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Impacts of Environmental Change and Microplastic Pollution on Zooplankton

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Abstract. Zooplankton are an important part of the ecosystem, carrying out the function of energy transfer in the food web, linking the lower to the higher trophic levels of species. They are often under the combined influence of the surrounding environment and other aquatic life. This research aims to study the effects of environmental changes, such as changes in the several properties of seawater, microplastic pollution on zooplankton populations and the interactions between other aquatic organisms and zooplankton. The results show that with environmental changes, the increase in sea temperature, pH value, eutrophication of seawater and the increase of microplastic pollution will harm the zooplankton population. At the same time, the size of zooplankton populations can affect the number of fish that feed on them, and the predation of fish can also affect their biomass and population structure. These studies can help humans better understand the mechanisms of ecosystem interactions in nature, assess and predict broader environmental change, maintain healthy ecosystems, and ensure future resource sustainability.

Keywords: Zooplankton, Ecosystem, Environmental change, Microplastic pollution.

1. Introduction

Planktons are tiny heterotrophic organisms that drift in water bodies, mainly relying on water flow for effective movement, usually feeding on phytoplankton or smaller zooplankton. The types of zooplankton are diverse, including many protozoa, small crustaceans, echinoderms, mollusks, etc., as well as the larval stage of some marine animals. Zooplankton have an important function in the marine ecosystem, they connect primary producers (phytoplankton) with higher nutrient levels of marine organisms [1]. The energy of phytoplankton and planktonic bacteria is transferred to higher nutrient levels by zooplankton [2]. Certain groups of zooplankton serve as valuable biological indicators for tracking the changes in the environment and climate, reflect the overall health of marine ecosystems. Over the past decade, several studies have been conducted on the impacts of climate change on zooplankton and their roles in marine ecosystems. Researchers are interested in how changes in the physical and chemical properties of the ocean, such as temperature, pH and salinity, affect zooplankton. Feeding rate changes, possible toxicity due to microplastic pollution, and the abundance and variety of phytoplankton and other aquatic life that affect zooplankton populations are also continuously studied [3]. These researches show the complex relationship between zooplankton and the environment, highlighting their sensitivity to ecological changes and their importance in nutrient cycling. However, most of these studies have focused on a single area of water, the localized studies make it difficult to assess global patterns. Variability of climate change greatly increases the complexity of the results, which causes ecological modeling to be limited to accurately predict variables.

This paper synthesizes the major findings of zooplankton research in recent years, focusing on their interactions with environmental factors and other species. It provides a more comprehensive overview of zooplankton ecology and status in aquatic ecosystems. This is necessary for understanding ecosystem dynamics to predict future changes in environments and ecosystems and also for zooplankton conservation and ecological balance maintenance.

2. Links Between Zooplankton and Environmental Change

2.1. Environmental Change and Pollution

Due to the sustained attention to environmental issues, the responses of zooplankton to environmental change have become an important area of research. Plankton in marine ecosystems are always involuntarily affected by changing climate. The impacts of ocean acidification, water temperature rise and eutrophication on zooplankton communities are the focus of global research. One study looked into the implications of long-term environmental changes upon zooplankton and followed changes in planktonic abundance and environmental conditions of eight areas along the Arabian Sea coast of the west coast of India from 2010 to 2019. At each study site, monthly surface water samples were taken at low tide to assess nutrients such as nitrogen and oxygen, primary productivity such as phytoplankton (chlorophyll-A), and zooplankton biomass. The results showed that over the ten years, the sample water temperature, salinity, and pH values showed a significant increase trend, while water phosphate, nitrate, and chlorophyll showed a significant decrease [4]. During the research period, the overall density of zooplankton showed a significant decline, from 22.81 ± 1.07 individuals per 20 liters in 2010 to 13.46 ± 0.78 individuals per 20 liters in 2019[4]. Meanwhile, habitat and seasonality also affect the abundance of zooplankton. In mangrove terrain with nutrient-rich sediments, zooplankton communities can develop better. In addition, human activities have also contributed to the decrease in density, as industrial and domestic water discharges affect changes in salinity, phosphate content and pH value in water.

