longest animals on the planet, over 60 m for some siphonophores. If the smallest plankton was the size of an ant, the longest one would be the length of Great Britain.

Visible from space

Massive proliferations ("blooms") of plankton can span several thousand square kilometers across the ocean surface and can be seen from space. Using mathematical models, satellite images can be used to estimate surface plankton composition and abundance. NASA and ESA continue to develop major innovations for ocean remote sensing, for example the recently launched PACE satellite.

Guardians of biodiversity

Plankton communities sustain marine food webs, meaning disruptions to plankton will impact fisheries, aquaculture, and tourism. Increases in Harmful Algal Blooms (HABs), for example, have an estimated impact of up to $7B/year in the USA.

Limited understanding

Plankton live throughout the water column, which can be up to 11 km deep, and most are invisible to the naked eye and have very short life cycles (hours to weeks). The vast majority of the planktonic realm remains unexplored and science has mainly focused on a limited number of relatively conspicuous and easily accessible planktonic organisms. We do not yet have a consistent and informed vision of the composition, distribution and dynamics of global plankton communities.

New technologies to enable Plankton-Based Solutions

The 16th century witnessed the first scientific explorations of the visible world, but it is only now in the 21st century that in depth exploration of the mostly invisible world of plankton has been initiated. Over the last 10 to 20 years, dedicated ocean exploration campaigns coupled with new technologies (e.g. high throughput environmental DNA sequencing, automated imaging systems, remote sensing) have led to realization that plankton biodiversity and potential is likely an order of magnitude greater than previously thought (including the discovery of more than 150 million marine genes).

"The ecosystem is like a computer: we can delete a species like a file, but removing plankton is like messing with the deepest parts of the computer. It will definitely make it crash… The difference is that there is no backup for our planet"
- Federico M. Ibarbalz, Centro de Investigaciones del Mar y la Atmósfera (CIMA/CONICET-UBA), Buenos Aires, Argentina

VARIOUS TYPES OF PLANKTON

The term “plankton” is derived from the Greek planktos, meaning **to drift**. Plankton live **suspended** in the water column but **cannot swim against water currents**, therefore drifting along with them. Planktonic communities contain an extraordinary diversity of organisms from all across the Tree of Life, covering several orders of magnitude in size[2,3]. The **biological production** of **marine ecosystems** is mainly sustained by **unicellular photosynthetic organisms** (“phytoplankton”, including microalgae[4] and photosynthetic bacteria) that generate **biomass** using **light energy**, **nutrients** and **CO_2** captured in the sunlit surface layer. Plankton communities include a huge **diversity** of **zooplankton**[5], comprising diverse lineages of **unicellular** predators, as well as **multicellular animals** such as small **crustaceans** (e.g. “krill”), but also larger organisms such as **jellyfish**.

Reaching concentrations of up to **1 billion** cells per liter of seawater, **bacteria**, and **archaea** (“bacterioplankton”) obtain energy by **breaking down particulate** and **dissolved organic matter** (e.g. phytoplankton detritus), thereby **regenerating nutrients to restore ecosystem balance**.

Last but not least, planktonic communities contain extraordinary **concentrations** (up to 10 billion per litre of seawater) of **viruses** (“virioplankton”) that **primarily infect** some other organisms having dramatic impacts on the dynamics of planktonic community. **Fungi** are also part of the planktonic organisms, though there is very limited knowledge about them.

Taxonomy and classification of plankton constantly evolves and is yet to reach full scientific consensus. The recent advances in plankton science tend to indicate that the complexity of marine plankton does not match strictly with our existing definitions. For example, **protists** are of critical importance[3] and consist of a wide range of· mostly unicellular organisms. Protists comprise phytoplankton and zooplankton as well as **mixoplankton** (**a very abundant type of plankton combining** photosynthesis and predation)[2]. The diversity of planktonic organisms, **proportional to their contribution to ocean biomass** is illustrated in Figure 1.

The Open Ocean Biomass
Plankton classification

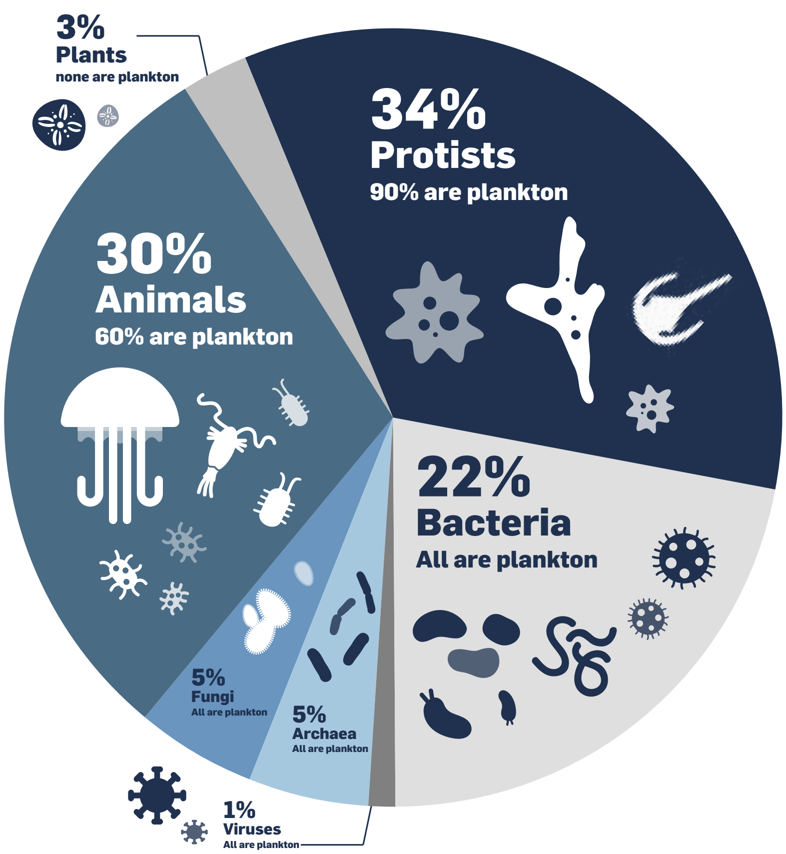


Figure 1: Respective contributions of plankton to total ocean biomass[6]
These numbers are indicative of the plankton contribution to the total ocean biomass.

CONSEQUENCES OF HUMAN ACTIVITIES ON PLANKTON

Human activities have severe impacts on plankton communities by **modifying the ocean's physics** (e.g. mixing and temperature) and **chemistry** (e.g. acidification, eutrophication, chemical pollution). Collectively, these human-induced changes not only **jeopardize** plankton biodiversity, but also the vast array of marine life that depends on plankton. This highlights the **urgent** need for **concerted global efforts** to mitigate these impacts and preserve marine biodiversity.

Summary of the multiple roles of plankton in the ocean:

