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THE DECADE OF OCEAN SCIENCE: THE IMPORTANCE OF "REDISCOVERING" THE TINY AND INVISIBLE WORLD OF PLANKTON

A Década da Ciência Oceânica: a importância de "redescobrir" o minúsculo e invisível mundo do plâncton

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ABSTRACT

The Decade of Ocean Science for Sustainable Development (2021-2030) has just started, and multiple stakeholders, including scientists, policymakers, civil society, funders, and the private sector will join transnational efforts to reverse the severe cycle of ocean biodiversity decline. This viewpoint article emphasizes goal number 14 that refers to the conservation and sustainable use of marine resources, and will particularly discuss the challenges of plankton research in the ongoing Anthropocene and methods to promote a true societal understanding of these species. There are many challenges for this "tiny and invisible world", especially because they are understudied and their importance in marine trophic webs, global biodiversity, and many plankton-mediated ecosystem services is often overlooked. This article discusses and highlights the ecological aspects of plankton communities according to the seven outcomes of the Ocean Decade. Although the impacts on benthic and nekton components (such as fish and corals) are more commonly known and recognized by society, plankton worldwide are also threatened by the loss of suitable habitats, range shift of species, organic pollution, invasive species, plastics, and global climate change (e.g., extreme floods and droughts, heat waves, and warming). Ocean literacy is currently challenged in terms of the understanding of plankton, and it is important to explain the relevance of this "invisible world" to people of all ages, cultures, and school levels. Rapid, straightforward, and appropriate communication is required to engage the public and improve awareness and science-based policies related to this important, overlooked, and threatened component of marine life.

Keywords: marine plankton, marine food web, ocean decade, sustainable development, marine biodiversity.

RESUMO

A Década da Ciência Oceânica para o Desenvolvimento Sustentável (2021-2030) começou e muitas partes interessadas, incluindo cientistas, legisladores, sociedade civil, financiadores e o setor privado, uniram esforços para reverter o terrível ciclo de declínio da biodiversidade dos oceanos. Este artigo enfatiza o objetivo número 14, que se refere à conservação e ao uso sustentável dos recursos marinhos, especialmente a discussão dos desafios da pesquisa sobre a perspectiva do plâncton no Antropoceno em curso e como promover uma compreensão real desse grupo pela sociedade. Existem muitos desafios para esse "mundo minúsculo e invisível", sobretudo devido à negligência quanto ao seu papel e ao desconhecimento de sua importância na sustentação das teias tróficas marinhas, biodiversidade marinha e inúmeros serviços ecossistêmicos. Com referência aos aspectos ecológicos, este artigo também discute e destaca as comunidades do plâncton de acordo com os sete resultados esperados para a década. Embora os impactos sobre a fauna bentônica e nectônica (como peixes e corais) sejam muito mais conhecidos e reconhecidos pela sociedade, o plâncton também está ameaçado pela destruição de habitat, poluição orgânica, espécies invasoras, plásticos e mudanças climáticas globais (por exemplo, secas, inundações, ondas de calor e aquecimento das águas). Para explicar a importância do plâncton em nossas vidas, surge o desafio de que esse "mundo invisível" seja conhecido por pessoas de todas as idades, culturas e níveis de escolaridade. Respondendo às necessidades da sociedade, os cientistas devem traduzir a linguagem técnica feita pelas universidades e outros produtores de conhecimento básico. A comunicação fácil é necessária para envolver o público e melhorar a consciência desse importante componente da biodiversidade.

Palavras-chave: *plâncton marinho, teia alimentar marinha, década dos oceanos, desenvolvimento sustentável, biodiversidade marinha.*

INTRODUCTION

In 2017, the United Nations proclaimed 2021-2030 as the Decade of Ocean Science for Sustainable Development to combine worldwide efforts from all sectors with the aim of reversing the undesirable cycle of ocean health decline. Moreover, this Decade provides an opportunity to achieve the 17 sustainable development goals listed for the 2030 Agenda (Schuckmann *et al.*, 2020). Many global stakeholders including scientists, policymakers, civil society, funders, and the private sector must embrace and work together to achieve these goals, particularly goal number 14 ("Life Below Water") (Claudet *et al.*, 2020). In this regard, this viewpoint article emphasizes this goal that refers to the conservation and appropriate use of oceans, seas, and marine resources for sustainable development. Our aim is to discuss the challenges of marine plankton research in the ongoing Anthropocene and methods to promote an in-depth comprehension of this "invisible world" by society, which is critical for the improvement of ocean conservation and science-based policies from the perspective of these tiny organisms that form and support the basis of marine trophic webs.

