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Review Article

Ecotoxicological Impacts of Micro and Nanoplastics on Marine Fauna

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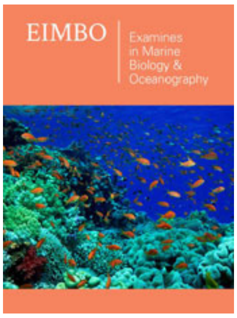

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Abstract

Mismanagement of plastics has resulted in increasing plastic wastes in the environment, particularly the marine environment acting as the ultimate sink of plastics disposed into waters and even onto land. Micro- and nanoplastics in the marine environment undergo aggregation, sedimentation, deposition and enter the food chains as they are ingested by marine fauna. The uptake of micro- and nanoplastics by marine fauna poses multiple ecotoxicological effects comprising the blockage of alimentary canal and gills, behavioral change, physiological interference especially of the endocrine, antioxidative, immunity and hepatic systems, as well as adverse effects on reproduction and development of marine fauna. The ecotoxicological effects are often complicated by the ability of the micro- and nanoplastics to adsorb a wide range of chemicals. Nanoplastics have been found to affect cellular functions and membrane integrity and are able to cross the blood-brain barrier of certain aquatic species. The effects vary with the types of plastics, species of marine fauna, the dose as well as the sizes of plastics. This review systematically and concisely presents the toxicological effects of micro- and nanoplastics on marine fauna and highlights the need to understand the effects of these plastics at environmental concentrations instead of experimental concentrations. It also calls for the study of ecotoxicological effects of micro- and nanoplastics to be extended to more plastics types and sizes as well as more marine species.

Keywords: Microplastics; Nanoplastics; Marine; Ecotoxicology; Bioaccumulation; Adsorption

Introduction

The presence of micro- and nanoplastics in the environment has become a hot topic of discussions and scholarly publications due to the impacts they pose on the ecosystems and the health of both producers and consumers along the food chains. There is currently a lack of consensus on the definitions for microplastics and nanoplastics. Desforges et al. [1] classified plastics of 1μm to 5mm as microplastics while Rocha-Santos and Duarte called those less than 5mm microplastics [2]. Similarly, the definitions for nanoplastics vary with EU Commission considering nanoplastics as plastic fragments in the range of 1 to 100nm, [3] and Hartmann et al. [4] defining them as those with sizes ranging from 1nm to 1μm [4]. Dimensions of the sizes of micro- and nanoplastics were often not specified, leading to ambiguity in determining whether the sizes actually referred to the diameters or the lengths.

Considering the inconsistency in size definitions, in this paper, microplastics refer to plastic fragments between 100nm and 5mm in any one of their dimensions while nanoplastics are plastic fragments less than 100nm in any dimensions [5]. Micro- and nanoplastics enter the environment through multiple pathways, one of which is through the use of cosmetic and cleaning products containing micro- or nanobeads [6]. Feedstock for plastics manufacturing and accidental release of plastic resin pellets or powder from air blasting also constitute direct entries of micro- and nanoplastics into the environment [7]. Indirectly, micro- and nanoplastics are formed from the degradation of large plastics discarded into the environment via physical, chemical and biological means, as well as tearing of synthetic lint from cloth washing and wearing of plastic materials over time [8]. These plastic fragments can be carried by wind into the atmosphere and eventually settle onto ground or are washed down by rain. Rainwater runoffs often transport these fragments from the air or the ground into waterways resulting ultimately in the entry of micro- and nanoplastics into the marine environment [9]. The withdrawal of water contaminated with micro- and nanoplastics to water treatment plants causes entrapment of these plastics in the sludge produced during water treatment which are later returned to the environment via application of the sludge as fertilizer [6]. Similarly, channeling industrial wastewater and blackwater laden with micro- and nanoplastics to wastewater and sewage treatment plants also results in their accumulation and escape from these plants. Stephen et al. [10] found that even 3D printing emitted ultrafine synthetic particles and this aggravates concerns for the widespread presence of micro- and nanoplastics in the environment [10].

To date, micro- and nanoplastics have been detected in almost all ecosystems, particularly the marine and freshwater ecosystems. Microplastics were found in the water and sediment of inland seas 11 and ice cores of the Arctic where as much as 38 to 235 particles/m^3 of microplastics were reported [11,12]. Desforges et al. [1] reported 9,180 microplastic particles in each cubic meter of seawater of the Northeast Pacific Ocean, while Norén and Naustvoll revealed a maximum of 102,000 particles in each cubic meter of the Sweden coastal waters [13]. The prevalence of micro- and nanoplastics was also reported to have increased twofold in the North Pacific subtropical gyre over the last forty years, indicating that there is a trend of micro- and nanoplastics accumulation in the environment over time [12].

