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Understanding microplastics in aquatic ecosystems – A mini review

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Abstract

Microplastic is defined as plastic debris with a size less than 5mm. It is characterized based on colour, shape, and polymer type. Microplastics have been discovered in a variety of aquatic environments, including freshwater, estuarine, and marine waters. The presence of microplastic in aquatic systems poses a threat not only to aquatic organisms, but to human consumers of food harvested from these environments. This paper reviews the key characteristics of microplastics, how they contaminate aquatic ecosystems, and their effects on aquatic organisms. Efforts have been made to highlight the knowledge gaps in these areas and measures that deserve attention for addressing the problem.

Keywords: Microplastics, Aquatic organisms, Trophic transfer, Consumer health, Possible measures

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Background

With the passage of time, the world entered the Plastic Age, and we now live in a plastic-filled world (Thompson et al., 2009). Plastic is now ubiquitous in our daily lives and products, resulting in an estimated 12,000 Mt of plastic waste in landfills and the natural environment by 2050 (Geyer et al., 2017). Plastic has become the preferred material due to its numerous advantages, such as low cost, durability, and lightweight. All of these accolades for plastic, however, are the same factors that contribute to its hasty disposal and, as a result, detrimental environmental consequences (Adane and Muleta, 2011; Lebreton and Andrady, 2019).

Microplastic is defined as plastic trash with a diameter of less than 5 millimetres (Frias and Nash, 2019; GESAMP, 2015). Microplastic is derived from primary sources, such as microbeads in personal care and cosmetic products (Guerranti et al., 2019), or secondary sources by breakdown of bigger plastic trash into numerous smaller debris under the action of physical, chemical and biological processes (Efimova et al., 2018; Zhang et al., 2021). One of the most prominent anthropogenic aspects of microplastic pollution is the improper disposal of plastic trash, which has accelerated the accumulation of microplastics in aquatic environments (Geyer et al., 2017). Plastics that are broken down into micro particles can easily spread into fresh and marine aquatic habitats (Firdaus et al., 2020; Li et al., 2021; Bharath et al., 2021; Napper et al., 2021), creating difficult problems.

In recent years, the issue of microplastic has come to the forefront of global attention, leading to studies on different aspects of microplastic pollution that suggest that there is a potential hazard for water quality, aquatic life (Anbumani and Kakkar, 2018; Jahan et al., 2019; Naqash et al., 2020; Rezania et al., 2018) and human health (Gabriel et al., 2018; Karbalaei et al., 2018). Microplastics are frequently mistaken for prey by many aquatic organisms and the trophic transfer creates serious consequences that are a matter of global concern (Athey et al., 2020; da Costa Araújo et al., 2020; Dong et al., 2021; Huang et al., 2021). This mini review aims to provide the key information on microplastic characteristics and how it affects the aquatic ecosystems. The knowledge gaps that have been identified provide ideas for pursuing research to understand the severity of the problem and managing it as effectively as possible.

Microplastic characteristics

Microplastics, like other pollutants, have unique properties that influence their long-term fate in the environment. Typically, there are four characteristics of microplastics, namely, sizes, colours, shapes, and polymer types. Researchers classify microplastics into various size groups in order to study their size distribution (Edo et al., 2020; Sathish et al., 2020; Zhou et al., 2021). The size classification is important to avoid confusion between microplastic and nanoplastic, which are both produced by plastic fragmentation. Nanoplastic has been classified as having a size range of 1 nm to 1 µm (Gigault et al., 2018), whereas microplastic has a size range of 1 µm to 500 µm (Frias and Nash, 2019). Microplastic size affects its abundance, with the smallest size being the most abundant, and that as the size increases, the abundance of microplastic decreases (Lots et al., 2017; Yaranal et al., 2021). Smaller-sized microplastics often pose a greater threat to the aquatic organisms than larger-sized microplastics (Choi et al., 2020).