We intend to highlight some main research lines and challenges involving plankton (e.g., zooplankton, phytoplankton, and ichthyoplankton) communities. Despite being essential to the maintenance of marine life, they are little known and overlooked by people in general, even those with higher education. Plankton assemblages are taxonomically diverse, and include species from groups such as viruses, bacteria, protists, and animals. Although viruses are the smallest biological entities in the ocean, typically 20-200 nm in diameter, they are integral components of marine planktonic systems and, among their many functions, they act as catalysts of nutrient regeneration and recycling in the ocean (Fuhrman; Needham & Hewson, 2019). Other plankton members are bacteria, which are unicellular prokaryotic organisms that measure less than 0.5 – 1 µm in their longest dimension, and heterotrophic bacteria initiate the microbial loop (Ducklow, 2001), an alternative to the conventional marine trophic web.

We can consider that the *Challenger* Expedition (1872-1876) was the beginning of marine plankton studies, whereby samples of microscopic organisms floating in the water column were collected and later termed "plankton" by Victor Hensen in 1887 (Karleskint; Turner Jr. & Small Jr., 2009). Thus, plankton organisms are defined as creatures (most being extremely small except large jellyfishes, macrozooplankton) that drift in the water column and are carried by tides and currents. Some plankton groups drift throughout their entire life cycle (holoplankton), while others are classified as plankton only at the beginning of their life (meroplankton) at the larval stage (e.g., crabs and corals). Plankton are classified by scientists in several ways, including by size, type, and time spent drifting. Here, we will discuss three of the groups more commonly studied: phytoplankton, zooplankton, and ichthyoplankton.

The importance of plankton

Although phytoplankton communities are composed of microscopic organisms, they play an essential role in the marine food web and the main global biogeochemical processes, such as the carbon, oxygen, nitrogen, phosphorus, and silica cycles (Falkowski *et al.*, 2003; Reynolds, 2006; Litchman *et al.*, 2015). Therefore, the fundamental role of phytoplankton is the solar-driven conversion of inorganic materials into organic matter via oxygenic photosynthesis in the sunlit zone of oceans, contributing to approximately half of the global primary productivity (Falkowski *et al.*, 2003; Litchman *et al.*, 2015), oxygen production, and the biological carbon pump (Guidi *et al.*, 2016). Despite this important ecological and biogeochemical role, phytoplankton are more commonly known for to the harmful potential of a few species (Hallegraeff; Enevoldsen & Zingone, 2021).

Other important components are the zooplankton. This subgroup of plankton communities corresponds to the animal fraction of plankton, and generally relates to the majority of heterotrophic organisms, such as holoplankton (e.g., copepods) that dominate the community, and meroplankton (larval stages of benthic and nektonic animals such as corals, mollusks, and crabs) (Boltovskoy, 1999). These organisms are an important link in the transfer of energy between primary producers and other trophic levels, such as fish, sharks, and turtles (Kennish, 1986; Kiørboe, 2008). Research on larval stages provides information about seascapes acting as nurseries and reproduction areas (Costa *et al.*, 2020). Zooplankton and fish productivity are intimately linked in the ocean because most fish species are perpetual zooplanktivores (Dam & Baumann, 2017). They have short life cycles and respond quickly to environmental changes; therefore, these zooplanktonic organisms can be bioindicators of stressful conditions or environmental impacts through natural and/or anthropogenic modifications (Campos *et al.*, 2017; Bedford *et al.*, 2018).

The larvae and eggs of marine fishes, termed ichthyoplankton, are usually pelagic, as they drift in the ocean, and interact with pelagic predators and planktonic prey (Houde, 2019). Ichthyoplankton samples can reflect the spawning areas and seasons of commercial fish species, and their abundance allows us to infer the relative population size of the spawning stock (Borja *et al.*, 2019; Costa *et al.*, 2020). In addition, these organisms are influenced by oceanographic variables, since they are affected by major physical processes such as changes in temperature and salinity, cold fronts, upwellings, currents, and biological processes, such as the availability of food and the presence of predators (Olivar *et al.*, 2010). Thus, studies on these organisms are crucial, as drastic environmental changes can impact their survival (Pankhurst & Munday, 2011) and, consequently, the sustainability of fisheries resources. If fish larvae do not find suitable habitats for their survival after hatching, they will die before being incorporated into the adult population, leading to fish stock decline and elimination of fishing grounds (Houde, 2008).