As micro- and nanoplastics enter the marine ecosystems, they are partly removed via abiotic and biotic interactions leading to their aggregation, sedimentation, deposition and eventual entry into the food chains [2]. Unlike large plastic litters whose effects on marine organisms are observable through entanglement, smothering as well as blockage of the alimentary canal and toxic effects after ingestion, the environmental and ecotoxicological impacts of micro- and nanoplastics are not well characterized [14]. This is partly attributed to the diverse constituents and sizes of micro- and nanoplastics which give rise to complex biochemical interactions with marine organisms. While microplastics release chemicals as they are bioaccumulated and biomagnified up the trophic levels, nanoplastics could interact at cellular level and may disrupt physiological processes. This mini review examines the ecotoxicological effects of micro- and nanoplastics separately to provide better understanding of how these plastics affect the marine fauna, hence the health of consumers along the marine food chains.

Ecotoxicological Impacts of Microplastics on Marine Fauna

Generally, plastics contain additives which can be leached into the environment and cause various levels of toxicity. Studies showed correlation between the concentrations of plastic additives in the body of marine fauna and the amount of plastics they ingested or present in the environment they inhabited [15]. For instance, the Polybrominated Diphenyl Ethers (PBDEs) in tissues of *mycophid* fish sampled from the South Atlantic correlated with the additives of plastics found in the area [16]. Lugworms (*Arenicola marina*) sampled from sediments contaminated with polystyrene were also found to have higher levels of Polychlorinated Biphenyls (PCBs) compared to those from sediments without polystyrene contamination [17]. Microplastics can adsorb different chemicals in their surroundings such as phenanthrene, triclosan and nonylphenol and these adsorbed chemicals can be released together with plastic additives upon ingestion as already exhibited in the tissues of affected lugworms [18]. Chrysene, PCB 28 and derivatives of PBDEs were detected in fish which ingested polyethylene pellets [19].

Other common additives of plastics comprise phthalates, bisphenol A, acetaldehyde, formaldehyde, polyfluoronated compounds and lead heat stabilizers, each of which exhibits different toxicity to the marine fauna [20]. Pthalates could interfere with endocrine system in fish via interacting with hormone receptors [21]. Nonylphenol also exhibited similar effect [22]. In fact, chemicals leached from microplastics, particularly Polyethylene Terephthalate (PET) had been found to demonstrate estrogenic activity [23]. The complex chemicals from plastics and adsorbed onto microplastics could be disruptive to ecological structure and functions as well as physiological processes such as immunity and endocrine system, and animals' ability to elude predators. Browne et al. [18] revealed alteration of feeding behavior and mortality in lugworms which ingested triclosan-sorbed Polyvinyl Chloride (PVC) [18]. Experimental study on fish fed with microplastics sorbed with persistent organic pollutants and heavy metals revealed higher hepatoxicity characterized by glycogen depletion, tumor formation and lipidosis, as well as endocrine disruption, than microplastics alone [18,19].

Microplastics have also been reported to disrupt antioxidative system which plays crucial role in detoxification in living organisms. Examples of enzymes involved in antioxidative system are catalase, superoxide dismutase and glutathione peroxidase [24]. Jeong et al. [25] demonstrated that microplastics increased production of reactive oxygen species in rotifers and marine copepod, leading to intensified activities of superoxide dismutase, glutathione peroxidase, glutathione reductase and glutathione s-transferase [25]. The extent of such disruption is often size-dependent and contrary to the rationale that smaller microplastics have longer retention time and higher bioavailability, hence greater toxicological effects, various studies found microplastics to exhibit greatest effects at different sizes [24]. Exposing peppery furrow shell (*Scrobicularia plana*) to polystyrene at 1mg/L for 14 days in the laboratory resulted in enhanced activity of superoxide dismutase particularly in the gill and digestive glands [26]. The study points to tissue-specific responses to microplastics among marine fauna and the responses are often species-specific where red mullet (*Mullus surmuletus*) demonstrated only a slight increase in the activity of gluthathione with negligible change in the activities of superoxide dismutase and catalase in microplastics-enriched environment [27].

Ecotoxicological effects of chemicals-adsorbing ability of microplastics have been demonstrated via enhanced fluoranthene toxicity of polystyrene contaminated with fluoranthene in marine mussels which set off oxidative system at cellular level and interfered with fluoranthene detoxification more intensely than polystyrene alone [28]. Microplastics are also known to bind antibiotics and antimicrobials, thus facilitating their transfer to organisms [24].