Microplastic colours are commonly classified as transparent, white, black, and others such as yellow, red, blue, and green. White and transparent microplastics dominated on Indian beaches and in the influent and effluent of wastewater treatment plants in China (Long et al., 2019; Yaranal et al., 2021). Coloured microplastics, on the other hands, have been discovered in the Ganges River, with blue being the most prevalent colour (Napper et al., 2021). Coloured microplastic sinks more easily into the water column than white or transparent microplastic due to the presence of pigments, which add weight to it (Zhou et al., 2021). Microplastic colour is important in aquatic ecosystem because the product may be mistaken for food by aquatic organisms by virtue of its colour.

Microplastics has been categorized into various basic shapes such as fragments, fibres, films, foams, and beads. Most of the time, fibres were found to be the most prevalent microplastic shape type (Firdaus et al., 2020; Li et al., 2021; Napper et al., 2021). Many studies have reported that fragment types can dominate aquatic environments (Baini et al., 2018; Khalik et al., 2018; Yaranal et al., 2021). Microplastics in the form of foam materials are abundant near mariculture sites (Zhou et al., 2020). Typically, the bead type is the least of all or may even be non-existent in many aquatic environments because it is mostly derived from primary sources. It is commonly used in personal care and cosmetics but has been banned in a number of countries (Free et al., 2014). Other shapes of microplastics are secondary microplastics that originate from the breakdown of larger macro-debris from textiles, plastic bags, packaging material, and other consumer products (Salvador et al., 2017; Falco et al., 2018; Townsend et al., 2019; Lant et al., 2020). Evidently, the shape of microplastics can help identify their origin from primary or secondary sources.

Microplastics are man-made long-chain polymeric materials that are classified based on the polymer type. Microplastic density varies and has an impact on its distribution in aquatic systems. Polyethylene (PE) and polypropylene (PP) tend to float because their density is lower than that water. Polystyrene (PS), polyvinyl chloride (PVC), polyamide (nylon) (PA), and polyethylene terephthalate (PET) are denser than water and tend to sink (Guo and Wang, 2019). In aquatic environments, PE, PP, and PS are the most frequently found polymers (Efimova et al., 2018). PE and PP commonly occur in surface waters and sediments along the Pearl River in Guangzhou, China (Lin et al., 2018). PE is commonly used in plastic bags for packaging, whereas PP fibres are widely used in ropes, nonwoven fabrics, air filters, diapers, and fishing nets (Nor and Obbard, 2014; Yaranal et al., 2021). When discarded, these products become a source of microplastic.

Microplastics in Aquatic Ecosystems

Microplastics have been found to contaminate a wide range of waterbodies, with their occurrence and abundance varying according to the intensity of human activities and waste management systems (Free et al., 2014; Townsend et al., 2019). Direct discharge of domestic waste and industrial drainage, and waste treatment plans are the well-known routes of microplastic to aquatic environments (Estahbanati and Fahrenfeld, 2016). Microplastics collected in drainage systems and wastewater treatment plants can reach a density as high as 68-910 particles per litre (Leslie et al., 2017). A large amount of microplastic is released into the receiving water because some drainage systems are not designed to remove these particles and treatment plants are not always effective in removal of microplastics before discharging this product into aquatic systems (Magni et al., 2019; Mak et al., 2020). In addition, a substantial proportion of microplastics is retained in sludge after wastewater treatment (Leslie et al., 2017; Magni et al., 2019). Soil amendment with sludge becomes a major source of microplastics in agricultural soils and a possible cause of microplastic contamination in aquatic systems via surface runoff (Corradini et al., 2019; Edo et al., 2020; Gao et al., 2020). Extreme weather events such as hurricanes, floods, and storms aggravate the transport of plastic trash from land to aquatic bodies, as seen by higher microplastics in Mexican urban-overdeveloped beaches when extreme weather events occur (Alvarez-Zeferino et al., 2020).