In the Bohai Sea in northeast China, there has also been a recorded decrease in the abundance of zooplankton in coastal regions. The Bohai Sea is a nearly closed inland sea and the seabed sediments are mostly silt and ooze. Because it is mostly surrounded by land, the thermal dynamics of the Bohai Sea water are deeply affected by the land, resulting in obvious seasonal changes in surface water temperature. In the Bohai Sea, water quality in the study area is significantly impacted by organic pollutants and metallic mercury. They often enter the marine ecosystem through agricultural runoff, wastewater discharge, and urban runoff. Unlike what is observed in the Arabian Sea, the pH of the waters of the Bohai Sea is in a state of decline, a decrease in pH may lead to seawater acidification and exacerbate eutrophication and organic pollution [5]. In this situation, the number of phytoplankton species showed an increasing trend from 2019 to 2021. The phytoplankton community is mainly composed of diatoms, accounting for approximately 78% of the total abundance and 82% of the taxa, respectively [5]. Phytoplankton are better able to adapt and tolerate environmental changes than zooplankton. In contrast to phytoplankton, the abundance of zooplankton in the study area showed a decreasing trend between 2019 and 2021[5]. The observation highlights those changes in the population level of phytoplankton do not appear to directly influence the numbers of zooplankton in the ecosystem. Although there is no direct correlation between phytoplankton and zooplankton abundance, aquatic eutrophication caused by algal blooms still affects zooplankton community structure. In the Songhua River, with the increase of water eutrophication, the composition of zooplankton no longer has large number of big arthropods, but more inclined to small rotifers and ciliates. As pH levels continue to rise, small metazoan organisms such as rotifers and ciliates emerge as the dominant indicator groups, particularly in heavily polluted environments [6]. Their ability to tolerate high nutrient environments allows them to flourish compared to other species in their niche. Many zooplankton are more sensitive to the ocean acidification, with diversity decreasing by approximately 30% as the average pH drops from 8.1 to 7.8. Meanwhile, in recent ten years, the sea surface temperature in the Bohai Sea has been rising at a rate of 0.011°C per year, which can also limit the development of zooplankton [5]. Warmer surface water typically has lower oxygen content, which increases its energy demand. Therefore, with the continuous effect of future ocean acidification and global warming, the abundance and diversity of plankton is projected to maintain the decreasing trend.

In addition to population abundance, climate change can also lead to phenological changes in zooplankton. In a study conducted in 2024, it was found that temperature and ice conditions affect the seasonal abundance of some taxa by studying the seasons and timing of rotifers appearing in the coastal areas of the Gulf of Finland, as well as the juvenile and adult stages of three copepods animals [7]. Warmer years lead to the early appearance of *Temora longicornis* in copepods, while earlier ice breaks are consistent with the increased seasonal appearance of *Acartia spp* and the early appearance of *Eurytemora affinis* in copepods [7]. Zooplankton is the link between primary producers (phytoplankton) and higher tropic level. Their populations are sensitive to environmental factors such as ocean temperature, salinity and pH, and the acidification and eutrophication of ocean water caused by current climate change have significantly affected their abundance and population structure, and further affected the food resource supply of fish and other marine animals.

2.2. Microplastic Pollution

Microplastics (MPs) are tiny plastic fragments that measure 5 millimeters or less in diameter. As one of the unavoidable pollutants in modern industry, they have become a major environmental problem, especially in marine ecosystems. Plankton, fish, and other marine species often actively or passively ingest MP, which is difficult to be decompose, meaning that they can persist in the nature and living organisms for long periods. It allows them to accumulate in various ecosystems, particularly within the food chain. Zooplankton are easily ingested MP because their natural prey sources are similar in size and density [8]. In the Bohai Sea of China, research has shown that during the rainy season, 92.8% of MP in zooplankton are plastic fibers. These fibers are widely dispersed among different groups of zooplankton. Blue MP dominates in quantity, with an average length of 1230 ± 1430μm. The minimum size is 49μm and the maximum size is 10331μm [9]. The percentage of fiber content in zooplankton is significantly higher than that in seawater of their habitat, which means MP is easily ingested but difficult to excrete, and therefore accumulates in the bodies of zooplankton for a long time [9]. Zooplankton exposure to MP pollution has also been observed in coastal areas of northeastern Brazil[10]. Copepods dominated the affected species (90%), with significantly higher mean MP abundances in the heavy rainfall season, the range of size is from 20 to 2000μm, and the main types again dominated by fibers [10]. Apparently, when rainfall increases, food webs become more susceptible to microplastic contamination. Meanwhile, MP have also been found to be prevalent in zooplankton located in the Hudson-Raritan estuary and enter the food chain through zooplankton. Three copepods, *Acartia tonsa*, *Paracalanus crassirostris* and *Centropages typicus*, were sampled and analyzed, and MP was observed in all of them. in the form of fragments and beads [11]. Zooplankton are filter feeders that consume a variety of small particles, for zooplankton in surface estuarine, feeding activities essential for their survival are the primary pathway through which they ingest microplastics.

In the samples extracted from the western English Channel, located 12 kilometers south of Plymouth in the UK, most zooplankton (13 out of 15) showed the ability to ingest MP. MP in the bodies of copepods, euphausids, and doliolids are ingested through filter feeding, while doliolids inhale MP into their body cavities through the anterior siphon and into their intestines [12]. MP not only appears in granular form, but if zooplankton ingests irregularly shaped fibrous MP, they may entangle in their intestines, limiting their ability to eat, digest and absorb food and posing toxicity risks [12]. Antennules, furca, and the swimming legs of copepods are necessary for their abilities and behaviors such as movement, ingestion, and mating. Small MP (0.4-3.8 μ m) was observed to be stuck between these body structures of copepods, which may limit their normal physiological activities such as hunting, avoidance and reproduction [12].

