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A REVIEW: MICROPLASTIC IN AQUATIC ECOSYSTEM SOURCE, IMPACT AND MITIGATION STRATEGIES

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Abstract

Plastics are essential to contemporary life, yet because of their persistence, they are a significant environmental pollution, and microplastics (MPs, <5 mm) are particularly problematic in aquatic systems. This paper summarizes the state of the art on MPs' origins, kinds, effects, and mitigation techniques. MPs are mostly released into aquatic habitats via land based sources, including landfill leaks, personal care products, and improperly handled plastic debris. MPs can be categorized as primary, which are purposefully produced (such as fibers, pellets, or microbeads), or secondary, which are created when bigger plastics break down. Pollutants like as organic chemicals, microbial populations, and heavy metals can be absorbed and transported by them due to their large surface area and hydrophobicity. In terms of ecology, MPs impair eating, growth, reproduction, and survival across species by causing mechanical injury through ingestion and entanglement. Additionally, particle size and form affect toxicity; fibers have effects on organisms that are very long-lasting. Consuming fish exposes humans to the chemical mostly, which raises questions regarding bioaccumulation, tissue transfer, and possible long-term health hazards. Invasive species and illnesses are also spread by MPs, which changes the dynamics of aquatic microbes and the way ecosystems function. Mitigation necessitates all-encompassing approaches that incorporate breakthroughs like waste-to-energy technology, biodegradable materials, and upcycling using the 4R framework: reduce, reuse, recycle, and recover. Upcycling and recycling have potential, but their widespread use is constrained by technological and financial issues. According to available data, reducing plastic inputs urgently requires coordinated policy, viable alternatives, and public

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involvement. Filling up the information gaps about the impacts of Microplastic contamination on the environment and human health is crucial to creating practical worldwide solutions.

INTRODUCTION

Synthetic polymers known as plastics are widely employed in many aspects of contemporary life, including consumer goods, building, packaging, and home goods. (Andrady & Neal, 2009). However, because of human-caused environmental contamination, plastics have emerged as a major worldwide environmental concern. In the past 10 years, the pervasiveness of plastics on land, in the water, and along coastlines has been extensively documented (Barnes et al., 2009). Between 1950 and 2014, the yearly manufacturing of plastics surged 200-fold, indicating that the trend is intensifying (Li et al., 2016), Thus, 400.3 million tons of plastic will be produced worldwide in 2022 (Kum et al., 2025). Plastics are carried by water currents and are persistent in marine ecosystems (Kum et al., 2025). Consequently, plastic pollution is becoming a major issue in every ocean basin. (Thushari & Senevirathna, 2020). Plastics are commonly classified into nano-, meso-, macro-, and mega-sized categories. Particles less than 5 mm in diameter are sometimes referred to as microplastics (Arthur et al., 2009). Oceans, lakes, seas, rivers, coastal areas, and even the Polar Regions have all been significantly influenced by the presence of microplastics in the marine environment, which is a serious danger to the entire ecosystem (Auta et al., 2017). Human activities are putting an increasing amount of strain on coastal and marine environments (Auta et al., 2017). Between 80 and 85 percent of marine litter is made of plastic (Auta et al., 2017) . Plastic manufacturing has grown dramatically over the past few decades, from 1.7 million tonnes in the 1950s to 299 million tonnes in 2014, and it became the fastest-growing sector of the municipal trash stream between 1950 and 2003 (Auta et al., 2017).

2. Sources of Microplastic

The primary land-based sources of their introduction into the marine environment include mishandled or lost plastics, the disposal of plastic trash, and poorly maintained landfills, such as those without a fence around them or with no suitable synthetic material to cover wastes (Duis & Coors, 2016). The public's attention has recently been drawn to microplastic particles found in personal care products, mostly due to news media reporting (Duis & Coors, 2016). Thus, the role of microplastics from personal care products which the EU defines and regulates as cosmetics is specifically highlighted (Buzek, 2009), to the general environmental contamination caused by microplastics (Duis & Coors, 2016).