Microplastics in freshwater systems are transported and deposited in the coastal and marine environments due to the high unidirectional flow of freshwater. In fact, rivers serve as a primary channel for both macro- and microplastic transit into the sea, which accounts for more than 80% of the total plastic load in the marine environment (Schmidt et al., 2017). Estuaries connect freshwater and marine water, and often become microplastic transfer pathway from river to sea. They are also prone to accumulation of microplastics as they have long been regarded to be a sink for sediments and pollutants (Eulie et al., 2018). Estuaries are microplastic pollution hotspot where microplastics comprised more than 90% of total number plastics (Fok and Cheung, 2015; Zhao et al., 2015). Microplastic can also be directly transported into the marine environment via coastal tourism and recreation, commercial fishing, and marine industries, as well as direct dumping into the ocean. Coastal tourism and recreation have contributed to a rise in the amount of plastics thrown along beaches and coastal resorts. These eventually enter the ocean and accumulate there (Lozoya et al., 2016). Commercial fishing, on the other hand, increases the amount of microplastic in the ocean since fishing gear is frequently discarded or is lost (Andrady, 2011).

Microplastic can also invade mangrove forest areas, which are found primarily in the intertidal zone at the confluence of land and sea. Mangrove root systems are known to trap litter, and microplastic particles have been found adhering to mangrove trunks (Garcés-Ordóñez et al., 2019; Li et al., 2018). Plastic sources in the mangrove area, like in other aquatic systems, come from the community waste disposal and direct dumping into the drainage system. Most abundant quantities of microplastic in mangrove areas found near urban and industrial zones (Maghsodian et al., 2021), tourist attractions and near mariculture sites (Zhou et al., 2020). The widespread use of consumer plastic products such as bottles and fishing-related materials such as line and film, contributed to a high level of microplastic pollution in many mangrove habitats (Nor and Obbard, 2014). Even if plastic waste is not disposed directly in the mangrove area, it can be carried away by the water current and get trapped there.

Effect of Microplastic on Aquatic Organisms

Microplastic has an impact on aquatic organisms through a variety of mechanisms, including direct ingestion, indirect ingestion (trophic transfer), and physical adherence. Direct ingestion is linked to feeding habits of aquatic organisms and preferences. Species with selective feeding habits are less likely to consume microplastics than species exhibiting generalist feeding habits (Mizraji et al., 2017; Peters et al., 2017). Besides, species that prey on larger mesozooplankton consumed more microplastics than the species that feed on smaller plankton (Lopes et al., 2020). Direct ingestion of microplastic by aquatic organisms is common due to their mistaking microplastic for prey. Many aquatic organisms, such as zooplankton, zooplanktivores, fish larvae, and planktivorous fish, are at risk from direct ingestion of microplastics, which are similar in size and resemble in appearance to natural food items. For example, Amberstripe scad (*Decapterus muroadsi*) ingests microplastics because these particles resemble their copepod prey. The fish consumed mostly blue polyethylene microplastic fragments that were similar in size and colour to their blue copepod prey (Ory et al., 2017). Blue is the most commonly ingested microplastic colour (Lopes et al., 2020; Ory et al., 2017; Sarijan et al., 2019; Steer et al., 2017). Red microplastics, on the other hand, have been found to be more prevalent in fish whose diet consists of red algae (Mizraji et al., 2017), whereas black microplastics have been found to be abundant in oysters and mudskipper fish (Jahan et al., 2019; Maghsodian et al., 2021). Microplastic ingestion has also been recorded in submerged carnivorous plants, where microplastics were ingested by the bladders (Yu et al., 2020a). The adverse effects of microplastics have been examined in laboratories. Reduced feeding is one such effects and it is concentration-dependent (Cole et al., 2015; Yu et al., 2020b). Microplastics damage the organs (Caccamo et al., 2016; Lei et al., 2018; Yang et al., 2020), affect the growth, survival, and fecundity (Cole et al., 2015; Welden and Cowie, 2016; Yu et al., 2020b), and potentially reduce the population growth (Shore et al., 2021). Microplastic consumption also harms wild fish health, as evidenced by lower condition factors (K) of omnivorous fish specimens with higher microplastic content collected from several upper tidal pools in Las Cruces, Chile's central coast (Mizraji et al., 2017).