Ecotoxicological Impacts of Nanoplastics on Marine Fauna

Similar to microplastics, nanoplastics contain chemical additives and provide the surfaces for adsorption of chemicals which upon release into the environment or after ingestion, can interfere with physiological functions and exhibit toxicity on marine fauna (Figure 1). However, due to their smaller sizes, nanoplastics have larger surface areas for chemical leaching and adsorption, making them potentially harder to detect and their effects more complex to characterize than microplastics. Their small sizes also permit them to interact at cellular level resulting in another dimension of toxicological concern. Nanoplastics of polystyrene have been demonstrated to permeate the membrane bilayers and induce alteration of membrane structure due to their solubility in the membrane (Figure 1). This hampers diffusion across membrane and disrupts cell functions [29]. Chemicals adsorbed onto nanoplastics can enter tissues, causing long-term toxicity [14].

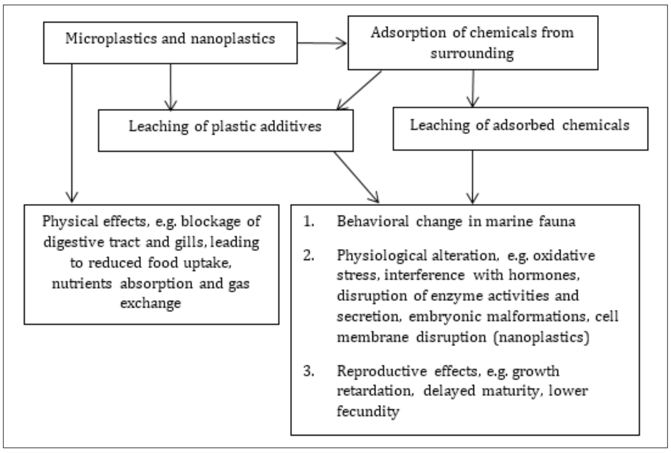

Figure 1: Ecotoxicological effects of micro- and nanoplastics.

Latex nanoparticles were already detected in the gills and intestines of the Japanese rice fish (*Oryzias latipes*), and to lesser extent in their liver, blood and brain, thus indicating the ability of nanoplastics to cross the blood-brain barrier [30]. Exposure to 500nm polystyrene at concentrations of 1.25 and 2.5mg/L was found to lower fecundity of a marine copepod (*Tigriopus japonicus*) [5]. Blue mussel *(Mytilus edulis)* produced pseudofeces and experienced reduced filtering activity when exposed to 30nm polystyrene particles at concentrations between 0.1 and 0.3g/L [31]. 50mg/L of 200nm polystyrene stimulated pre-apoptosis among the Mediterranean mussels (*Mytilus galloprovincialis*) while 90nm polystyrene at less than 3.85mg/L resulted in deformation in the embryos of sea urchin (*Paracentrotus lividus*) [32,33].

Nonetheless, Booth et al. [34] revealed negligible toxicity of 2- poly(methylmethacrylate)-based Plastic Nanoparticles (PNPs) and fluorescent PNPs at concentrations ranging from 500mg/L to 1000mg/L on *Corophium volutator* [34]. Baudrimont et al. [35] examined the toxic effect of polyethylene nanoplastics on marine diatoms (*Thalassiosira weissiflogii*) and found no deleterious effect on their cell growth at concentrations up to 10,000µg/L [35]. Contrarily, polymethylmethacrylate nanoplastics at concentrations exceeding 4.69mg/L caused death of rotifers and the 48h median lethal concentration was estimated at 13.27mg/L [36]. Brine shrimps (*Artemia franciscana*) exposed to cationic amino-modified polystyrene nanoplastics showed mortality after 14 days and 1µg/L of the nanoplastics increased molting in the shrimp larvae [37]. Similar to microplastics, the toxicity of nanoplastics is type-specific, species-specific and dose dependent.

Conclusion

With increasing use of plastics and entry of plastics into the environment, the presence of micro- and nanoplastics in the marine ecosystems is a persistent problem. In comparison to large plastics, micro- and nanoplastics are harder to detect and it is significantly more complicated to characterize their ecotoxicological effects which are often species-specific, type-specific, size-dependent and dose-dependent. Micro- and nanoplastics can also adsorb chemicals and metals from their surrounding which renders understanding of their ecotoxicological effects even more complex. Current studies focus mainly on exposing various marine fauna to different types of micro- and nanoplastics in laboratory and polystyrene micro- and nanoparticles seem to receive more attention in such studies than other micro- and nanoplastics. These studies revealed the potential of these plastic fragments to cause behavioral change and interfere with physiological processes especially the endocrine and antioxidative systems in marine fauna. They also affect the growth and reproduction of the marine fauna. Furthermore, nanoplastics pose the danger of cellular interactions and membrane disruption.

There is a need to also examine the ecotoxicological effects of these plastics at environmental concentrations and their interactions with other environmental contaminants to provide a more realistic picture of how these plastics affect the marine fauna. Research in this area should be expanded to different types of micro- and nanoplastics commonly present in the marine environment. With climate change altering the physico-chemical properties of marine environment, it may also be crucial to examine how the ecotoxicological effects of micro- and nanoplastics are influenced [38,39].

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