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From Ingestion to Community Changes: The Effects of Nearshore Microplastics on Zooplankton: A Review

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Abstract. Microplastics are widely present in coastal waters. Because their size and appearance resemble those of natural food sources, they are frequently ingested by zooplankton. This mini-review examines how exposure to microplastics affects zooplankton feeding, development, reproduction, community structure, as well as energy transfer and carbon flux. Drawing on 15 original studies published between 2013 and 2023, this review examines topics such as microplastic intake, feces, reproduction, larval survival, and population growth in marine copepods. The results indicate that the size, shape, and degree of degradation of microplastics all influence the feeding preferences of zooplankton. Exposure to seawater containing high concentrations of microplastics reduces the feeding rates and reproductive development of planktonic organisms, and their feces may also transfer microplastics to other predators or to deeper waters through the food chain. However, direct evidence regarding the impact on changes in population structure remains limited, necessitating the conduct of more realistic, long-term, multi-species studies to assess the associated risks.

Keywords: Microplastics, Zooplankton, Feeding, Trophic transfer

1. Introduction

Global plastic waste continues to be discharged into the oceans as a result of human activities. Exposed to ultraviolet radiation, waves, and mechanical abrasion, such plastic breaks down into microplastics (MPs) smaller than 5 mm [1]. Furthermore, factors such as river runoff, urban wastewater, et al. have led to severe pollution in nearshore areas, where marine life is highly exposed [2, 3]. Microplastics are not a homogeneous class of pollutants; the characteristics of each type of microplastic influence whether zooplankton will ingest them. For example, different types of microplastics vary in density, diameter, shape, and surface characteristics. These differences affect their distribution in seawater and how easily they are detected and consumed by zooplankton. Furthermore, as microplastics gradually degrade in the ocean and form biofilms, they may release chemical signals similar to those emitted by food, raising the likelihood that zooplankton will consume them [1-4].

Zooplankton serve as a key link between phytoplankton and fish during periods of high nutrient levels [5, 6]. Planktonic animals such as copepods feed on primary producers, providing food for fish larvae and subsequently contributing to the transport of carbon and nutrients through their feces

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[7, 8]. Microplastics may affect plankton in two ways. First, microplastics can reduce the normal feeding and energy intake of zooplankton; this loss of energy can affect their normal growth, reproduction, and population size [9, 10]. Through zooplankton's prey selection, trophic level transfer, and the sinking of fecal particles, microplastics further influence the marine food web and carbon cycle [6-8]. Therefore, this review explores how zooplankton ingest microplastics, and analyzes the toxicity and individual effects of microplastics on zooplankton. It also analyzes how these effects alter community structure.

2. Exposure and intake

Cole et al. directly demonstrated that various marine zooplankton are capable of ingesting fluorescent polystyrene microplastics that are similar in size to their normal food [5]. These particles can be filtered by zooplankton, actively ingested, or attached to the parts of their bodies used for feeding. The particles are subsequently excreted from their bodies in their feces. Cole et al. observed nylon fibers in the bodies of juvenile *Calanus finmarchicus* and nylon particles in their feces, providing direct evidence that zooplankton can ingest and excrete microplastics [11]. Although the residual microplastics in their bodies decrease over time, the impact of these microplastics on the individuals themselves diminishes. However, these microplastics are encapsulated within fecal particles, and as these fecal particles sink in the ocean, they carry the plastic from the ocean surface to deeper water layers.

Bioavailability depends on particle size, shape, and the behavior of the organisms. For example, the toxicity of smaller polystyrene particles had a strong and chronic effect on Tigriopus japonicus, suggesting that plastic toxicity to organisms cannot be fully characterized by particle concentration in water alone [12]. Furthermore, different species of zooplankton exhibit varying perceptions and preferences toward plastic debris, fibers, and microbeads [4]. For example, food cues associated with aged plastic particles are more likely to be ingested by zooplankton [1-4]. Therefore, it can be concluded that because aged plastic particles are covered with a biofilm, they are more likely to be mistaken for food by zooplankton than clean plastic microbeads in a laboratory setting.

Zooplankton may also be exposed to microplastics by feeding on prey contaminated with microplastics. Costa et al. first had Tigriopus fulvus larvae ingest polyethylene particles, and then fed those larvae to Aurelia larvae [6]. Subsequently, when the researchers examined the jellyfish's bodies, they found microplastics; however, they observed that these microplastics did not adversely affect the jellyfish's activity. This experiment demonstrated that microplastics can be transferred from one organism to another through predation. However, it did not prove that ingesting organisms containing microplastics leads to the production of toxins from those microplastics within the jellyfish. Furthermore, it is unlikely that these microplastics will gradually accumulate in organisms at higher trophic levels.