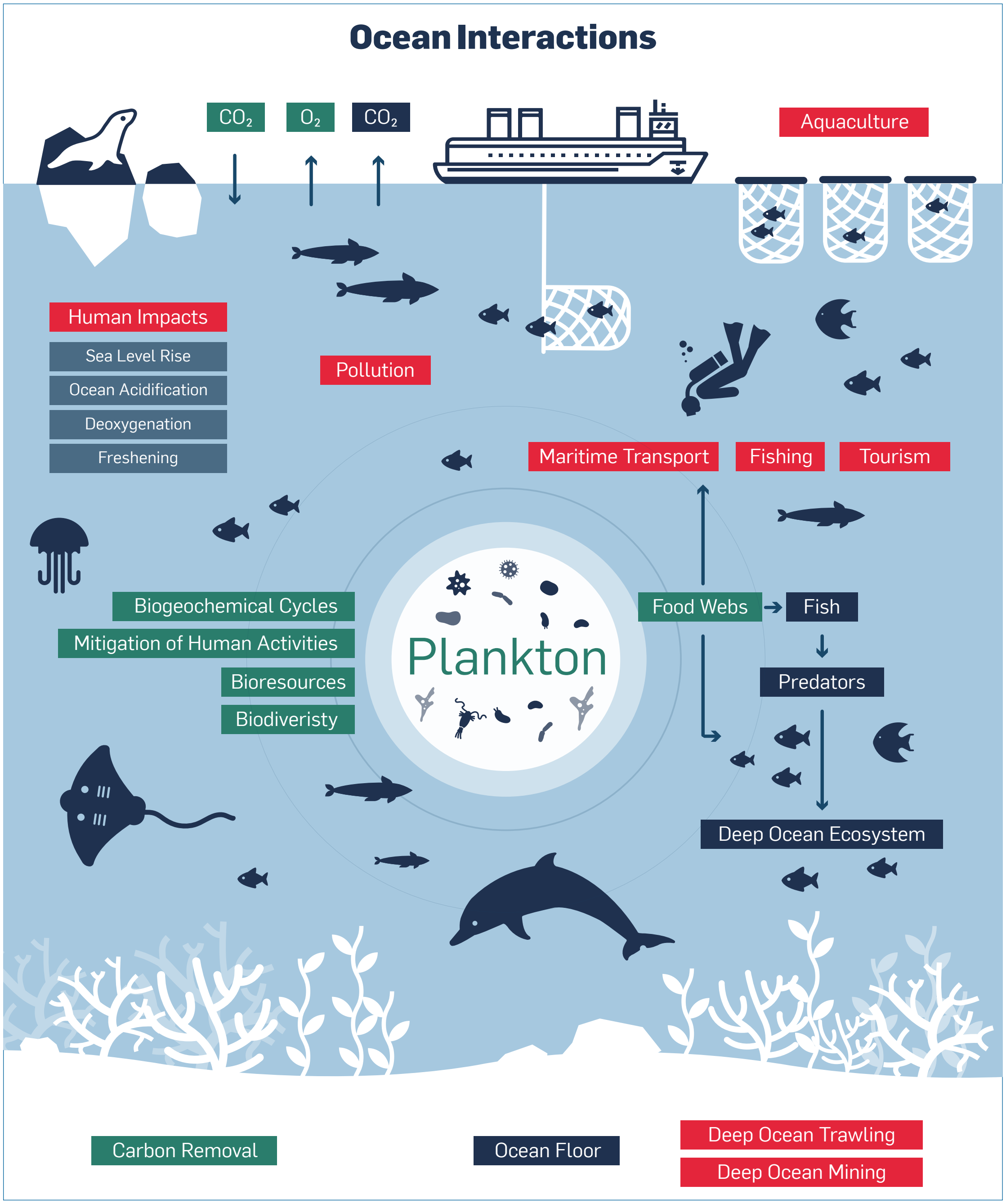


Figure 2: Roles of ocean plankton

Ocean plankton (shown in the center) provide essential ecosystem services shown in **green**.

Human impacts on the ocean are indicated in **red**. Other aspects of the ocean environment are shown in **blue**.

Image created by Rayne. Scheepers and Tabea Rauscher (EMBL) and Chris Bowler (CNRS).

Source: Priorities for ocean microbiome research, https://doi.org/10.1038/s41564-022-01145-5.

Human activities impact the abundance, biomass, distribution, and community composition of plankton through:

1) **Run-off of nutrients** from terrestrial agriculture resulting in eutrophication, stimulating Harmful Algal Blooms (HABs)[7]

2) **Chemical**, **oil and plastic pollution** destroying and disrupting marine ecosystems

3) **Fossil fuel** burning leading to **ocean warming** and **acidification**

4) **Infrastructures** (dams, lagoons, wind turbines, and maritime infrastructures) impacting hydrodynamic flow, salinity, light, habitats, and nutrient availability

5) **Maritime activities** (shipping practices, ballast-water, etc.) disrupting ecosystems and resulting in the introduction of **non-native plankton** species and expansion of pandemics

6) Access to **potable water** from local populations and livestock through the growth of toxic plankton (cyanobacteria) and planktonic larval stages of pests — notably mosquito larvae

7) Increased use of **antibiotics** contributing to antibiotic-resistant bacteria in wastewater treatment plants, causing superbugs to proliferate, especially in the global south[8]

Plankton biodiversity is undoubtedly changing, but the debate over whether global plankton biomass is diminishing remains unresolved, although many experts suspect that this is the case. These ongoing disruptions to plankton ecosystems due to human activities will inevitably have major impacts[9] on marine life as we presently know it, likely leading to unforeseen, and potentially dramatic, consequences.

NEW TECHNOLOGIES OPENING A NEW (BLUE) HORIZON

Ancient mariners acknowledged the abundant life in the open ocean but were puzzled about its food source, as visible plants were nowhere to be found. Only in the late 17th century with the invention of the microscope did scientists realize that the larger marine organisms were being fueled by microscopic organisms originally termed "animalcules", now referred to as plankton. It is only in recent decades, however, with technological developments such as improved sampling platforms, advanced light and electron microscopes, high throughput DNA sequencing, remote sensing from space, and artificial intelligence (AI), that we have started to **comprehend the true diversity** and **global importance** of planktonic ecosystems in terms of productivity, cycling of essential elements, and short and long-term impacts on Earth's climate[10]. Nonetheless, new knowledge has yet to be integrated into many sectors, critically including those involved with fisheries management, environmental health, aquaculture, and biotechnology. **Coordinated discussions** and **global action** are required to fully exploit the possibilities offered by new technologies for addressing the impacts on plankton from human activities as well as a nascent interest in plankton applications from industry. Progress should be driven by science with extreme caution, but technological developments are a game changer for our capacity to understand and act upon plankton-related issues, opening new avenues for the protection of our planet and for more sustainable innovations to meet SDGs.

Technological ways to bridge knowledge gaps in plankton research

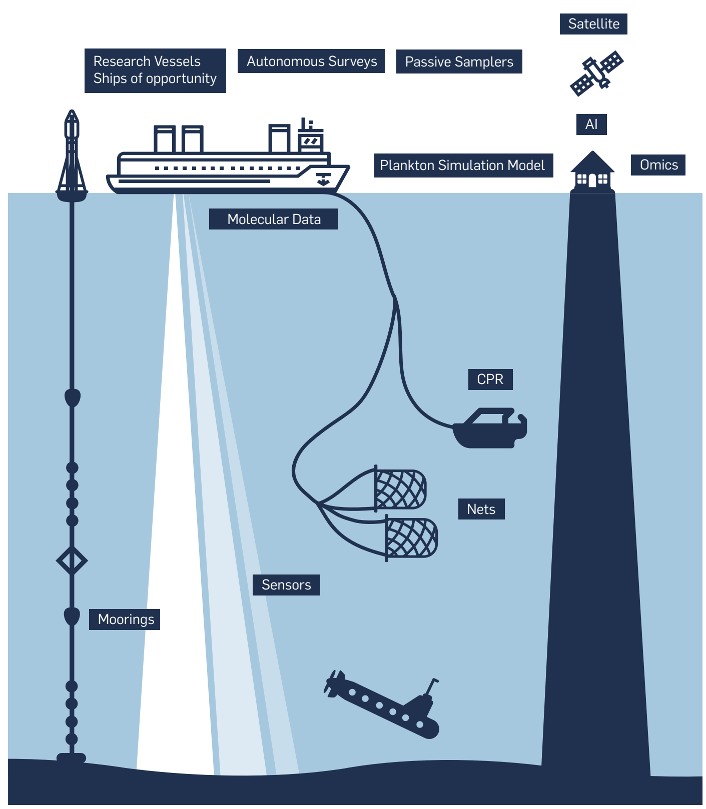


Figure 3: Overview of technologies monitoring plankton health

III. PLANKTON-BASED SOLUTIONS

Plankton biodiversity is undoubtedly changing, but the debate over whether global plankton biomass is diminishing remains. Management and controlled exploitation of plankton communities have the **potential** to make **key contributions to addressing the most urgent planetary crises**. This section outlines a framework for plankton-based solutions (PBS), which are interlinked, with strong overlap and co-benefits between them.