3. Global prevalence of microplastic

Region / Country	Sample Type	Average Concentration
Malaysia	Seawater	1,200 particles/m^3
China	River water	850 particles/m^3
India	Coastal sediment	450 particles/kg
Indonesia	Fish tissue	3–15 particles/fish

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4. Types of Microplastic

4.1 Primary Microplastic

Primary microplastics are plastic particles that are intentionally manufactured to be microscopic in size, typically less than 5 mm in diameter before entering the environment (Andrady, 2011). Unlike secondary microplastics, which result from the breakdown of larger plastic debris, primary microplastics are produced in small dimensions for direct use in various industrial and consumer applications (Cole et al., 2011). Common examples include microbeads used in personal care products, resin pellets (nurdles) that serve as raw materials in plastic manufacturing, synthetic fibers from textiles, and micro-abrasives employed in industrial cleaning (Napper, 2018). Microplastics are purposefully made for a variety of uses in medications, toiletries, cosmetics, etc. The following are some of the several kinds of primary microplastic: Synthetic fibers, plastic pellets, and microbeads (Mathew et al., 2024).

4.2 Secondary Microplastic

Secondary microplastics are plastic particles that originate from the fragmentation or degradation of larger plastic debris such as bottles, bags, fishing nets, and packaging materials due to physical, chemical, and biological processes (Andrady, 2011). These particles are not intentionally manufactured in microscopic form; instead, they are produced through mechanical abrasion, UV radiation, thermal oxidation, and microbial degradation acting over time on larger plastics in the environment (Auta et al., 2017). Fragmented plastics, weathered plastics, degraded plastic films, paint and coatings, and tire wear particles are examples of secondary microplastics, a subgroup of microplastics that are produced over time as a result of the deterioration and fragmentation of larger plastic objects (Mathew et al., 2024).

5. Effects of Microplastic

5.1 Ecological Impacts on Aquatic Ecosystem

Because of their high specific surface area and effective adsorption, MPs have been shown to be a crucial transporter for chemicals and bacteria that can seriously endanger aquatic biota and even the environment. MPs are known to be pollution vectors and have strong hydrophobicity. Numerous investigations on the relationship between MPs and other contaminants have been conducted in recent years (Yuan et al., 2020). Some heavy metals and hydrophobic chemicals from the environment are among the two primary types of pollutants that MPs carry: monomers, additives, and other byproducts that are present in MPs (Yuan et al., 2020).

5.2 Effects on Aquatic Biota

MPs' effects on living things may be separated into two categories: physical and chemical. When MPs debris entangles and swallows aquatic species, it can directly affect their mechanical health (Wang et al., 2018). Following swallowing, the debris will provide a false impression of fullness, which may impact appetite and perhaps result in intestinal obstruction or injury to the digestive system (Wang et al., 2018). In creatures' digestive tracts, MPs gather, and smaller particles may even penetrate and remain in the circulatory system. (Yang et al., 2018). Size influences how MPs build up inside the organism, which in turn influences how living things grow and reproduce. Jeong et al. investigated the negative impacts and aggregation effect of varying MP sizes in rotifers (Jeong et al., 2016). The findings demonstrated that organisms could more readily absorb and collect MPs particles of smaller sizes, which decreased the organisms' growth rate, fecundity, and lifespan (Jeong et al., 2016). According to study by other scientists, MPs can pierce intestinal epithelium into biological tissue, inflicting more harm to organisms (Bouwmeester et al., 2015). MPs come in a variety of forms, including spheres, threads, and pieces, and their

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effects on organisms vary depending on their shape. It was discovered that the fiber morphology was the most harmful to adult T. monodon among these forms (Gray & Weinstein, 2017). Additionally, studies have shown that because fibers cannot be fully eliminated, they are more likely to become entangled in the gut and eventually cause an organism's death if they are retained in the body for an extended period of time (Gray & Weinstein, 2017). More often than spherical or other MP types, fibrous MPs tend to collect in oysters (Jahan et al., 2019). Because it is easier to retain and less excreted, organisms may suffer harm to their gastrointestinal systems or die from digestive tract obstruction (Ma et al., 2019).

6 Human Health Implication

6.1 Entry into Food Chain

Over 800 animal species were found to have been polluted by plastic by ingestion or entanglement in a 2016 UN analysis, which is 69% more than the number found in a 1977 review that estimated just 247 impacted species (Murray & Cowie, 2011). 220 of these 800 species have been discovered to naturally consume microplastic waste (Smith et al., 2018). Several species and trophic levels, including fish, invertebrates, marine mammals, and fish-eating birds, consume plastic (Gall & Thompson, 2015). When dissecting carcasses and doing laboratory studies, plastic particles are sometimes discovered accumulated in the digestive track of an organism. Animals' bodies may retain micro- and nanoplastics, which favor smaller particles (Murray & Cowie, 2011), and move to the surrounding tissue or circulatory system from the digestive tract (Lusher et al., 2017).

Due to their tiny size, a diverse range of marine creatures can consume microplastics. Direct or indirect ingestion through trophic transfer is possible (e.g., up the food web). It has been reported that planktonic creatures and larvae at the base of the food chain consume microplastics (Cole et al., 2013), in small and large invertebrates (Thompson et al., 2004) and in fish (Lusher et al., 2017). The predatory Crucian carps were found to exhibit trophic transmission of microplastics (Cedervall et al., 2015). Because plastic particles are frequently concentrated in an organism's digestive tract, eating entire bivalves and tiny fish increases the likelihood that humans may be exposed to microplastics (Cedervall et al., 2015).

7. Microplastic as Vector of Contaminants

Biological pollutants may be carried great distances by hydrological forcing such winds and currents; mollusks, crabs, and bryozoans have been observed rafting on floating debris in the open ocean (Kiessling et al., 2015). Rafting dispersal can encourage the spread of invasive species, especially given the massive volume of trash and the extreme permanence of plastic items in the world's seas. There is still much to learn about the interactions between plastic particles and aquatic microbiota in smaller size ranges, especially in light of the possible harm that microplastics may cause to microbial structure and metabolism (Caruso et al., 2018). It is true that plastic waste may encourage adherence and colonization by microorganisms that produce biofilms and act as pioneering surface colonizers (Lobelle & Cunliffe, 2011) The dispersion and bioavailability of microplastics may be impacted by variations in particle density brought on by the process of biofilm growth on their surface (Kaiser et al., 2017), have concentrated on this subject and shown that biofouling alters microplastics' buoyancy, favoring their sinking to sediments, especially in marine settings (Caruso, 2019). It has been recommended that empirical data be gathered on size-specific fouling rates and the resulting variations in litter density (Ryan, 2015). Conversely, after biofouling, plastics that were formerly positively buoyant may turn negatively buoyant and sink to the seabed, where they would accumulate into sediments (Woodall et al., 2014).

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8. Strategies for Effective Management of Plastics

To reduce the amount of plastics entering the environment and their fragmentation into MP, it is essential to handle plastic trash effectively (Wu et al., 2017). An effective strategy for managing plastic trash is to combine upcycling techniques with the 4Rs: "Reduce," "Reuse," "Recycle," and "Recover'(Solis & Silveira, 2020). Reducing total plastic waste creation is one of the best strategies to stop MPs from being produced. This may be achieved by using less plastic, switching to biodegradable materials, improving product design, and encouraging recycling and reuse (Walker, 2018). It can also be beneficial to use environmentally friendly substitutes like bioplastics, stay away from superfluous packaging, and use less microbeads, which are the main source of MPs (Hunt et al., 2021). Another tactic to cut down on plastic waste is to reuse plastics (Nafea et al., 2024). Just 20% of single-use plastics can be replaced with reusable ones, creating a $10 billion potential (Lendal & Wingstrand, 2019). About half of the 5 million tons of plastic generated annually in the UK are used for packaging, making it a significant user of single-use plastics and a source of plastic trash (Smith, 2025). Reusable packaging is therefore essential to reducing plastic pollution. