The effects of microplastic contamination of marine snow on the deep sea food chain and carbon sequestration by phytoplankton

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Introduction

Marine snow is a fundamental driving force of life in the deep sea. Marine snow is formed by decaying organic matter from dead animals, phytoplankton, and fecal matter that falls down in a continuous shower to the ocean floor (Kiørboe 2001). Marine snow is a crucial food source for many animals such as zooplankton and vampire squid at depths where light is limited for photosynthesis to support secondary production (Ferreira et al. 2022). Many factors affect the movement and quantity of marine snow, such as the ocean currents, phytoplankton concentrations, and microplastics (Kiørboe 2001). Currents change where the marine snow travels and eventually falls, while the amount of phytoplankton and microplastics mixed in with it alter the buoyancy of marine snow and control how much makes it down (Porter et al. 2018). However, microplastics have much more severe effects once they become intermixed with marine snow.

Microplastics are formed when plastic trash degrades into minuscule particles which often enter the ocean. They typically start as beach litter pulled in by the waves or pushed in by wind, or trash washing in from rivers or other water bodies (Zhang et al. 2021). They then sink down through the water column, being generally denser than water (Hale et al. 2020). They blend in with marine snow, also sinking through the water column. Many animals mistakenly consume microplastics mixed in with marine snow, as they appear similar to marine snow in both size and shape (He et al. 2022). Consuming plastic has numerous negative effects on animals, such as damage to organs and decreasing survival rates (Zolotova et al. 2022). Microplastics have many effects on both zooplankton and larger animals like fish, reducing survival and reproduction rates (Zolotova et al. 2022). Additionally, microplastics impact primary producers like phytoplankton, thus affecting entire food chains.

Some of the most significant producers of the ocean are phytoplankton. Phytoplankton are an essential food source for zooplankton and other organisms (e.g., filter feeders) in surface waters. This is what makes the ocean an effective carbon sink. Phytoplankton photosynthesize, powering the ocean's food web with energy from the sun by combining water and carbon dioxide to produce glucose and oxygen. As phytoplankton are consumed and excreted, the carbon they store sinks towards the ocean floor. Dead or decaying blooms of phytoplankton also provide a substantial source of organic matter to the deep sea. Microplastics in phytoplankton make these blooms more buoyant and unlikely to sink, decreasing the ability for other organisms to effectively use the carbon. Zooplankton consuming phytoplankton also feel the effects of consuming microplastics. Overall, this decreases the population and size of zooplankton, which has implications for higher-level consumers throughout the food chain.

This paper discusses the effects on microplastics on marine snow, zooplankton, and other organisms in the deep sea, and seeks to connect the many ways in which they are harmful, which we still do not fully understand.

Effects of microplastic consumption by life in the deep sea

Studies suggest that microplastics can damage fishes' liver, brain, intestine and gills, along with affecting fertility rates, metabolic balance, and behavior (Zolotova et al. 2022). In aquatic invertebrates, they may reduce fertility and feeding behavior along with slowing development and increasing the amount of oxygen needed for the organism to survive (Zolotova et al. 2022).

As mentioned previously, microplastics often are found in phytoplankton blooms (He et al.). Zooplankton that consume the phytoplankton find it more difficult to reproduce and are also much less likely to survive or be healthy prey (He et al.). This in turn affects the predators of said zooplankton, and the predators of those animals, as each level suffers a hit to its food source. Zooplankton that die due to consuming too many microplastics or seek out less real food are also not contributing to digesting phytoplankton and passing it into marine snow through their fecal pellets, further lessening the efficiency of the deep sea as a carbon sink (Cavan et al. 2017).

Numerous other organisms consume microplastics by mistake. Amphipods are one such example. In a study of Lysianassoidea populations in six different ocean trenches, over 72% of the specimens examined had consumed at least one microplastic particle (Jamieson et al. 2019). Across the trenches, the number of particles consumed per individual ranged from one to eight (Jamieson et al. 2019). This study reports the deepest bioavailability of microplastics to date. As with many other animals, the adverse effects of microplastic ingestion include intestinal blockage, which leads to them eating less and dying faster (Jamieson et al. 2019).

Vampire squid are also affected, likely due to their feeding strategy, as they are filter feeders (Malafaia and Barceló 2023). A study involving the vampire squid and midwater squid revealed multiple particles in most individuals.

Copepods, which make up a large number of zooplankton, also often consume microplastics due to the size of the particles overlapping with that of microalgae (Bai et al. 2021). The effects are once again varying impediments on food intake, causing the copepods to starve. Interestingly, different species of copepods at different ages respond to microplastics differently (Bai et al. 2021). Microplastics consumed by copepods, when passed in fecal pellets, sink deeper and become smaller and therefore more dangerous, as now more of them can be consumed and cling to smaller particles of marine snow (Bai et al. 2021). Copepods are also a vital food source for predators of varying sizes.

The contamination of and detriment to bivalve larvae and filter-feeding grown bivalves naturally leads to a lessened population of grown mussels and other bivalves. As mussels provide a habitat or a food source for numerous animals in their ecosystem, this affects more than just the larvae themselves (Inoue et al. 2021). Microplastics have also been shown to interact with the byssus, the fibers that mussels use to anchor themselves, a potential detriment to their ability to stay in one place to feed (Inoue et al. 2021).

Effects of microplastics on food chain

Microplastics enter deep sea food chains by mixing with marine snow. Deep sea zooplankton, like many other deep sea organisms, rely on marine snow as their primary source of food.

Microplastics, similar in appearance, are often mistaken for food by the zooplankton (Botterell et al. 2019). The zooplankton begin to die off due to the numerous negative effects of consuming plastic detailed above, reducing a crucial food source for many deep sea predators and threatening the entire food chain (Raymont 1971). The zooplankton that do survive long enough to be eaten pass on microplastics to the organisms higher up the food chain (Miller et al. 2020), in turn causing harm to higher predators.

As for how microplastics get into food chains, marine food chains often start with phytoplankton–microscopic marine algae– which harness energy from the sun via photosynthesis. Microplastics build up in higher trophic levels, as each consumer when consumed themselves, passes them on to the next. Given that approximately 10% of energy is transferred to each higher level, predators consume a lot of microplastics trying to sustain themselves (Genoni and Montague 1995). For example, studies have found that zooplankton consume microplastics, comb jellies eat the plastic-laced zooplankton, and so on, with each new consumer collecting microplastics from its prey (Parolini et al. 2023). These organisms, such as vampire squid and fish, also experience the effects of microplastic poisoning. At high enough levels of built-up trash, they begin to starve due to their inability to digest plastic, not feeling a need to seek out actual food when they already feel full (Malinowksi et al. 2023). This decreases a crucial food source for many deep sea consumers.

Decapods face a similar threat from larvae dying off due to consuming microplastics instead of food particles, and this accumulation harms those in higher trophic levels, including humans (D’Costa 2022). The particles, traveling along the food chain, have been found in the tissues of many animals who feed from the sea, from molluscs to mammals and even birds. Likewise, this is concerning for humans who eat seafood.

Future directions

If this problem remains unchecked, zooplankton die-off will only worsen, shaking the food chain and drastically reducing the amount of carbon the ocean can sequester. Scientists are searching for ways to remove or break down microplastics from the oceans. One approach is biomimetic filtering using the same approaches as deep sea species, leaving out marine snow by either making hydrophobic surfaces that let water with marine snow pass through or filtering by particle size (Hamann 2016). Ciliary feeding, as demonstrated by feather duster worms, creates a current with cilia to pull in particles and then capture them, sometimes with a sheet of mucus. Impingement feeding is similar, using the current generated by a ring of cilia to move particles to food-collecting surfaces. Collision feeders have also inspired technology, as they use adhesive surfaces or nets of mucus to retain particles that collide with them. Filter feeders allow water to stream through, using the same principle as a sieve (Hamann 2016).

Another possibly promising method harnesses biotechnology using microbes that are capable of degrading microplastics to clean up the waters (Shen et al. 2019). This method is difficult to study, as conditions for these microbes to thrive are not easy to meet in the field. The process also varies based on factors such as the size of the particles, the species of microorganism, and the amount of carbon in the water.

Conclusions

Overall, microplastics are a problem affecting many aspects of marine life. They have significant effects on the health of any organisms that consume them, and the problem doesn't stop there, as they are passed on and biomagnified through the food chain. Introducing what amounts to poison with no nutritional value also causes problems in the entire ecosystem.

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