A. PLANKTON-BASED SOLUTIONS FOR THE CLIMATE CRISIS

a. Carbon absorption

Some plankton use **photosynthesis** to transform CO_2 into organic matter that **supports marine life**, part of which sinks to the ocean floor when these organisms die or are consumed. Every kg of phytoplankton can fix up to 2kg of CO_2 (2kgCO_2/kg phytoplankton)[11]. Through this biological carbon pump[12] (and notably microbial activity[13]), atmospheric carbon dioxide (CO_2) sequestered by plankton is transported to the deep ocean, effectively removing it from the active carbon pool for centuries to millennia, if not longer. **This reduces the overall concentration of atmospheric CO_2, thereby mitigating climate change**.

This **biological carbon pump** represents in volume a minor part of the ocean carbon absorption, as the major part of this process comes from the **physico-chemical pump** which absorbs carbon and additional heat from the atmosphere. Still, the biological carbon pump has created and still maintains a misbalance **in natural carbon concentration** from the surface of the ocean to the deep. Hence, would the **current plankton mix change** in the wrong way, the ocean would lose a consequent part of its ability to mitigate current climate changes. Carbon being sequestered in ocean sediment, the question of **Sea Bed Mining** should also be explored with respect to the risk to the plankton-driven biological carbon pump.

Adding iron compounds to seawater in certain iron-poor parts of the ocean has been suggested to enhance **organic production** and, thus biological **removal of CO_2** when the organic matter sinks. **Alkalinization** has also been proposed to raise the solubility of CO_2 in seawater, de facto countering the effect of **ocean acidification**[13]. However, the **moratorium agreement**, adopted on 30 May 2008 at the United Nations Convention on Biological Diversity in Bonn, Germany, enforced a **complete ban on ocean fertilization projects** until scientists better understand the potential risks and benefits of manipulating the oceanic food chain[14]. While part of the science community supports the necessity of this moratorium, some scientists are calling for the re-opening of these investigations in **controlled environments** to be reconsidered, in order to provide the means to better assess potential outcomes of such large-scale geoengineering.

b. Decarbonizing our economies

Many **high-emission materials and processes** could be replaced or optimized using **plankton biomimicry**. For example, diatoms, a very abundant group of phytoplankton, create a **silica shell** at ambient temperature, unlike **conventional glass** production which requires a temperature of more than 1500°C[15]. Plankton have also been explored as a promising route to biofuel production[16]. While there is significant interest in this concept, the reality of the challenges involved has tempered expectations, pending radical technological improvements. Beside the exceptional nutrient content and high productivity opening new ways to mitigate climate impact of our food systems, plankton also possess a variety of defense mechanisms, such as the production of toxins or bioluminescence, which offer avenues for biotechnological applications. For example, plankton are among the **stickiest** organisms on Earth and could thus be an inspiration for **biological sources of gels**, **glues**, and **nanomaterials**. Of the tens of thousands of known plankton species, only a **handful** have been **studied** in any detail, meaning there is an almost **unlimited potential** for climate friendly **innovation lying within plankton**.

c. Supporting the water cycle

A significant part of climate change is due **to disruption** of the water cycle and concentration of water vapour in the atmosphere[17]. Some species of plankton emit sulfur compounds that, upon reaching the upper atmosphere, contribute to the **formation of cloud condensation nuclei** (NB: the characteristic smell of the sea is often attributed to these sulfur compounds, showcasing the influence of plankton, even on our sensory experience of the ocean). These nuclei are **essential** for the formation of **clouds**, which **in turn play a critical role in restoring the Earth's water cycle and climate regulation**. Limiting our impact on these plankton communities is essential to maintaining the water cycle.

B. PLANKTON-BASED SOLUTIONS FOR THE BIODIVERSITY CRISIS

a. Supporting marine ecosystems

Plankton provide the basis of marine food webs by being the initial energy supply for all components of the ecosystem. Plankton **sustain all forms of life** in marine ecosystems, including corals, seaweed, sharks, whales, and mussels. Photosynthetic plankton are also the sole producers of certain molecules (lipids, certain pigments, and sugars) essential for the proper development of higher trophic networks. Without this primary source, the survival rates of eggs, larvae, and juveniles of numerous organisms (including fish) are significantly impacted. This process facilitates a balanced and thriving marine environment.
Furthermore, the photosynthetic activities of plankton contribute to **oxygen production** and **carbon sequestration**, which are crucial processes for sustaining biodiversity in marine habitats. Through these mechanisms, well-balanced plankton populations foster resilience in marine ecosystems, enabling them to better withstand and recover from disturbances, thereby supporting the restoration and preservation of marine and coastal biodiversity.

> *"Plankton productivity limits the growth of crustaceans, shellfish, fish, sharks, porpoises and other marine life, just as the primary productivity of land plants limits the growth of elephants, giraffes and monkeys."*
> *Paul Falkowski[18]*

Global photosynthesis

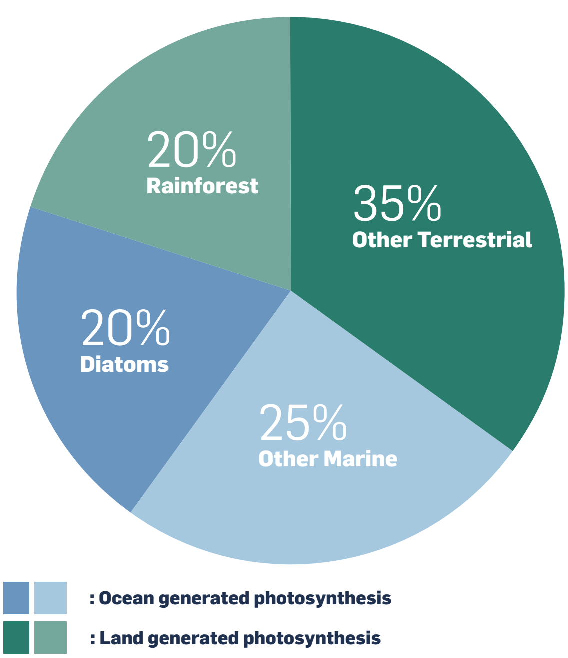


Figure 4: Global photosynthesis
These numbers are indicative.

b. Limiting Harmful Blooms of algae and jellyfish

Marine microalgae play a pivotal role in supplying oxygen and supporting the biomass within marine food webs. However, hotter ocean temperatures, acidification, coastal urbanisation and nutrient pollution (sewage, agricultural runoff, industrial discharge, ...) are destabilizing planktonic ecosystems and favoring the development of harmful algal blooms (HABs) along the world's coastlines. HABs endanger marine coastal species, causing the loss of "cultural ecosystem services" when important species are affected. HABs also jeopardise human health by contaminating seafood with toxins and exposing people to harmful compounds released in the air during blooms.

Akin to biocontrol in agriculture, **Plankton Food Web Manipulation** by adding predators (e.g. restocking fish in lakes), or stimulating algicidal bacteria (e.g. by restoration of seaweeds and seagrasses) has been proposed as a means to control HABs. Similar to the ethical concerns of iron-fertilization experiments, society should be aware **of unintended consequences** of biomanipulation as a way to repair the environment. However, studying those basic principles in controlled environments to better understand them should be supported. In the case of HABs induced by humans, **the most reasonable way to limit their proliferation is** to constrain and reduce harmful anthropogenic activities.

Similarly, fast-growing and visible "**jellyfish blooms**" disturb food webs and fisheries by eating or outcompeting other organisms. They are promoted by various anthropogenic factors such as **overfishing**, **eutrophication**, **artificialization of coasts**, **or introduction of invasive**. Thirty of the hundreds of known jellyfish species are prone to these irregular blooms, impacted by a range of the named causes[7,19,20]. Yet the exact causes need to be further investigated if we are to find solutions.

c. Supporting coral communities and seaweed forests

Corals are keystone species in **reef communities** which harbor exceptional biodiversity, and survive via a **symbiotic relationship** with a microalga they source from free-living plankton. **Better monitoring** and **management** of **surrounding plankton communities** could therefore be **key** to **preserving** and **reviving** coral ecosystems. It has been shown that **coral ecosystems can be rescued** by taking specific plankton microbiomes from **healthy coral reefs** and seeding them on unhealthy ones, known as "Coral Microbial Transplant (CMT)" experiments.