Challenges for plankton research in the Ocean Science Decade (2021-2030)

As expected for a large international project involving humans, many transnational, regional, and local challenges for the Ocean Decade must be addressed and actions undertaken to overcome them. Seven outcomes proposed by the UN Decade of Ocean Science for Sustainable Development that synthesize the *ocean we want* at the end of the Decade in 2030 are expected: (1) a safe ocean, (2) a clean ocean, (3) a transparent and accessible ocean, (4) a sustainable and productive ocean, (5) a healthy and resilient ocean, (6) a predicted ocean, and (7) an inspiring and engaging ocean. Taking into account the ecological aspects described above, we will discuss how actions related to plankton communities can contribute to achieving these global goals.

1 A safe and clean ocean

A safe ocean and a clean ocean (1 and 2) are close outcomes that we will discuss together. A "safe ocean" means that human communities are protected from ocean hazards. These hazards are described as storm surges, chemical or biological pollution, oil spills, and coastline erosion that can damage the quality of life, including plankton, in coastal and marine ecosystems. A "clean ocean" is closely related to the identification, mitigation, and removal of pollution sources. Thus, these two outcomes can promote alterations in planktonic communities. The success of these goals implies a sustainable condition for marine interactions between plankton and other organisms, most of which are related to the maintenance of food webs.

Among the sources of anthropogenic impacts that directly work on plankton communities are oil spills that can go unnoticed in tropical marine food webs. However, traces of oil ingestion have been observed in planktonic organisms (Campelo *et al.*, 2021), as well as the negative effects on the physiology and growth of the symbiont dinoflagellate *Symbiodinium glynni*, which could interfere with the symbiont-host relationship of tropical corals (Müller *et al.*, 2021) that are important ecoengineers in the oceans (Rossi *et al.*, 2019). These long-term effects are especially relevant in coastal areas affected by large amounts of oil (Lourenço *et al.*, 2020; Soares *et al.*, 2020a).

Another anthropogenic impact is the excessive increase in nutrients discharged from coasts, mainly nitrogen and phosphorus, which lead to the cultural eutrophication process (Nixon, 1995). The eutrophication process is defined as an increase in the rate of organic matter supplied to an ecosystem (Nixon, 1995), mainly due to the uptake of inorganic nutrients by phytoplankton and an increase in primary production, which can promote a series of deleterious cascading effects in the environment (Malone & Newton, 2020). While the increase in primary phytoplankton productivity can be beneficial when it increases the productivity of the system as a whole (MacKenzie *et al.*, 2019), it can be classified as a harmful bloom when it has significant negative impacts on health (animal, human, or environmental), economies, tourism, aquaculture, and fisheries (Glibert & Burkholder, 2018).

Harmful algal blooms (HAB) are caused by a variety of toxic and non-toxic phytoplankton species from different taxonomic groups (e.g., diatoms, dinoflagellates, haptophytes, cyanobacteria, raphidophytes, and dictyochophytes), which in high biomass can lead to anoxia when decomposed (Hallegraeff; Enevoldsen & Zingone, 2021). When species produce toxins, they can affect marine organisms as well as humans through the consumption of contaminated organisms (Loeffler *et al.*, 2021). Thus, as toxin-producing phytoplankton species flourish, they also have a major impact on fisheries, aquaculture, and related activities (Glober, 2020), leading to food insecurity and socioeconomic vulnerability.

Nevertheless, in addition to anthropogenic eutrophication, the occurrence and impacts of HAB are likely to increase in the face of emerging issues such as climate change, rising sea surface temperatures, and ocean acidification (Hallegraeff, 2010; Trainer *et al.*, 2020), as well as through interactions between global climate drivers and local environmental factors (León-Muñoz *et al.*, 2018). For example, a harmful algal bloom of the ichthyotoxic Dictyochophyceae *Pseudochattonella verruculosa* during the 2016 austral summer (February-March) killed nearly 12% of the Chilean salmon produced, coinciding with the strong El Niño of 2015-2016 that resulted in an extremely dry summer on the southeast Pacific coast with a record low streamflow and higher than normal solar radiation (León-Muñoz *et al.*, 2018). These extreme meteorological conditions allowed vertical advection of saline (~30) and nutrient-rich waters, which ultimately resulted in an enhanced *Pseudochattonella verruculosa* bloom and the worst mass mortality of fish and shellfish ever recorded on the western Patagonia coast (Clément *et al.*, 2017; León-Muñoz *et al.*, 2018; Mardones *et al.*, 2019).

To achieve a clean, healthy, and sustainable ocean for food supply, measures to prevent, control, and predict the occurrence of HAB should be adopted, highlighting: (1) the reduction of anthropogenic inputs of nutrients in coastal areas (e.g., implementation of effective sewage systems), to control the process of anthropic eutrophication; (2) knowledge of the causes of blooms, including those produced through natural factors (Glibert & Burkholder, 2018); (3) the implementation of long-term monitoring programs with high temporal resolution (e.g., daily resolution and continuous automated measurements) that are able to predict the occurrence of blooms, allowing measures to be taken proactively to avoid further damage, especially to the fishing industry and water provisions; and (4) the initiation of harmful algae monitoring programs in countries where they are currently lacking. For this, government support is essential for the training and maintenance of technical personnel specialized in science-based and long-term monitoring programs.

Blooms also occur with cnidarians and ctenophores (Purcell, 2005), which are important macrozooplanktonic predators of early fish life stages (Purcell, 1985; Purcell *et al.*, 2014). In the northwestern Mediterranean, species such as *Pelagia noctiluca* (both as an adult and larvae) consume ichthyoplankton, particularly anchovies, which are a species of commercial interest (Tilves *et al.*, 2016). In addition, the ctenophore *Mnemiopsis leidyi* feeds on fish eggs and competes with zooplanktivorous organisms for food (Purcell *et al.*, 2001), such as fish larvae. Since predation is another source of ichthyoplankton mortality (Miller & Kendall Jr., 2009), the increase and abundance of blooms of gelatinous zooplankton threaten fish larval recruitment, aquaculture, and adult fish populations (Bosch-Belmar *et al.*, 2017; Dong, 2019; Syazwan *et al.*, 2020).

Another emerging concern that puts the "clean ocean" UN goal at peril is the increasing amount of plastics in the world's oceans. Plastic waste pollution has become a serious environmental problem globally (Geyer; Jambeck & Law, 2017) and will be a key theme during the UN Decade considering that it is a global and transnational problem (Stubbins *et al.*, 2021). When plastics in the natural environment are exposed to different physical, chemical, and biological processes, they break down and form smaller fragments (Wang *et al.*, 2016). One of the most common fragments is called microplastic (MP; 1-5 mm) (Frias & Nash, 2019), which is one of the most serious problems that humanity is currently facing. Due to their small size, MPs are potentially bioavailable via ingestion, and they have been recorded in a wide range of marine organisms (Graham & Thompson, 2009; Murray & Cowie, 2011; Hodgson; Bréchon & Thompson, 2018; Roman *et al.*, 2016; Duncan *et al.*, 2019; Dantas *et al.*, 2020), including zooplankton (Botterell *et al.*, 2019) and ichthyoplankton (Steer *et al.*, 2017; Gove *et al.*, 2019).

Several effects of microplastics in zooplankton communities have been reported (Boterrel *et al.*, 2019) and most of which are related to reduced feeding (Cole *et al.*, 2013), changes in reproductive cycles (Cole & Galloway, 2015), decreased growth and development (Lo & Chan, 2018), and temporal shifts in lifespan (Lee *et al.*, 2013; Cole & Galloway, 2015). The capacity of microplastic ingestion by zooplankton varies between species, life-stage, type, and microplastic size at the time they were indiscriminately ingested via filter-feeding and later, when they are egested in fecal pellets (Cole *et al.*, 2013). However, further studies are necessary to understand their effects on plankton at the community-level and the ecosystem-level impacts on pelagic zones. Moreover, the impact of microplastics on plankton-mediated ecosystem services, such as carbon sequestration, is largely unknown. Exposure of microplastics to phytoplankton can result in a substantial reduction in their growth and photosynthetic ability (Wang *et al.*, 2019), as well as a breakdown of coral symbiosis (Soares *et al.*, 2020b), and these effects are more severe with small-sized microplastics (Zhang *et al.*, 2017).