These studies also demonstrate that the exposure levels of these organisms cannot be represented by a single concentration value. In the experiments, the plastic particles in seawater varied in shape and degree of degradation. Furthermore, the degree to which different plankton filter water and their dietary preferences vary. Consequently, the same particle concentration may represent different doses within different plankton species. Studies should also account for particle distribution, morphology, mass, and degree of degradation, as well as the amount excreted by the organisms. Otherwise, such toxicity results may simply be due to differences in the bioavailability of the particles to different organisms. Figure 1 shows Intake and Excretion of Nylon Microplastics by Calanus finmarchicus.

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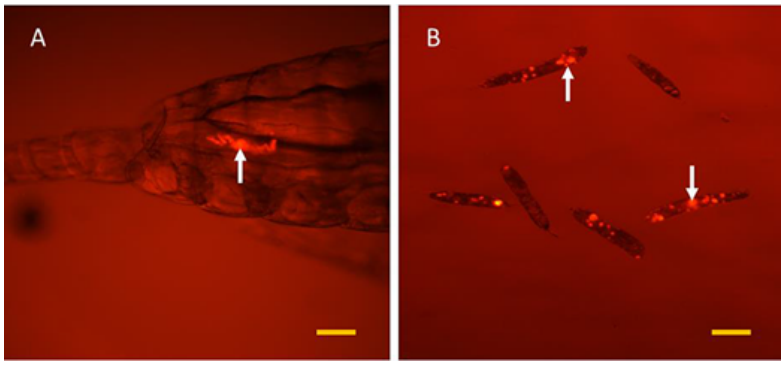


Figure 1. Uptake and excretion of nylon microplastics by Calanus finmarchicus: (A) Nylon fibers in the gut; (B) Nylon particles in feces. The yellow scale bar represents 100 μm [11]

3. Feeding and energy, development and reproduction

When plankton ingest microplastics, this may prevent them from feeding normally. As a result, their food intake and energy intake are reduced. Studies have shown that polystyrene microplastics cause Calanus helgolandicus to eat less and interfere with their normal reproduction. Microplastics also alter their food preferences and fecal particle density [7].

Reduced feeding in plankton will result in a decrease in the energy available for growth and reproduction. A good example is C. finmarchicus, where six days of exposure to plastic altered lipid accumulation and molting in larvae, although the response in adults was not as pronounced [11]. Everaert et al. [10] used a dynamic energy budget model to link reduced filtration rates to population changes. Data show that the 48-hour filtration rate EC50 was 1,956 ± 311 particles/L, while the model predicted that a concentration of 593 ± 376 particles/L would reduce the annual average population equilibrium density by 50%. Although this metric may exaggerate energy loss in smaller individuals, these values are still significantly higher than normal environmental concentrations [10].

From this, it becomes clear that plankton are most vulnerable during the reproductive period and the larval stage. PET pellets and the plasticizer DEHP reduced the egg production of Parvocalanus crassirostris. After 24 consecutive days of exposure to plastic, their numbers dropped to only 60% of those in the control group; however, once exposure ceased, the effects diminished significantly [13]. Similarly, in other experiments, microplastics also affected the feeding, reproductive development, and DMS production of Tigriopus japonicus [14]. In another experiment, the study species Acartia tonsa was similarly exposed to plastic particles, which also affected larval body size and survival rates, egg size, population growth rates, and fecal particle settling [8]. The experiments indicate that plankton show a reduced feeding response when in contact with plastic particles, leading to lower energy intake and negative impacts on reproduction and other issues.

The conclusion of these studies is that the microplastics have no immediate effect on the death of the various types of plankton, but it does cause some effects on their physiology. The sublethal effects are also likely to be maintained in the population due to the fact that the plankton reproduces a lot and this means that they will reproduce many generations before any changes can occur. Along with the results obtained by Heindler et al., it seems that as soon as the plankton are placed in water without the presence of plastic particles, they begin to recover [13]. In other words, the findings imply that such effects are not long-term and it is based on the presence of zooplankton in an area where there are microplastics.

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4. From individual effects to community-wide changes

The toxicity of microplastics may alter the balance of population proportions within a community. This is because each species has a different level of sensitivity; if microplastics cause a decline in the feeding and reproductive abilities of less sensitive species, while tolerant species remain unaffected and stable, the proportion of tolerant species in the community will increase—even if their numbers do not actively grow. Different species have varying sensitivities to microplastics, influenced by taxonomic category and life stage, leading to significant differences in their impacts [3-5, 8, 12]. Therefore, differences in exposure and sensitivity are the primary reasons why individual toxicity may alter community composition.