Because microplastics are similar in volume to zooplankton food, zooplankton are often affected by marine microplastic pollution, which interferes with their normal physiological activities and deposits in the body, while moving towards higher nutrient levels. The accumulation of MP in zooplankton organisms not only brings physiological effects to their individuals but can also be transported between different trophic levels and transferred to upper predators through zooplankton, causing potential cascading effects. A study conducted by *T. Fulvus* copepods nauplius as prey and the ephyrae stage of *Aurelia sp.* jellyfish as a predator creates an artificial food chain [13]. When MP accumulates in the intestinal of copepods, aggregates containing fluorescent MP were observed near the stomach filaments of ephyra after ingestion of contaminated copepods by jellyfish [13]. The transfer of MP nutrients was successfully demonstrated between copepods and ephyra jellyfish.

3. Interactions Between Zooplankton and Other Marine Life

Zooplankton feed on phytoplankton, the essential microscopic plants that serve as the foundation of aquatic food webs. As primary consumers, zooplankton convert the energy stored in phytoplankton and supports several marine life, including large mammals, fish, and seabirds. When they ingestion and excretion, they help break down complex organic matter, recycling nutrients like nitrogen and phosphorus into water bodies. They also transport organic carbon from the surface layer to deeper ocean layers, playing a fundamental and multifaceted role in the ocean carbon cycle and output [2]. The abundance and distribution of zooplankton can directly affect fish. For many species, the availability of zooplankton is critical to their development. Therefore, fluctuations in zooplankton populations due to environmental changes can have a significant impact on fisheries.

Commercial fishing relies on fish populations in the water, and the main prey resource in the larval stage of fish is zooplankton biomass. In the 1980s, a decline in zooplankton biomass in the North Sea was noted in parallel with a decrease in the population of commercial fish [14]. Like mammals and birds, fish require eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) for growth and tissue development during their juvenile stage. In water, EPA and DHA are synthesized by only a few phytoplankton groups, which force fish to obtain the nutrients they need to grow by eating zooplankton that feed on the phytoplankton [14]. Zooplankton are more popular with fish larvae than fish feed made from grains and poultry by-products. European perch (Dicentrarchus labrax) raised on 100% concentration zooplankton feed has a greater body length and weight than that are feeded by commercial fishmeal [15].

Zooplankton does not only affect other marine life in one way; fish predators also shape its community structure. In Greenland lakes, the composition of zooplankton communities in lakes inhabited by stickleback fish shows significant differences compared to those fishless- or char-only lakes [16]. Stickleback-only lakes are dominated by calanoid copepods because their efficient sensorimotor system supports their survival under intense predation pressure, which greatly changes the structure of the zooplankton population [16].

In Oregon, the trophic cascade involving sea urchins and kelp has indirect effects on zooplankton populations and gray whales. When sea urchin coverage increased, kelp conditions, gray whale predation rates, and zooplankton abundance all declined simultaneously [17]. Predation by sea urchins reduces kelp cover, reducing the available quality habitat for zooplankton and leading to a decline in zooplankton abundance [17]. With fewer zooplankton, their predator, the gray whale, spends less time foraging. Short-term mass predation of planktonic-feeding fish can strongly affect the biomass and community composition of zooplankton. Large zooplankton, such as Daphnia, would decrease immediately after fish predation, allowing small cladocerans and rotifers to proliferate [18]. Although rapid recovery of total zooplankton biomass was observed within 2 weeks of fish removal, the community structure did not recover to the level it had before being affected by predation from fish, evidence that the short-term resilience of larger zooplankton was low [18]. After the elimination of predation interference, the recolonization of zooplankton can occur from eggs in sediments. Some zooplankton diapause eggs can survive in aquatic sediments for decades or longer in response to extreme environmental conditions [19]. However, not all zooplankton enter the diapause phase, and many pelagic copepods do not appear to exhibit diapause, while those in shallow marine environments often do [19]. This has helped zooplankton improve survival and recolonization in extreme conditions.

Attention and action on environmental issues, such as reducing greenhouse gas emissions to mitigate ocean acidification, improving plastic waste management, developing and promoting biodegradable materials, can better maintain the balance of the marine ecosystem from the base of the food chain.

At the same time, it can also act as a biological indicator, providing researchers understand and detect environmental changes.

4. Conclusion

In conclusion, with the change in the ocean environment, the biomass and diversity of zooplankton are harmed by the increase of ocean acidification, eutrophication and pollution. It is also being altered by its predators in terms of population size and structure. When subjected to over predation by fish, larger zooplankton is taken their place in the population by smaller, faster-reproducing zooplankton. These changes will further affect the energy intake of higher nutrient-grade fish, forming a chain reaction. The study summarizes common trends in zooplankton in many water areas around the world and provides a more comprehensive picture of the various factors that affect them. However, due to the dispersed time and space range of existing studies and the lack of comprehensive and standardized datasets, studies are more localized and hardly representative of the overall global pattern. Interactions between zooplankton, the environment and other species are subject to complex and multifaceted anthropogenic or natural interventions, so they are not fully understood today. With the development of technology and the sharing of information from global cooperation in the future, the detection of zooplankton populations and dynamics will be improved and more comprehensive data will be obtained.

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