It is known that microplastics have invaded important seascapes used for fish spawning and larval development (Gove *et al.*, 2019). In the western English Channel, fish larvae were recorded to have ingested MPs with different characteristics (Steer *et al.*, 2017). Organisms such as adult fish and zooplankton that feed on fish larvae indirectly consume MPs, making them able to transfer MPs through marine food webs to large animals. Therefore, it is essential to develop greater knowledge of trophic relationships of plankton because they largely determine the fate of the larval fish cohorts (Houde, 2001) in the ongoing UN Decade. The presence of microplastics within marine food webs has challenged researchers worldwide to understand how zooplankton and ichthyoplankton interact with these tiny particles inside and outside of their bodies and the effects of these pollutants in marine food webs (e.g., bioaccumulation). For phytoplankton, the utmost transnational efforts must occur to explore the physiological, energetic, and biochemical responses of this community to different types and sizes of microplastics, since the entire productivity in the ocean and coastal systems depends on these primary producers.

Another important aspect for achieving a “clean ocean” is the competition and possible outbreaks of invasive species, also known as biological pollution. The entry, establishment, and spread of non-indigenous plankton species in new receptor ecosystems, such as macrozooplanktonic organisms as invasive jellyfishes and ctenophores (Purcell; Uye & Lo, 2007; Fuentes *et al.*, 2010), can cause irreversible ecological changes, intense socio-economic damage, and significant public health issues (Mooney, 2005). Once they arrive in a given marine area, invasive species compete with native species and change community structures and food webs, thereby modifying native seascapes and leading to biodiversity loss (e.g., functional, phylogenetic, and taxonomic richness) (Bax *et al.*, 2003; Molnar *et al.*, 2008).

In zooplankton, the copepod *Temora turbinata* (Dana, 1849), which is considered an exotic species to the tropical southwestern Atlantic coast that was probably introduced by ballast water into this ocean, is an example of this invasion. Before the identification of *T. turbinata*, the only species of this genus in Brazilian waters was *Temora stylifera* (Dana, 1849) (Ferreira *et al.*, 2009). Studies have shown (Campos *et al.*, 2017; Soares *et al.*, 2018; Conceição *et al.*, 2021) that this species may be eliminating or displacing its native congener *T. stylifera,* which was once quite common in coastal areas of Brazil (Villac, 2009) to more distant and oceanic regions, through competition. The potential for genetic adaptation and effective acclimatization of *T. turbinata*, along with its tolerance to temperature, salinity, and pollution, favor its advancement in coastal waters (Ara, 2002).

In the ocean, the main pathways invasive species dispersal are ballast water and biofouling from ships, man-made structures at sea, canals, aquaculture activities, and releases from aquaria (De Castro *et al.*, 2017). Currently, marine litter is also considered a source of invasive species (Reisser *et al.*, 2013; Rech; Borrel & García-Vasquez, 2016; Miralles *et al.*, 2018), since the organisms that inhabit these materials are transported with the litter to other regions. However, it is important to emphasize that, due to the paucity of prior information about the baseline-type assessment of a given region, it is difficult to determine whether a species is invasive and reach a plateau of certainty (D’Costa; D’Silva & Naik, 2017). The “invisibility” and small size of most planktonic organisms make their monitoring complex, although genetic studies on the biodiversity of the target coastal areas are still imperative (Lacerda *et al.*, 2021). Furthermore, considering that resting stages (cysts) of various harmful species of phytoplankton can also be transported and deposited in sediments, only to flourish when environmental conditions are favorable (Smayda, 2007) such as warming, the problem of plankton bioinvasion under climate change can also be considered a silent peril to achieving the UN goals for the oceans.

2 *A sustainable and productive ocean*

A sustainable and productive ocean is related to the provision of food supplies during this decade. This goal of food security for the people is directly related to the persistence of the marine food web and the provision of biomass. To achieve this, the planktonic community needs to be conserved to continue fulfilling its major energy role. As explained above, phytoplankton are the primary producers, and zooplankton are the consumers that will transfer the energy to other trophic levels (including food resources for humans). It is important to understand that impacts at the base of the food web, including the occurrence of harmful algal blooms, as already explained, will generate drastic alterations in trophic levels and energy fluxes (Rossi *et al.*, 2019).

Climate change is a main influencer of the transformation of primary and secondary productivity patterns (i.e., microphytoplankton and zooplankton). For example, ocean warming will potentially result in longer periods of water column stratification, thus affecting primary productivity and diurnal plankton migrations, and possibly leading to discontinuities in food availability. In this regard, phytoplankton growth depends on the sea surface temperature and the availability of light and limited nutrients, including nitrogen, phosphorus, silicon, and iron. In more stratified marine waters, especially those of tropical and subtropical ecosystems, higher temperatures may assist phytoplankton growth, but nutrient availability is limited by a lack of mixing (Rossi *et al.*, 2019). However, due to the progressive warming of the oceans, there is a possibility of expansion of HAB toward higher latitudes (Benedetti *et al.*, 2021), where blooms of some species have been established and/or intensified in the last decades (Gobler *et al.*, 2017; Griffith; Doherty & Gobler, 2019). In addition to phytoplankton, zooplankton are an excellent model for understanding climate change impacts and range expansion for several reasons. One is that, as zooplankton consist of animals with variable body temperatures, their physiological functions (ingestion, respiration, excretion, defecation, and growth) and life history traits (e.g., time to maturity, fecundity, development rate) are extremely sensitive to temperature (Dam & Baumann, 2017; Benedetti *et al.*, 2021).

To understand the role of plankton in achieving a sustainable and productive ocean in the ongoing UN decade, it is important to consider plankton as a member of a complex and extremely important process that involves blue carbon. Blue carbon is known as the part of the carbon cycle that involves sea life (Barnes, 2020), and in marine environments, this process occurs through phytoplankton that take up atmospheric CO_2 during photosynthesis (Falkowski *et al.*, 2003). The interaction between phyto- and zooplankton can provide some information as to how the carbon budget and sequestration relate to the importance of copepods in estimating blue carbon (Guidi *et al.*, 2016). These small zooplanktonic crustaceans prey on phytoplankton or ciliates and are considered a key group at the base of trophic webs, linking primary producers with higher levels (Hemraj *et al.*, 2017). Copepods are important components because they increase particulate organic carbon flux to deeper layers through diel vertical migration and by sinking fecal pellets and carcasses (Turner, 2015). Another aspect that should be considered in understanding carbon sequestration and sinking (in marine animal forests or deep-sea sediments) is the benthic-pelagic coupling promoted by small copepods that can be neglected depending on sampling strategies (Rossi *et al.*, 2019; Garcia *et al.*, 2021).

3 A healthy and resilient ocean

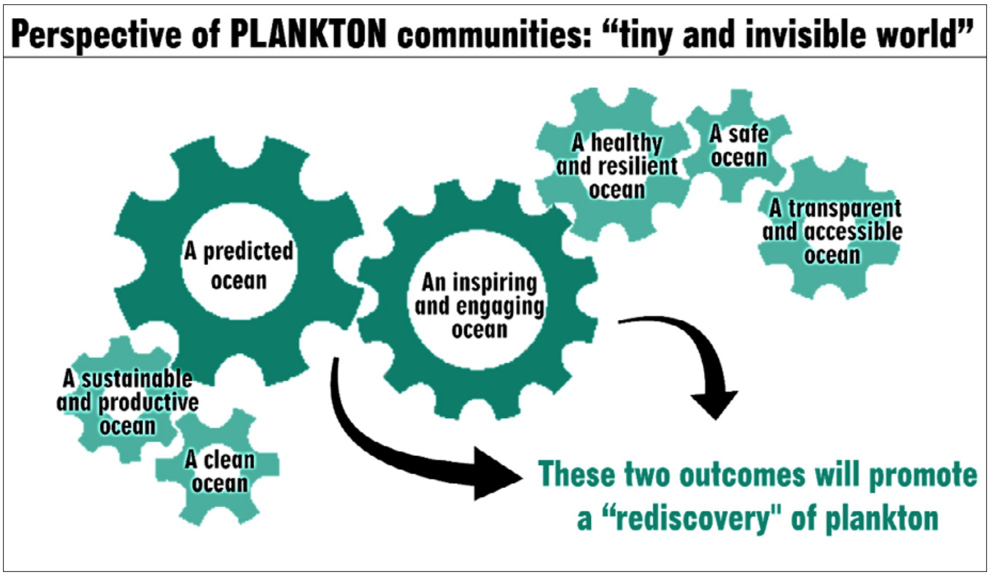
A healthy and resilient ocean connects long-term and transnational science-based actions that are expected to maintain ocean ecosystem services, including climate stability. However, climate change is on the agenda of social, academic, and political discussions. Such drastic and long-lasting changes are mainly characterized by higher global mean and sea surface temperatures, changes in precipitation, variations in extreme weather and climate events, and an increase in mean sea level (IPCC, 2021). The increase in surface sea temperature affects the range expansion, hatching, larval dispersion, development, and growth of fish larvae (ichthyoplankton), as well as the survivability of these organisms in the oceans (Pankhurst & Munday, 2011; Watson *et al.*, 2018; Dahlke *et al.*, 2020). The rising ocean temperatures and marine heatwaves (Smale *et al.*, 2019) cause changes in fish larvae feeding habits (Brodeur *et al.*, 2018), leading to a mismatch between phytoplankton blooms and fish egg hatching (Sommer & Lengfellner, 2008), which decreases the efficiency of marine trophic webs. This topic should be further researched during this Ocean Decade, especially in poorly known oligotrophic and tropical seas (e.g., South America).

