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REVIEW PAPER

Microplastics in Marine Ecosystems

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Abstract

Large plastic debris is broken down into smaller pieces by different mechanisms such as weathering, light degradation and biodegradation, eventually turning into microplastics (<5 mm). Microplastics can also enter the marine ecosystems directly via rivers, waste discharges, and the dumping of waste by the people. Marine organisms are directly and indirectly exposed to accidental feeding from microplastics. Microplastics, apart from the physical effects of being consumed by living organisms, can be a carrier of contaminants to be absorbed. Numerous studies have reported pollutants can be absorbed by microplastics and enriched in seas and oceans. Therefore, the study of the presence, distribution and accumulation of microplastics in aquatic ecosystems can create a comprehensive model in the integrated management of these emerging pollutants. In this study, the origin, fate and behavior of microplastics in marine ecosystems were examined to determine the sources of microplastics in these ecosystems and their effects on living organisms and trophic transmission.

Introduction

During the twentieth century, rapid industrialization and urbanization in coastal environments, along with the widespread production and use of synthetic materials in various applications (industrial, pharmaceutical, urban and commercial) has greatly expanded, leading to many environmental issues (Masoudi et al., 2022; Burcea et al., 2020; Ates et al., 2020; Danabas et al., 2020). Since the development of synthetic polymers in the mid-twentieth century, global production of plastics has increased significantly (Andrady, 2011; Derraik, 2002). Plastic waste has significant environmental and economic effects on marine systems. Low weight and high durability are two key useful properties for plastics that also turn waste plastics into an environmental threat. Plastics easily move long distances from contaminated areas and accumulate in cavities (mainly in the oceans), which have important environmental and economic effects (Thompson et al. 2009; UNEP 2005). Although studies on plastic pollution are mainly focused on marine systems, abandoned plastics also affect land and freshwater systems, including being eaten by animals, trapping animals, blocking drainage systems, and aesthetic effects (Ryan et al., 2009). These plastics accumulate in sediments along the shoreline in the tidal zone as well as in the pelagic zone, and in the bottom sediments (Browne et al., 2010; Thompson et al., 2009).

It is estimated that about 70 to 80% of the materials entering the marine environment are from land sources (Bowmer and Kershaw, 2010). In fact, plastic waste includes any type of disposable material resulting from human, industrial and plastic production activities that, regardless of its size and frequency, are found in the sea and beaches, and include indirect activities such as rivers. Streams, municipal wastewater treatment systems, floods, and winds that carry these substances into the sea or ocean (UNEP, 2005). Plastic waste has been reported extensively in marine environments around the world, even in places far from urban areas such as the Pacific islands (Moore et al., 2001). The main sources of plastic waste entering the ocean and affecting the marine environment are activities from urban areas including activities (industrial and human), boating, shipping, fishing and aquaculture. Materials are imported directly into the seas and oceans (Derraik, 2002; Ryan et al., 2009). Low weight, high strength, resistance to chemicals, flexibility, high buoyancy of foam and resin products and cost-effectiveness of plastics (Thompson et al., 2009) make them so-called essential materials for everyday life. Currently the most widely used synthetic plastics include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS) and polyethylene terephthalates (PET). In total, these plastics represent 90% of the total weight of plastics production in the world (Andrady and Neal, 2009).

Origin, fate and behavior of microplastics in the marine ecosystem

Plastics are materials made from a wide range of synthetic and semi-synthetic organic compounds that can be formed when soft and then become very hard or slightly flexible. The International Union of Pure and Applied Chemistry (IUPAC) define plastics as polymeric materials that may contain other materials to improve performance or reduce costs (Vert et al., 2012). The main feature of this material is reflected in the etymology of the word plastic: the word plastic is derived from the two Greek words plastikos (πλᾰστῐκός) meaning "malleable" and plastos (πλαστός) meaning "molded". Other characteristics may include: ease of construction, low cost, impermeability to water and chemicals, as well as resistance to light and temperature (da Costa et al., 2016). These properties have led to the replacement of many materials with plastics, and plastics are now available in a wide range of products, from paper clips to ships (Andrady and Neal, 2009). This success has manifested itself in a variety of forms, and also biodegradable plastics due to increasing ecosystem concerns (Reddy et al., 2013). Therefore, given these diverse applications and versatility, the latest detailed report on world plastic production shows an increase.

During the 20th century, rapid industrialization and urbanization in coastal environments, along with widespread production and use of plastics in multiple applications (industrial, pharmaceutical, urban, and commercial), have greatly expanded, leading to many environmental issues. Since the development of synthetic polymers in the mid-20th century, global production of plastics has increased significantly. In addition, world annual production of polyethylene (PE) and polypropylene (PP) (the most popular forms in the marine ecosystem) grew at a rate of 8.7% per year between 1950 and 2012 (Andrady, 2017). Plastics enter the environment in a disposed form, such as packaging materials, and accumulates in it. Plastic waste is estimated to account for approximately 10% of all municipal waste worldwide (Barnes et al., 2009). Although some of this plastic waste is recycled, most of it goes to landfills, where it may take many years to decompose (Cole et al., 2011). The main concerns are about plastics entering the marine environment, which is estimated to account for about 10% of all plastics produced (Thompson, 2006). This kind of plastic debris, known as macroplastics, has long been the focus of ecosystem studies, including in certain areas of the sea that tend to accumulate due to the convergence of surface currents (Eriksen et al., 2013) Although plastics are highly durable in the environment, their surface weathers and produces a myriad of micro- to nano-sized plastic parts. Plastics are classified in the industry as one of the five major groups of polymers, together with fibers, coatings, adhesives, and elastomers (Andrady, 2011; Koelmans et al., 2015; Song et al., 2017). Common types of plastics used are: polyvinyl chloride (PVC), nylon and polyethylene terephthalate (PET), which tend to sink, and polyethylene (PE), polypropylene (PP) and polystyrene (PS) which tend to float (Avio et al., 2017). Other polymers include polyvinyl alcohol (PVA), polyamide (PA), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), and resistant polystyrene (HIPS) (Avio et al., 2017).

Plastics are rarely picked for recycling (less than 5%) which results in their accumulation in the sea, thus large plastic debris can disintegrate into smaller pieces through various mechanisms such as: weathering (Arthur et al., 2009; Andrady, 2017), light degradation (Barnes et al., 2009), and biological decomposition (O'Brine and Thompson, 2010) and eventually become microplastics (< 5 mm) (Cole et al., 2011). Microplastics can also enter the sea directly via rivers, waste discharge, and the dumping of waste by people on the shore (Čulin and Bielić, 2016). Microplastics have been reported globally in the sea (Fok and Cheung, 2015; Isobe et al., 2017; La Daana et al., 2017). Marine organisms such as fishes (Lusher et al., 2017), marine birds (Amélineau et al., 2016), marine turtles (Tourinho et al., 2010), marine invertebrates (Davidson and Dudas, 2016), and marine mammals (Besseling et al., 2015), are exposed to random feeding of microplastics. Microplastics can absorb pollutants in marine areas and can act as a carrier for these pollutants to enter the marine food web (Reisser et al., 2014).

Sources of microplastics in the marine ecosystems

It is estimated up to 90% of plastic waste in the sea could be attributed to land activities (Duis and Coors, 2016). Human activities such as shipbuilding or ship recycling, industrial and urban cleaning, sewage, and tourist waste on shores may introduce microplastics (Čulin and Bielić, 2016). It is estimated that the amount of microplastics will increase significantly by 2025 (Jambeck et al., 2015). The remaining industrial and household microplastics are transported to the marine environment through wastewater or by natural events such as storms and floods. Another source of land-based microplastics is drugs, including swallowed and inhaled drugs. In these drugs, microplastics are used as drug carriers (Kockisch et al., 2003; Corbanie et al., 2006). Similar to personal hygiene products, microplastics in medicines enter the marine environment through wastewater (Cole et al., 2011). Another study has shown that atmospheric precipitation is probably another source of synthetic fibers in the marine environment, of which 29% are microplastic (Dris et al., 2016). The contribution from the rate of precipitation has been reported at sampling sites from 2 to 355 pieces per square meter per day. These fibers are thought to come from several sources, including clothing and homes, the degradation of macroplastics, and the disposal and incineration of waste (Dris et al., 2016). Due to their low weight, microplastics can be transported by wind to the marine environment (Free et al., 2014).

Ocean resources of microplastics

The remaining 10 to 25 percent of marine plastics are produced from oceanic sources. Human activities such as shipping, fishing, recreational equipment, and the marine industry introduce large amounts of microplastics into the marine environment (Ramirez-Llodra et al., 2013). Research by Good et al. (2010) shows that about 64,000 tons of fishing tackle are dumped into the ocean each year. This study shows that floating plastics, including microplastics, accumulate in ship transport routes close to fishing areas and ocean convergence areas (Cózar et al., 2014). Discarded and lost fishing gear (called ghost gear) can trap marine life. Some microplastics have irregular shapes, indicating that they are made of larger plastic pieces such as fibers (Ribic et al., 2010).

Microplastic separation based on density differences (Density Separation)

Usually, concentrated salt solution (NaCl) with a density of 1.2 g cm^3 and $ZnCl_2$ with a density of 1.8 g cm^3 and 2.4 g cm^3 are used to separate and classify plastic particles from sediment particles. The density of plastic particles is between 2.3-0.8 g cm^3 depending on the type of polymer and the production process, and the density of sand particles or sediments is 2.65 g cm^3. Concentrated salt solution (NaCl) is used to separate plastic particles with a density less than 2.1 g cm^3, and $ZnCl_2$ will be used to separate plastic particles with a density higher than 1.2 g cm^3 (Zakeri et al., 2020).

Filtration: Purification of plastic particles from the supernatant obtained from the separation method based on density difference is done by passing the solution containing plastic particles through a filter while applying vacuum.

Sieving: Microplastics from samples are separated using sieves with different mesh sizes. The use of sieves with different mesh sizes is used to classify microplastics in different categories.

Visual Sorting and Separation: Accurate sorting to separate plastics from other materials, such as organic contaminants (shell pieces, animal parts, dried algae or algae, etc.) and other items (colored coatings of metals, bitumen, glass, etc.) is done by directly examining the mixture with the naked eye or using a laboratory microscope.

Finally, the identification of microplastics will be completed using the "recovery of extracted samples" method. In this step, other materials that are attached to the surface of the extracted microplastics (such as sand and organic materials) are washed. There are different solvents for washing (H_2O_2 or one of NaOH, HCl or HNO_3) to break down the biological material on the surface of the plastic particles. The samples are immediately sorted and the microplastics are separated from the original sample, then separated microplastic are dried and stored in a dark environment with a controlled temperature (constant room temperature) to reduce degradation during storage (Gholizadeh and Cera, 2022).

Effects on living organisms

Microplastics and macroplastics enter the body of marine organisms in different ways. A recent study reported that about 700 marine species consumed microplastics and macroplastics (Gholizadeh and Cera, 2022; Abarghouei et al., 2021; Bagheri et al., 2020; Provencher et al., 2017). Due to the large presence and small size of microplastics, both pelagic (surface) organisms and benthic organisms (benthic) feed on them (Rummel et al., 2016). The physical effects of eating microplastics have been widely reported, including internal and external rupture and damage to the gastrointestinal tract, leading to false satiety, physical deterioration, and malnutrition. Lazar and Gračan, 2011, Van Franeker et al., 2011, Bråte et al., 2016; Rummel et al., 2016). Obstruction of the gastrointestinal tract leads to false satiety, which in turn leads to effects such as: reduced reproduction, drowning, reduced predation avoidance, malnutrition and death. There is also the possibility of adsorption and accumulation of potentially toxic compounds in plastic particles and their transfer from seawater to living organisms (Gregory, 2009). Such side effects can also occur in smaller marine organisms (Besseling et al., 2012).

Trophic transmission

Zooplankton is known as a key marine species for energy, they are widely hunted by fish and other marine life. However, the effects of microplastics transmitted to other living organisms through zooplankton are still unclear. A study by Setälä et al. (2014) showed that microplastics could be transferred from a lower trophic pathway (mesoplankton) to a higher trophic pathway (macroplankton) through planktonic organisms. In addition, according to a study by Murray and Cowie (2011), microplastics can be transmitted from a microplastic-contaminated prey to a predator (in this case, polypropylene filaments contained by the fish into the lobster that feed on the fish); this indicates these omnivorous organisms can be exposed to microplastics through inactive ingestion of sediments or trophic level. Farrell and Nelson, (2013) recorded the transfer of spheres from oysters and their accumulation in gastric, hepatopancreatic, ovarian, and gill tissue samples. In nature, trophic transmission of microplastics may be increased due to this fact that prey or predator can be exposed to a wide variety of microplastics as well as different concentrations during their lifetime.

Fishes

Presence of microplastics is widely reported in fishes in the Mediterranean (Alomar and Deudero, 2017), Atlantic Sea (Lusher et al., 2015), North and Baltic Seas (Lenz et al., 2016; Rummel et al., 2016), the Aegean and Mediterranean Seas (Yabanlı at al., 2019), Marmara Sea in Turkey (Çullu et al., 2021), Erzurum in Turkey (Çomaklı et al., 2020) and European coasts (Neves et al., 2015; Bråte et al., 2016). Malnutrition, starvation and declining fish populations are potential long-term consequences of the presence of microplastics in the gastrointestinal tract of fish (Boerger et al., 2010; Cole et al., 2011). The presence of different microplastics in fish can be attributed to their feeding behaviors (Rummel et al., 2016). Non-selective scavenger fish, such as mackerel, may consume more microplastics than other fish. Mackerel are most affected because of their nutrient habitat, which is mainly located in the Plagia area and upper sea level, where floating and neutral floating microplastic particles are likely to be more available for consumption (Lusher et al., 2013). Mackerels also rely on their eyesight for nutrition, and they choose prey based on their color or shape, so the variety of colors and shapes of microplastics can confuse them (Nøttestad et al., 2015). de Sá et al. (2015) reported that common young globes (Pomatoschistus microps) used microplastics instead of natural prey. Eating microplastics significantly reduces the ability to hunt and affect prey selection. In vitro, the mortality rate of fish that consumed microplastics was significantly higher than control fish (Mazurais et al., 2015). In addition, the color of microplastics is also involved in their consumption as food by fish. Numerous studies have shown that epipelagic and mesopelagic fishes are more likely to consume microplastics during natural feeding activities because the microplastics and their prey are the same color (Boerger et al., 2010; Lusher et al., 2013).

Conclusion

The aim of current study was to survey the bioaccumulation of MPs by aquatic species in the marine environment. Also, the relationships between MPs and different habitats of marine species were examined. The level of MPs was compared in marine species from different ecosystems in the land and sea environments. Finally, since the origin, fate and behavior of microplastics in various marine ecosystems is different, this means that the sources of microplastics in these ecosystems could have significant effects on living organisms and trophic transmission.

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