In these experiments, there is limited evidence from field studies. Most studies cannot directly prove that microplastics are the primary culprit affecting plankton communities. Researchers found that in areas with higher microplastic concentrations, copepod abundance was generally lower. However, there was a positive correlation with the planktonic stage of Rosalina globularis [15]. This does not directly prove that microplastics cause copepod mortality, as other environmental factors such as water currents, food availability, and seasonality can also influence their abundance. In other experiments, such as the study by Zheng et al., microplastics were detected in wild zooplankton in the Bohai Sea, indicating that zooplankton in natural environments ingest microplastics just as they do in laboratory settings [2]. Gunaalan et al. detected microplastics in zooplankton and their fecal particles in the Kattegat and Skagerrak, albeit at low concentrations [3]. Therefore, the amount of microplastics ingested by wild zooplankton depends not only on the concentration in the water but also on the probability of encountering microplastics and whether they are actually ingested. The concentration of microplastics in zooplankton not only depends on the quantity of microplastics in the water but also on whether they can come into contact with and ingest these particles, and whether, after ingestion, the particles remain in their bodies or are excreted in their feces.

If only the total abundance of zooplankton is observed, a decline in the abundance of one taxon may be masked by an increase in the abundance of another taxon. When environmental factors cause a decline in the density of all species, changes in species richness may appear particularly dramatic. Therefore, the abundance, biomass, developmental stages, and reproductive output of each taxon should be analyzed simultaneously. Only by linking these indicators to particle content within the organisms and feeding rates can we better distinguish between direct exposure of plankton to plastic particles and effects arising from feeding and predation relationships.

5. Impacts on food webs and ecosystems

Changes in zooplankton feeding behavior may simultaneously affect other organisms in the food web. If zooplankton reduce their feeding due to microplastics, the abundance of a particular phytoplankton species that serves as their food source will increase, further altering the composition and proportions of phytoplankton. Furthermore, if zooplankton populations decline due to reduced reproductive rates, the fish larvae that feed on them will be forced to consume food with lower nutritional value.

Microplastics also alter the density of zooplankton feces and the transport of organic carbon in the ocean. Coppock et al. found that microplastics alter the density of fecal particles [7]. Shore et al. found that the sinking rate of fecal particles slows down due to the presence of microplastics [8]. If the sinking rate of their feces slows, these microplastics and organic matter will remain at the ocean's surface for a long time, where they will be consumed by other organisms, thereby reducing the rate of organic carbon transport in the ocean. However, while current research indicates that

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microplastics may affect ocean carbon transport, it has not yet determined what consequences this effect will have on overall ocean carbon storage.

These ecological impacts cannot be predicted in advance because many other factors are at play. For example, reduced feeding by plankton might lead to an increase in certain phytoplankton species, but this would merely result in some algae gradually gaining a dominant position. Furthermore, the sinking rate of fecal particles may not necessarily slow down; if other substances aggregate with the feces, the density of the feces will increase, causing them to sink faster. Therefore, the ultimate impacts of these processes on the ecosystem and their ensuing consequences remain difficult to ascertain. Researchers need to conduct more detailed field studies that take all factors into account.

6. Conclusion

This study indicates that zooplankton can ingest and excrete microplastics. Microplastics can also be transferred to different locations or trophic levels through prey and feces. Whether plankton are affected by the toxic effects of microplastics depends on the type and size characteristics of the microplastic particles, as well as the feeding behavior, species, and life stage of the animals. However, if plankton are exposed to seawater with high concentrations of microplastics over the long term, they may experience reduced feeding, impaired development and reproductive capacity, leading to a decline in population abundance. This would alter the abundance ratios of different species. Furthermore, microplastics can affect food webs and the transport of marine organic carbon. However, direct evidence of the potential impacts of microplastics remains very scarce, and simulated data exceed average values observed in natural marine environments. The results suggest that microplastics have the potential to alter nearshore plankton communities; however, the magnitude of these effects requires further evidence and dedicated research.

Existing research on microplastics in seawater is limited due to artificial conditions, such as excessively high concentrations that do not reflect real ecological risks. Moreover, the use of clean microbeads fails to simulate the biofilm-covered microplastics typically found in the environment, potentially affecting ingestion by zooplankton. Many studies also lack consideration of inter-species competition, generational succession, and environmental changes. Consequently, there is a need for long-term, multi-species field studies to address these limitations.

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