In addition, temperature-related impacts have previously been determined to shift spawning phenologies in the North Atlantic Ocean (Greve *et al.*, 2005; Genner *et al.*, 2010) and in the North Pacific Ocean near California (Asch, 2015). In this same region, a displacement in spawning and nursery areas (in the order of 500-1,000 km) was observed for three pelagic species, caused by an oceanic warming event, with consequences for the food web (Auth, 2018). These predictions indicate that changes in spawning timing and migration of fishes due to climate change will impact areas that were historically dependent on these fishes and modify the structure of their food web (Asch, 2015; Cheung *et al.*, 2015). Moreover, global warming will induce changes in the richness and range expansions of zooplankton and ichthyoplankton species, altering the composition and dynamics of tropical, temperate, and polar ecosystems (Benedetti *et al.*, 2021).

4 A transparent, an accessible, and a predicted ocean

A transparent and accessible ocean requires open access to data, information, and technologies for different stakeholders, including scientists, policymakers, civil society, funders, and the private sector of all countries to achieve the goals of the UN decade in reversing the cycle of decline in ocean health. A predicted ocean and an inspiring and engaging ocean refer to the capacity of society to understand current and future ocean conditions and also to recognize and value the ocean including the "invisible world" of plankton discussed in this viewpoint article. The participatory processes are made by different stakeholders, so as to find suitable solutions that prevent ongoing degradation, and a transdisciplinary approach is required for implementing science-based solutions (Franke *et al.*, 2020). The overall advancement of science outreach and global awareness needs to be discussed to improve personal conduct and science-based policies. If we consider that each outcome is a gear of a larger system, we will reach our goals by working together. However, to promote a "rediscovery" of plankton in this Ocean Decade, these gears must have different sizes. The gears that represent a predicted ocean and an inspiring and engaging ocean should be larger (Figure 1) to move the other parts of the system.

Figure 1 – Schematic representation of the proposed approach of plankton communities that will promote the "rediscovery" of plankton, considering the seven outcomes of The United Nation Decade of Ocean Science for Sustainable Development (2021-2030)



Source: gears image adapted from GetDrawings.com.

Various aspects of plankton ecology in marine and coastal ecosystems have been studied by numerous researchers and their partners. In a preliminary evaluation of the *Science Direct* database, the number of articles in the last twenty years involving the term "plankton" (Figure 2) tells us that much knowledge about this component of the biosphere is known. However, there is a challenge for this "invisible world", as we show in Figure 3 regarding questions that we propose for future and long-term studies especially in the UN Decade and the decades to come.