Microplastics are ingested indirectly by aquatic organisms at higher trophic levels when they eat prey that has previously consumed microplastics. After feeding zooplankton labelled with ingested microplastics, mysid intestine showed the presence of zooplankton prey and microplastics, indicating the trophic transfer of microplastics in the planktonic food web (Setälä et al., 2014). Microplastic transfer along the aquatic food chains causes different impacts on aquatic organisms. It can resulted in mutagenic and cytotoxic effects in *Danio rerio* adult fish after they were fed *Poecilia reticulata* fry that had previously ingested microplastics (da Costa Araújo et al., 2020). Microplastics have been shown to adsorb chemical pollutants from their surroundings, with a high sorption capacity for hydrophobic organic pollutants and heavy metals (Gao et al., 2019; Zhang et al., 2020). When combined with existing toxic plastic additives, these compounds pose potential ecotoxicological risks to a variety of aquatic organisms (Klein et al., 2021; Luo et al., 2019; Zimmermann et al., 2020). The potential effects of bioaccumulation and biomagnification of microplastics and associated chemical pollutants and additives are a matter of major concern (Alava, 2020; Saley et al., 2019), even though the evidence for microplastic bioaccumulation and biomagnification via aquatic food chains remains uncertain and unpredictable (Huang et al., 2021). According to Chagnon et al*.* (2018), even if microplastic is transferred from prey to predatory fish, it will not accumulate in the relatively large digestive tract of large predators. Furthermore, most aquatic organisms egest or excrete the majority of ingested microplastics (Christian et al., 2018; Woods et al., 2018; Xiong et al., 2019). Wang et al*.* (2021) suggested that biomagnification did not occur after the predatory marine crab (*Charybdis japonica*) consumed microplastic-contaminated mussels, possibly due to the crab's ability to egest microplastics.

Another way that microplastics contaminate aquatic organisms is through absorption or adherence. Kolandhasamy et al*.* (2018) found that adherence of microplastics to soft tissue of mussels accounted for about half of the microplastic uptake in mussels. Microplastics were also found on the skin and muscles of fish, as well as several body parts of copepods, implying that adherence is one of the possible routes for microplastic contamination of aquatic organisms (Abbasi et al., 2018; Feng et al., 2019; Benny et al., 2020; Yu et al., 2020b). In aquatic systems, microplastics primarily adhere to the surface of primary producers, limiting the amount of light available to the cells (Yu et al., 2020a).

Microplastics can also harm microalgae cell membranes, reducing the their photosynthetic activity (Li et al., 2020). When microplastics bind to the surface of the roots of a floating freshwater plant, the length of the roots shortens, indicating the root growth limitation (Kalcikova et al., 2017). Adherence appears to be the most important strategy for trapping microplastics in macroalgae, and morphology, such as the presence of phaeophycean hairs and the stickiness of the macroalgae's surface that played an important role in adherence (Feng et al., 2020). Microplastics have also been seen adhering to the seagrass (Datu and Tahir, 2019) but there is not enough scientific data on its effects on the eco-physiological functions of this important marine flowering vegetation.

Conclusion

This study summarizes current understanding about microplastics in aquatic ecosystems, including their characteristics, occurrence, and impacts. Microplastics (plastic debris < 5 mm) appears in aquatic systems in a variety of sizes, colours, shapes, and polymer types. Many studies on the occurrence and distribution of this pollutant in aquatic ecosystems have been conducted. Microplastics contaminate a wide range of water bodies. Direct discharge from drainage systems and wastewater treatment plants is the most common way microplastic enters aquatic systems. There is an urgent need to upgrade the existing wastewater treatment plants to boost microplastic removal efficiency. Considering the current stage of microplastic pollution, a microplastic water quality standard should be established, along with improved and standardised monitoring of this pollutant. Microplastic modelling is a useful tool for optimising microplastic management that deserves more attention. Monitoring and modelling of microplastics is crucial not only for gaining a better understanding of the issue, but also for validating the pollutant's effects, and raising public awareness.

Microplastics contaminate aquatic organisms through direct ingestion, indirect ingestion (trophic transfer), and physical adherence. Numerous laboratory experiments have shown that microplastic has negative effects on a variety of aquatic organisms. However, more research on microplastic effects is needed to avoid misinterpretation of non-environmentally realistic data and to better assess the potential risk of microplastics to aquatic ecosystems. Microplastics contamination of aquatic organisms poses a risk to human health through food chains. These consequences of microplastic pollution warrant global efforts towards combating the problem of plastic pollution.

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