In a similar manner, seaweed forests, which host an incredible diversity of coastal organisms, are highly dependent on their microbiome and surrounding plankton communities. **Plankton management** could thus be key for contributing to preserving ocean forests from the disruptions that are currently putting them at risk.

C. PLANKTON-BASED SOLUTIONS FOR POLLUTION

a. Plankton as bioindicators of ecosystem health

Plankton populations respond **rapidly** to **changes in their environment**, making them effective **early warning indicators** for detecting shifts in ocean conditions. Changes in plankton species composition can indicate **shifts in water quality**, due for example to eutrophication or pollution. By monitoring these changes, scientists can **assess the health of marine ecosystems** and the **impacts of human activities**[21].

Additionally, through the analysis of the **fossilized remains** found in sediment cores of biomineralized plankton such as foraminifera and diatoms, scientists can **reconstruct past ocean temperatures** and chemical conditions. These data generate critical insights into historical climate change and could help predict and anticipate future shifts in planetary processes. Hence, plankton science should play a crucial role in **identifying** and **understanding short- to long-term environmental patterns**, pollution, and climate change effects.

b. Cleaning waters and upcycling pollutants into valuable products

Microalgae are increasingly being used for **water treatment**[22], offering a cost-effective solution to environmental challenges like **eutrophication**, a process whereby water bodies become overly enriched with nutrients, leading to excessive growth of algae and the depletion of oxygen. Unlike traditional methods that are expensive and generate waste, the use of microalgae can clean water naturally by **absorbing these excess nutrients**[23]. This process, known as "**phycoremediation**", purifies water and takes up CO_2, while also providing algal biomass that could be used to generate valuable materials for **food**, **plastics**, **bio-based fertilizers**, or **animal feed** in the context of a circular bioeconomy. Besides, HABs could be considered to turn environmental challenges into business opportunities. The EU project Algae Service for LIFE examined the sustainable use of algae to improve water quality and reduce eutrophication in aquatic environments. Additionally, the project developed innovative technologies and methods for harvesting and utilizing algae, creating economic opportunities and supporting environmental conservation efforts.

Algal walls could also be considered as a more efficient alternative to vegetalized walls, to **clean air in cities**[24]. All in all, plankton offer attractive solutions for industries by turning waste treatment into a source of revenue.

c. Mitigate ocean plastic pollution

Fungi as well as many bacteria, including from the marine environment, have evolved strategies to **naturally degrade polymers**. Promoting a better understanding of the interaction between planktonic bacteria, fungi and polymers could help to **address plastic pollution in the ocean**[25, 26]. This would open the door to new **green chemistry solutions to eliminate harmful plastics** from the ecosystem through **bioremediation**.

D. PLANKTON-BASED SOLUTIONS FOR PEOPLE AND NATURE

Beyond their ecological significance, plankton, particularly phytoplankton and mixoplankton, have the potential to unlock a **spectrum of industrial** and **biotechnological** opportunities[27]. Despite the **breadth** of potential applications, only a handful of plankton are **currently produced** at an industrial scale partly due to **the lack of cultivation processes** that are scalable and affordable.

a. Food and nutrition

The biodiversity, abundance, distribution, and productivity of plankton directly influence the **health** and **productivity** of **fisheries** and **aquaculture** around the world. Plankton are therefore **directly linked to global food security**, which is particularly important in developing countries where seafood is a major source of income as well as a primary protein source, together with valuable omega-3 fatty acids, for more than three billion people[28].

Healthy plankton populations ensure robust fisheries & aquaculture, which are essential for the economic stability of coastal communities.

Plankton have long been used as a **niche producer of vitamins**, **food supplements**, **and colorants**. They can be used as **dietary supplements** for humans as they are rich in **proteins**, **vitamins**, **and minerals** (cf, the recent global development of spirulina used for generations in Africa). Human cultures with high seafood consumption, such as those in Japan and the Mediterranean, often exhibit **better health and longevity**.

This is attributed to the unique nutrients solely synthesized by some **plankton**, **and accumulated through the marine food chain**.

Some microalgae can produce up to **20 times** more proteins per unit area than **soybean plants**, with production levels potentially reaching up to 200 tons/ha/year. This means that in the future, plankton could represent **an alternative**

to existing agricultural production with a much more limited climate footprint, including no deforestation.
Animal feed (mostly for aquaculture) is one of the **oldest applications** of plankton and offers the **potential** to **enhance food sustainability**, **human health**, **and ecosystem robustness**. Plankton are essential foods for many shellfish and larval fish species.
Over the last 15 years, the availability of sustainable sources of proteins for **aquaculture has decreased by 30% whilst prices have multiplied by three**[29]. This trend, in addition to optimized production methods enabled by new technologies, may offer a **very competitive positioning for microalgae-based animal feed**.

There is currently a significant global market for planktonic species for use in **aquaculture** with attempts to **maximize production** through accelerated breeding in order to improve strains and multiply the production of key molecules (e.g. poly-unsaturated fatty acids and pigments such as fucoxanthin and beta-carotene).
This potential **goes far beyond microalgae** (e.g. the "thraustochytrids", non-photosynthetic plankton, which offer **a major source of omega 3 fatty acids**[30] that could help replace our dependency on fish).

b. High-value pharmaceuticals

Among plankton organisms, a number of studies[31,32] have identified **bioactive compounds** from microalgae with **benefits for human health** including **antifungal**, **antibacterial**, **antiviral** (e.g. anti-HIV), **anticancer**, **immunosuppressive**, **anti-inflammatory**, **antioxidant**, **anti-aging**[33], **photoprotective**, **neuroprotective**, **anti-diabetic** and **anti-obesity activities** as well as **cholesterol-lowering benefits**[34,35].

Plankton products can also be sourced for cosmetics[36]. The **rate of discovery** from traditional drug producers which have been the focus of pharmaceutical research for decades, is **decreasing** and it seems to be the **time to turn to plankton** and leverage their **potential**[31,37]. So far, more than **2000 secondary metabolites** have been identified. However, despite this strong **potential**, **few molecules are currently on the market** which could be explained by the relatively low levels of investment[37], the complexity of accessing genetic resources in marine laboratories, and the major science gaps in this topic.

c. Gene ownership issues

According to the **Nagoya Protocol to the Convention for Biological Diversity**, every country is entitled to sovereign ownership of the ocean resources in its **Exclusive Economic Zone**. The same also applies to genes discovered in the ocean. Today, just **10 nations own close to all marine genetic resources**. Over 130 countries, mostly from the Global South, have no ownership of marine genes at all.
The recently adopted United Nations Biodiversity of Areas Beyond National Jurisdiction Treaty **(BBNJ Treaty) covers ownership issues slightly but needs to be accelerated**.
The market of gene sequences represents **about 6 billion US$** a year; however, scientists who discover new genes, despite very recent UN agreement, **are not yet sufficiently obligated to disclose where the gene was found** or the nature of the organism that contained it. Plankton observe no boundaries but Nations are **not equal** in the discovery/ownership of genes: the technology is not widespread, is costly, and requires technical capabilities. **Developed countries thus have an advantage over developing ones**.

IV. KEY RECOMMENDATIONS

The Plankton Manifesto calls on decision makers to implement **specific measures** to **ensure that economics and environmental developments proceed with utmost consideration for plankton communities**, **people**, **and nature**. **These recommendations are interlinked and should be considered holistically**.

A. IMPROVE KNOWLEDGE TO BETTER MONITOR

1. Strengthen funding for plankton research activities. Plankton exploration and science suffer from a lack of targeted funding. The vast majority of plankton remains of unknown value to their ecosystem, and science struggles to find funding sources for what is arguably the most important group of organisms on the planet. Stabilized funding is also necessary for plankton time-series which are in operation: the value of a time series increases the longer it runs — continuity of funding is critical. A global approach is needed to understand immense planetary value and changes in plankton communities, including through:

a. Developing and deploying methodologies for monitoring plankton biodiversity and activities, especially from autonomous vessels and floats;

b. Developing shared screening platforms to identify molecules, genes, and species of interest for commercial applications;

c. Prioritizing the study of plankton in polar regions since the Arctic and Antarctic are especially sensitive to climate change;

d. Potentiating plankton time-series datasets so that changes can be monitored and compared at a multidecadal scale. Based on best available knowledge, generate a comprehensive plankton atlas, as well as develop a plankton-based health index to biomonitor the status of marine ecosystems;

e. Incorporating plankton into digital ocean twins by making realistic plankton models suitable for integration into ocean simulators;

f. Developing citizen science tools in order to include everyone everywhere in a global plankton assessment.

2. Based on existing global precedents, create a global platform to develop sectorial and cross-sectorial collaborations among science, industry, and policy. Despite the global distribution and importance of plankton, research is fragmented with relatively little exchange between scientists across subject arenas around the world. There is a need to break down silos and develop global knowledge sharing and collaboration between scientists, as well as with other relevant experts from policy and industry. This platform would bring together skills, best practices, and standards in order to avoid overlaps, improve science and policy interfaces, attract funding, and accelerate innovation.

3. Elaborate tools to assess and mitigate impacts of human activities on plankton. Guidelines need to be elaborated, for impact assessments, to systematically integrate plankton disruption or changes resulting from human projects related to the ocean, such as new marine or coastal infrastructures, maritime transports, fishing, tourism, aquaculture, etc. There is also a need to implement stricter regulations on pollutants including agricultural runoff, human sewage and industrial discharge, to minimize nutrient overloading and chemical contamination in aquatic environments, thus limiting harmful algal blooms and preserving plankton habitats and marine biodiversity.

B. CREATE PLANKTON AWARENESS FOR ALL

4. Launch a global "plankton literacy" project in education for both schools and politics/policy (distinct actions) to raise awareness about the critical roles of plankton in food webs and planetary functioning and their impact on our everyday lives. The lack of education starts in early school years. It is important that future generations are aware and understand the challenges facing plankton and ultimately survival of the human race, as well as business opportunities that may help to address these fundamental challenges. The word plankton needs to become as familiar to young children as cats, dogs, and lions. Plankton literacy should also be advocated to policy-makers in order to promote the integration of plankton into considerations for future environmental and biotechnology public policies.

5. Map of market dynamics for existing and potential plankton applications to ensure that public and private funding will underpin regenerative development in an optimized manner. This could enable more collaboration and efficiency among stakeholders. Better information and insights can increase the market attractiveness and help channel investments into more successful business opportunities whilst easing access to market.

6. Launch advocacy projects at a global level. Very little information about plankton is communicated to funding agencies, venture capitalists, startups, NGOs, and other stakeholders. This presents a missed opportunity, as their involvement could foster deeper exploration and investment in diverse aspects.

C. INTEGRATE PLANKTON INTO GLOBAL POLITICAL DISCUSSIONS

7. Urge UNFCCC Parties to explore further the role of plankton in climate mitigation.

a. The SBSTA Ocean and Climate Change Dialogue should recognize the role of plankton in sequestering carbon dioxide through the biological carbon pump, addressing current gaps and overlooked areas, as well as identifying a way forward to develop robust guidelines to account for this mitigation capacity (e.g. in the GHG inventories).
b. Countries should be invited to develop comprehensive strategies that include the conservation and restoration of marine ecosystems as part of their Nationally Determined Contributions (NDCs) related to climate action.

8. Urge CBD Parties to take ambitious action to conserve, restore and sustainably use coastal and marine biodiversity, including plankton, in line with the Kunming-Montreal Global Biodiversity Framework. Specifically, the role of plankton and the benefits they provide for climate, nature and people could be further integrated/reflected in:

a. The National Biodiversity Strategies and Action Plans (NBSAPs) by inviting Parties to revise their strategies in the light of the Framework, establishing robust and quantified measures to protect these ecosystems, including through the Programme of work on Marine and Coastal Biodiversity.
b. The Monitoring Framework of the Kunming-Montreal Agreement by integrating dedicated indicators related to plankton, such as the changes in their biomass and diversity, to ensure Parties can regularly review and assess progress made.
c. Support science aimed at assessing the potential of plankton for Blue carbon, through a precautionary, inclusive, and well-planned programme to ensure that marine Carbon Dioxide Removal technologies (such as nutrient fertilization, alkalinization, de-eutrophication) do not negatively impact plankton and the services they provide, in accordance with CBD COP10 Decision on Biodiversity and Climate Change (Decision X/33).

9. Address the remaining definitions in the Biodiversity Beyond National Jurisdiction (BBNJ) treaty by:

a. Including plankton and their services in the criteria to be defined for future area-based management tools. This will help to ensure comprehensive conservation strategies that address not just the more visible marine species but also the microscopic organisms that form the basis of the ocean's food web and drive most of its biogeochemical processes.
b. Enforcing policy dialogues with WIPO (World Intellectual Property Office) and national patent offices to provide a workable equitable legal framework for access to marine genetic resources from plankton in the high seas, as well as reducing country inequalities by providing nations with access to technology and ensuring access to biological resources. This should be done by leveraging the historic New Treaty on Intellectual Property, Genetic Resources and Associated Traditional Knowledge signed in May 2024. This would allow for knowledge, specifically about the genetic potential of plankton, to be shared ethically and fairly to minimize inequalities.

All of this information needs to be produced and taken into account in international agreements and policy documents. It should eventually trigger and be reflected in more regular and ambitious projects from national and international NGOs working in Marine Conservation and the environment.

10.Urge international food organizations to explore how improved management of plankton could further support Food Security across the world.

a. Plankton should become fully integrated into ongoing discussions on "Blue Food" resulting from the UN Food System Summit in order to mitigate world hunger and malnutrition.
Plankton should be considered by International food organizations at CFS (Committee on Food Security), COFI (Committee on Fisheries), etc., in order to contribute to the development of a sustainable aquaculture industry.
b. Plankton should be explored to improve and leverage direct nutritional benefits (e.g., Spirulina and Chlorella) while defining regulations and guidelines to ensure healthy plankton communities supporting fishing and ocean farming. Monitoring and understanding of plankton communities should be used for an improved prediction and management of fishing & aquaculture activities for all relevant stakeholders.

GLOSSARY

1. OVERVIEW OF PLANKTON CLASSIFICATION

Terrestrial ecosystems are dominated by various multicellular photosynthetic plants as **producers**, and animals communities as **consumers**[2]. Also present are the bacteria and fungi which act as **decomposers**. Viruses attack all of these organism types. Open-water ecosystems are dominated by plankton which, while including representatives of these functional groups (producer, consumer, decomposer), differ from terrestrial systems in important ways. Most importantly, **plankton** are dominated by unicellular microscopic organisms that are involved with complex trophic (food web) interactions.

Producers
There are no multicellular plants in the plankton; the role of producers is taken by single-celled microbes, most of which are <0.01mm in size, growing in the sunlit surface waters. These are either **prokaryote** (bacteria-like) or **protist**-like organisms, generically termed **microalgae** or **phytoplankton**. They perform photosynthesis, using light and inorganic nutrients (notably N, P, Fe). Another microalgal group, the **mixoplankton**, also additionally obtain nutrients by eating (consuming) prey. Producers are consumed by mixoplankton, and zooplankton, and also succumb to virus attack. Changes in the biodiversity and activity of these organisms strongly affect food webs including those supporting fisheries, while some species can create harmful algae blooms (**HABs**)[38]. Planktonic producers are relatively well-studied, but most understanding comes from research on very few species. The following subgroups may be identified:

- **Cyanobacteria**: sometimes termed 'blue-green-algae', these are photosynthetic bacteria, common throughout illuminated waters. Most are ca. 0.001-0.01mm. Some can fix N_2 and hence help fertilize the water. Some are symbionts, living within other microalgae; the two organisms benefit by exchange of chemicals and nutrients. Some cyanobacteria are toxic, notably forming HABs in freshwater bodies including reservoirs and lakes. Some can alter their buoyancy but they are otherwise non-motile. Some species are important in biotechnology and food additive industries.
- **Protist phytoplankton**: typically much larger organisms than cyanobacteria, these include the **diatoms** (ca. 0.01-0.2mm) which are especially common in turbulent waters that keep them suspended in the illuminated water column. They are often viewed as being important feed organisms for consumers and for supporting CO_2-sequestration via the **biological carbon pump**. Diatoms need silica for their cell walls; while some can alter their buoyancy they are otherwise non-motile. Various other protist phytoplankton are motile. Few of this group are HAB species. Some are exploited in biotechnology and aquaculture.
- **Mixoplankton**: Mixoplankton: protists that not only photosynthesise but also eat prey which may include their competitors, and sometimes even their predators. Most mixoplankton were previously grouped with protist phytoplankton; only in the last decade has the importance of these organisms been recognised[38]. Many **dinoflagellates** are mixoplankton and, like most mixoplankton, they are strongly motile. However, some mixoplankton, notably the chalk-producing **coccolithophorids**, are non-motile. Most HAB species are mixoplankton, producing a range of toxins and mucilage harmful to wildlife, aquaculture and humans.

Consumers
Collectively termed zooplankton, most plankton consumers are protist microbes, while the others are animals. Zooplankton range from 0.003mm to many metres in size. A few species and life stages of zooplankton are well studied; most are poorly understood. The following subgroups may be identified:

- **Protist zooplankton**: these are single celled microbes, most of which are <0.2mm in size, but some species are >1mm. Most consumer activity in the plankton is performed by these organisms (e.g., **ciliates**, **dinoflagellates**), and their rapid growth rates enable them to control growths of many producers and also bacteria. Some are more correctly termed **mixoplankton**, combining eating with photosynthesis, the latter performed by symbiotic microalgae or using body parts stolen from prey. Protist zooplankton may exhibit great flexibility in the size of their prey; some can eat prey many times larger than themselves. They can display strong preferences between prey types and quality. Most are motile, but some await their prey to contact them. A few are toxic or bioluminescent. They are important intermediaries in food webs leading to metazoan zooplankton. Knowledge of the physiology and activity of these organisms is generally scant, limited to a few species.
- **Metazoan zooplankton**: these are animals, typified by copepods, krills and jellies but which include many other types and also juvenile stages of non-planktonic animals (including many fish, shellfish and benthic animals, such as barnacles, crab, lobster, starfish). Many are strongly motile, though others (notably, jellies) are weak swimmers. Typically they feed on organisms much smaller than themselves but cannot directly access the smaller producers or bacteria, thus depending on protist zooplankton or mixoplankton as intermediaries. The larger forms typically consume other metazoan zooplankton. While some display marked prey preferences, most likely feed more according to prey size; however, diet composition is invariably important. These organisms are key to food webs leading to fish, whales, birds etc. Detailed knowledge of the physiology and activity of these animals is mainly limited to, especially, adult female stages of certain copepods and krill.

Decomposers
The ecological role of these organisms is dominated by chemical transformations and interconversions (which are mainly metabolically costly and inefficient processes) rather than by producing biomass.

- **Bacteria/Archaea**: these prokaryotes (most <0.001mm) are responsible for decomposing particulate and dissolved organic matter, recycling nutrients back to inorganic form to support production. Some convert ammonium (major animal waste product) into nitrate, and others convert nitrate into N_2. Bacteria plankton are poorly understood in detail, aggravated by the complexity and lack of characterization of what supports their growth. They are consumed by protist zooplankton and also by mixoplankton (for which they provide critical nutrients for supporting photosynthetic production), while many likely succumb to viral attack.
- **Fungi**: most are microscopic (microfungi, yeast or swimming zoospores) acting as parasites for plankton and also recyclers of organic matter. Their role is the least known of all plankton types.
- **Viruses**: the most numerous plankton type (perhaps 100 millions per mL), these are infective agents of other plankton types as well as larger animals. Little is known of their ecological role but their rapid proliferation is suspected to eliminate plankton blooms over large areas over a few days, converting the biomass largely into dissolved organic matter that supports bacterial activity. As such, and because viruses are host-specific, their regulatory role of the **biological carbon pump** and contribution to the **microbial carbon pump** has been suspected (thus relevant for climate change scenarios).

2. GENERAL GLOSSARY

- **Alkalinisation**: addition of alkali chemicals to combat ocean acidification.
- **Archaea**: a type of prokaryote bacteria-like organism, key for certain biogeochemical transformations.
- **BBNJ**: Biological Diversity Beyond Areas of National Jurisdiction; international legally binding instrument under UNCLOS for the conservation and sustainable use of marine biodiversity beyond national jurisdiction.
- **Biome**: large naturally occurring community of organisms within a major habitat, e.g. ocean, lake.
- **Biomimicry**: design and production of materials, structures, and systems that are modelled on biological entities and processes.
- **Biological carbon pump (BCP)**: planktonic activity (including sinking of diatoms, faecal material and animal corpses) that collectively results in the sequestration of atmospheric CO_2 into particulates buried in the ocean floor. CF. microbial carbon pump.
- **Ciliate**: common type of protist zooplankton, though some are actually mixoplankton.
- **Coccolithophorid**: a type of protist microalgae that has cell walls covered in chalk plates (coccoliths). Over geological time, coccoliths are formed massive chalk deposits. At least some are mixoplankton; others are phytoplankton.
- **Consumer**: organism that consumes biomass, resulting in a net decrease in biomass as a portion of the consumed biomass is wasted. (CF. decomposer, producer).
- **Copepod**: common metazoan zooplankton, typically of ca. 1-5mm, but with juvenile stages down to ca. 0.01mm. Important feed organisms supporting fisheries.
- **Cyanobacteria**: photosynthetic bacteria, often termed 'blue-green-algae' in freshwater ecology.
- **Decomposer**: organisms that use especially dead biomass and dissolved organics, typically with a very low conversion efficiency such these organisms are important in releasing inorganic nutrients that support (primary) production.
- **Diatom**: common protist phytoplankton. Typically fast growing, their growth depends on the nutrient silicate as their cell walls are built of silica (glass).
- **Dinoflagellate**: common protist zooplankton or mixoplankton. Often highly motile, and includes toxic HAB.
- **Eukaryote**: organism consisting of a cell or cells with DNA as chromosomes held within a distinct nucleus. CF. prokaryote. Includes protists, and all higher plants and all animals (including zooplankton).
- **Eutrophication**: Process where water bodies become overly enriched with nutrients, leading to excessive growth of microalgae and the depletion of oxygen.
- **Fertilization**: addition of nutrients to promote production. Excess nutrients causes eutrophication.
- **HAB**: harmful algal bloom. Typically caused by cyanobacteria or mixoplankton, HABs include toxic and also nuisance species which generate foams and mucilage that damage ecosystems.
- **Jellies**: generic term for gelatinous metazoan zooplankton such as cnidaria ('jellyfish'), ctenophores ('comb-jellies') and siphonophores (which includes the largest plankton, of 60m length).
- **Krill**: a form of metazoan zooplankton. Up to >10cm in length, krill are important (often dominant) animals in certain marine systems, key for supporting Southern Ocean ecosystems and baleen whales.
- **Metazoa**: multicellular eukaryotes; metazoan zooplankton such as copepods and krills are important animals supporting fisheries. Others, such as jellies, can be associated with ecosystem damage.
- **Microalgae**:generic term for single-celled photosynthetic microbial organisms, such as the prokaryote cyanobacteria, and the protist mixoplankton and phytoplankton.
- **Microbial carbon pump (MCP)**: planktonic activity that collectively results in the sequestration of atmospheric CO_2 into forms of dissolved organic matter in the oceans that are recalcitrant, resisting decomposition for 100's-1000's years. CF. biological carbon pump.
- **Mixoplankton**: a type of protist microalgal plankton that is photosynthetic (like phytoplankton) and also eats (like protist zooplankton).
- **NDC**: Nationally Determined Contributions. NDCs embody efforts by each country to decrease national emissions and adapt to impacts of climate change.
- **Ocean acidification (OA)**: acidification of the oceans from the dissolution of atmospheric CO_2 into surface waters. OA may promote the growth of some producers but be deleterious to other organisms.
- **Phytoplankton**: planktonic microalgae that perform (primary) production. Unlike mixoplankton, they cannot eat.
- **Plankton**: organisms that are incapable of moving against water currents.
- **(Primary) Production**: growth and activity of producer organisms resulting in a net increase in biomass. This production then supports the growth of consumers and decomposers.
- **Producer**: organism responsible for primary production. (CF. consumer, decomposer). Typically involves photosynthesis (CO_2-fixation) and the consumption of inorganic nutrients (N, P, Fe).
- **Prokaryote**: single-celled organism which has neither a distinct nucleus with a membrane nor other specialized organelles. Including archaea, bacteria and cyanobacteria.
- **Protist**: generic term for single celled eukaryote organism. Protist biodiversity exceeds that of all other eukaryotes combined. Protist plankton include mixoplankton, many phytoplankton and most zooplankton.
- **SDG**: United Nations Sustainable Development Goals. A series of 17 goals with the aim of attaining "peace and prosperity for people and the planet", while tackling climate change and working to preserve oceans and forests.
- **Upwelling**: a physical process bringing deep ocean water, with its nutrients, to the surface. Often the site of enhanced (primary) production and thence of consumer activity supporting fisheries.
- **Zooplankton**: generic term for planktonic consumers, which are dominated by protist zooplankton, though the term often implicitly refers to the metazoan zooplankton such as copepods and krills, that support fisheries.

REFERENCES

(1) Smetacek, V. Revolution in the Ocean. Nature **1999**, 401 (6754), 647–647. https://doi.org/10.1038/44281

(2) Mitra, A.; Caron, D. A.; Faure, E.; Flynn, K. J.; Leles, S. G.; Hansen, P. J.; McManus, G. B.; Not, F.; do Rosario Gomes, H.; Santoferrara, L. F.; Stoecker, D. K.; Tillmann, U. The Mixoplankton Database (MDB): Diversity of Photo-Phago-Trophic Plankton in Form,Function, and Distribution across the Global Ocean. J. Eukaryot. Microbiol. **2023**, 70 (4), e12972. https://doi.org/10.1111/jeu.12972

(3) Burki, F.; Roger, A. J.; Brown, M. W.; Simpson, A. G. B. The New Tree of Eukaryotes. Trends Ecol. Evol. **2020**, 35 (1), 43–55. https://doi.org/10.1016/j.tree.2019.08.008

(4) Mitra, A.; Flynn, K. J.; Stoecker, D. K.; Raven, J. A. Trait Trade-Offs in Phagotrophic Microalgae: The Mixoplankton Conundrum. Eur. J. Phycol. **2024**, 59 (1), 51–70. https://doi.org/10.1080/09670262.2023.2216259

(5) Mitra, A.; Castellani, C.; Gentleman, W. C.; Jónasdóttir, S. H.; Flynn, K. J.; Bode, A.; Halsband, C.; Kuhn, P.; Licandro, P.; Agersted, M. D.; Calbet, A.; Lindeque, P. K.; Koppelmann, R.; Møller, E. F.; Gislason, A.; Nielsen, T. G.; St. John, M. Bridging the Gap between Marine Biogeochemical and Fisheries Sciences; Configuring the Zooplankton. Link. Prog. Oceanogr. **2014**, 129, 176–199. https://doi.org/10.1016/j.pocean.2014.04.025

(6) Bar-On, Y. M.; Milo, R. The Biomass Composition of the Oceans: A Blueprint of Our Blue Planet. Cell **2019**, 179 (7), 1451–1454. https://doi.org/10.1016/j.cell.2019.11.018

(7) Berdalet, E.; Fleming, L. E.; Gowen, R.; Davidson, K.; Hess, P.; Backer, L. C.; Moore, S. K.; Hoagland, P.; Enevoldsen, H. Marine Harmful Algal Blooms, Human Health and Wellbeing: Challenges and Opportunities in the 21st Century. J. Mar. Biol. Assoc. U. K. **2016**, 96 (1), 61–91. https://doi.org/10.1017/S0025315415001733

(8) Osei Sekyere, J. Current State of Resistance to Antibiotics of Last-Resort in South Africa: A Review from a Public Health Perspective. Front. Public Health **2016**, 4. https://doi.org/10.3389/fpubh.2016.00209

(9) Leles, S. G.; Bruggeman, J.; Polimene, L.; Blackford, J. C.; Flynn, K. J.; Mitra, A. Differences in Physiology Explain Succession of Mixoplankton Functional Types and Affect Carbon Fluxes in Temperate Seas. Prog. Oceanogr. **2020**, 190, 102481. https://doi.org/10.1016/j.pocean.2020.102481

(10) Sunagawa, S.; Acinas, S. G.; Bork, P.; Bowler, C.; Eveillard, D.; Gorsky, G.; Guidi, L.; Iudicone, D.; Karsenti, E.; Lombard, F.; Ogata, H.; Pesant, S.; Sullivan, M. B.; Wincker, P.; de Vargas, C. Tara Oceans: Towards Global Ocean Ecosystems Biology. Nat. Rev. Microbiol. **2020**, 18 (8), 428–445. https://doi.org/10.1038/s41579-020-0364-5

(11) Hedges, J. I.; Baldock, J. A.; Gélinas, Y.; Lee, C.; Peterson, M. L.; Wakeham, S. G. The Biochemical and Elemental Compositions of Marine Plankton: A NMR Perspective. Mar. Chem. **2002**, 78 (1), 47–63. https://doi.org/10.1016/S0304-4203(02)00009-9

(12) Polimene, L.; Sailley, S.; Clark, D.; Mitra, A.; Allen, J. I. Biological or Microbial Carbon Pump? The Role of Phytoplankton Stoichiometry in Ocean Carbon Sequestration. J. Plankton Res. **2017**, 39 (2), 180–186. https://doi.org/10.1093/plankt/fbw091

(13) Jiao, N.; Luo, T.; Chen, Q.; Zhao, Z.; Xiao, X.; Liu, J.; Jian, Z.; Xie, S.; Thomas, H.; Herndl, G. J.; Benner, R.; Gonsior, M.; Chen, F.; Cai, W.-J.; Robinson, C. The Microbial Carbon Pump and Climate Change. Nat. Rev. Microbiol. **2024**, 22 (7), 408–419. https://doi.org/10.1038/s41579-024-01018-0

(14) Oschlies, A.; Stevenson, A.; Bach, L. T.; Fennel, K.; Rickaby, R. E. M.; Satterfield, T.; Webb, R.; Gattuso, J.-P. Guide to Best Practices in Ocean Alkalinity Enhancement Research, 0 ed.; Copernicus GmbH, **2023**. https://doi.org/10.5194/sp-2-oae2023

(15) Korsunsky, A. M.; Bedoshvili, Y. D.; Cvjetinovic, J.; Aggrey, P.; Dragnevski, K. I.; Gorin, D. A.; Salimon, A. I.; Likhoshway, Y. V. Siliceous Diatom Frustules – A Smart Nanotechnology Platform. Mater. Today Proc. **2020**, 33, 2032–2040. https://doi.org/10.1016/j.matpr.2020.08.571

(16) Kenny, P.; Flynn, K. J. Physiology Limits Commercially Viable Photoautotrophic Production of Microalgal Biofuels. J. Appl. Phycol. **2017**, 29 (6). https://doi.org/10.1007/s10811-017-1214-3

(17) Revoir notre rapport à l'eau : interview d'Emma Haziza, hydrologue. Initiatives pour l'Avenir des Grands Fleuves. https://www.initiativesfleuves.org/actualites/revoir-rapport-a-leau-interview-demma-haziza-hydrologue/ (accessed 2024-06-26)

(18) Falkowski, P. Ocean Science: The Power of Plankton. Nature **2012**, 483 (7387), S17–S20. https://doi.org/10.1038/483S17a

(19) Condon, R. H.; Duarte, C. M.; Pitt, K. A.; Robinson, K. L.; Lucas, C. H.; Sutherland, K. R.; Mianzan, H. W.; Bogeberg, M.; Purcell, J. E.; Decker, M. B.; Uye, S.; Madin, L. P.; Brodeur, R. D.; Haddock, S. H. D.; Malej, A.; Parry, G. D.; Eriksen, E.; Quiñones, J.; Acha, M.; Harvey, M.; Arthur, J. M.; Graham, W. M. Recurrent Jellyfish Blooms Are a Consequence of Global Oscillations. Proc. Natl. Acad. Sci. U. S. A. **2013**, 110 (3), 1000–1005. https://doi.org/10.1073/pnas.1210920110

(20) Lombard, F. Jellyfish Proliferation, **2023**.

(21) McQuatters-Gollop, A.; Stern, R. F.; Atkinson, A.; Best, M.; Bresnan, E.; Creach, V.; Devlin, M.; Holland, M.; Ostle, C.; Schmidt, K.; Sheppard, L.; Tarran, G.; Woodward, E. M. S.; Tett, P. The Silent Majority: Pico- and Nanoplankton as Ecosystem Health Indicators for Marine Policy. Ecol. Indic. **2024**, 159, 111650. https://doi.org/10.1016/j.ecolind.2024.111650

(22) Pacheco, D.; Rocha, A. C.; Pereira, L.; Verdelhos, T. Microalgae Water Bioremediation: Trends and Hot Topics. Appl. Sci. **2020**, 10 (5), 1886. https://doi.org/10.3390/app10051886

(23) Despotović, D.; Aharon, E.; Trofimyuk, O.; Dubovetskyi, A.; Cherukuri, K. P.; Ashani, Y.; Eliason, O.; Sperfeld, M.; Leader, H.; Castelli, A.; Fumagalli, L.; Savidor, A.; Levin, Y.; Longo, L. M.; Segev, E.; Tawfik, D. S. Utilization of Diverse Organophosphorus Pollutants by Marine Bacteria. Proc. Natl. Acad. Sci. **2022**, 119 (32), e2203604119. https://doi.org/10.1073/pnas.2203604119

(24) Au, H. K. A. Urban Algae: Redefining Urban Spaces and Infrastructure Through Microalgae Ecological and Biophilic Values. **2022**.

(25) Zeenat; Elahi, A.; Bukhari, D. A.; Shamim, S.; Rehman, A. Plastics Degradation by Microbes: A Sustainable Approach. J. King Saud Univ. - Sci. **2021**, 33 (6), 101538. https://doi.org/10.1016/j.jksus.2021.101538

(26) Rüthi, J.; Cerri, M.; Brunner, I.; Stierli, B.; Sander, M.; Frey, B. Discovery of Plastic-Degrading Microbial Strains Isolated from the Alpine and Arctic Terrestrial Plastisphere. Front. Microbiol. **2023**, 14. https://doi.org/10.3389/fmicb.2023.1178474

(27) Kong, F.; Blot, C.; Liu, K.; Kim, M.; Li-Beisson, Y. Advances in Algal Lipid Metabolism and Their Use to Improve Oil Content. Curr. Opin. Biotechnol. **2024**, 87, 103130. https://doi.org/10.1016/j.copbio.2024.103130

(28) Zhou, X.-R.; Yao, Z. J.; Benedicto, K.; Nichols, P. D.; Green, A.; Singh, S. New Sustainable Oil Seed Sources of Omega-3 Long-Chain Polyunsaturated Fatty Acids: A Journey from the Ocean to the Field. Sustainability **2023**, 15 (14), 11327. https://doi.org/10.3390/su151411327

(29) DareWin presentation. Lux Research 2015, Rabobank 2015, IndexMundi 2017, **2017**.

(30) Patel, A.; Rova, U.; Christakopoulos, P.; Matsakas, L. Assessment of Fatty Acids Profile and Omega-3 Polyunsaturated Fatty Acid Production by the Oleaginous Marine Thraustochytrid Aurantiochytrium Sp. T66 Cultivated on Volatile Fatty Acids. Biomolecules **2020**, 10 (5), 694. https://doi.org/10.3390/biom10050694

(31) Camacho, F.; Macedo, A.; Malcata, F. Potential Industrial Applications and Commercialization of Microalgae in the Functional Food and Feed Industries: A Short Review. Mar. Drugs **2019**, 17 (6), 312. https://doi.org/10.3390/md17060312

(32) Leu, S.; Boussiba, S. Advances in the Production of High-Value Products by Microalgae. Ind. Biotechnol. **2014**, 10 (3), 169–183. https://doi.org/10.1089/ind.2013.0039

(33) Resende, D. I. S. P.; Ferreira, M.; Magalhães, C.; Sousa Lobo, J. M.; Sousa, E.; Almeida, I. F. Trends in the Use of Marine Ingredients in Anti-Aging Cosmetics. Algal Res. **2021**, 55, 102273. https://doi.org/10.1016/j.algal.2021.102273

(34) Perera, R. M. T. D.; Herath, K. H. I. N. M.; Sanjeewa, K. K. A.; Jayawardena, T. U. Recent Reports on Bioactive Compounds from Marine Cyanobacteria in Relation to Human Health Applications. Life **2023**, 13 (6), 1411. https://doi.org/10.3390/life13061411

(35) Mimouni, V.; Ulmann, L.; Pasquet, V.; Mathieu, M.; Picot, L.; Bougaran, G.; Cadoret, J.-P.; Morant-Manceau, A.; Schoefs, B. The Potential of Microalgae for the Production of Bioactive Molecules of Pharmaceutical Interest. Curr. Pharm. Biotechnol. **2012**, 13 (15), 2733–2750. https://doi.org/10.2174/138920112804724828

(36) Couteau, C.; Coiffard, L. Microalgal Application in Cosmetics; **2018**; pp 317–323. https://doi.org/10.1016/B978-0-12-811405-6.00015-3

(37) Riccio, G.; Ruocco, N.; Mutalipassi, M.; Costantini, M.; Zupo, V.; Coppola, D.; de Pascale, D.; Lauritano, C. Ten-Year Research Update Review: Antiviral Activities from Marine Organisms. Biomolecules **2020**, 10 (7), 1007. https://doi.org/10.3390/biom10071007

(38) Glibert, P. M.; Mitra, A. From Webs, Loops, Shunts, and Pumps to Microbial Multitasking: Evolving Concepts of Marine Microbial Ecology, the Mixoplankton Paradigm, and Implications for a Future Ocean. Limnol. Oceanogr. **2022**, 67 (3), 585–597. https://doi.org/10.1002/lno.12018

ABOUT THE UN GLOBAL COMPACT

As a special initiative of the United Nations Secretary-General, the **UN Global Compact** is a call to companies worldwide to align their operations and strategies with Ten Principles in the areas of human rights, labour, environment and anti-corruption. Our ambition is to accelerate and scale the global collective impact of business by upholding the Ten Principles and delivering the Sustainable Development Goals through accountable companies and ecosystems that enable change. With more than 20,000 participating companies, 5 Regional Hubs, 62 Global Compact Country Networks covering 73 countries and 15 Country Managers establishing Networks in 34 other countries, the UN Global Compact is the world's largest corporate sustainability initiative — one Global Compact uniting business for a better world.

For more information, follow **@globalcompact** on social media and visit our website at **unglobalcompact.org**.

685 Third Avenue New York, NY 10017, USA