Figure 2 – Number of articles published accessed through *Science Direct* in the last twenty years using the term "plankton" in the search

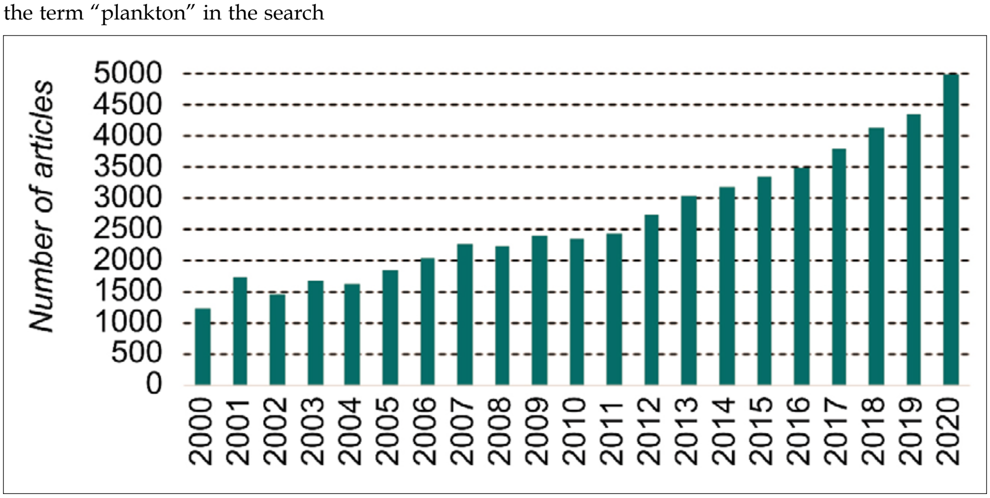
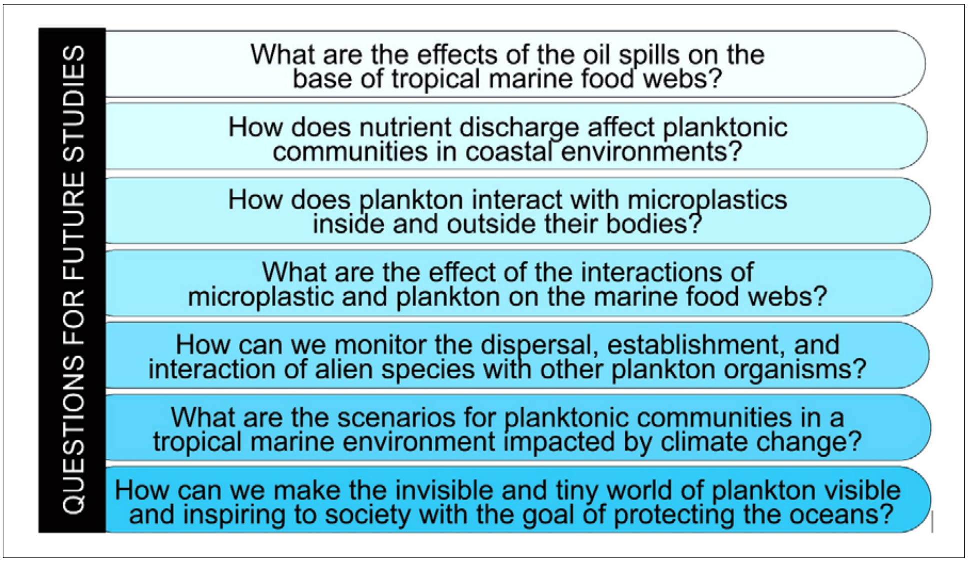


Figure 3 – Questions for future studies about planktonic communities that should be answered during the United Nation Decade of Ocean Science for Sustainable Development (2021-2030)



CONCLUSIONS

Although knowledge has accumulated in the past centuries and decades, plankton communities are unfortunately little known outside of the academic world. This information "wall" must be demolished for the knowledge to be shared and spread throughout the world, including to all education levels and those uneducated. The public understands the "negative side" of plankton through accidental contact with an organism that causes skin lesions, as the Portuguese man-of-war or jellyfishes (Haddad Jr.; Da Silveira & Migotto, 2010), or when they feel the red tide effects in the water supply causing toxicity to humans, the environment, or the food industry (Hallegraeff; Enevoldsen & Zingone, 2021). However, the importance of plankton to their own life (including the air that they breathe) and the coast that they enjoy remains a mystery for many people. To respond to the needs of society, scientists should translate the technical language used by universities and other basic knowledge produced to a level understandable by all. Straightforward communication is necessary to engage the public through books, newspapers, television, and social media to ensure the dissemination of research and deride fake news and clickbait videos. Efforts should be made to bring planktonic organisms nearer to society to explain their importance to all of us. Environmental education actions must be encouraged, involving awareness, knowledge, and sensitivity to this invisible world.

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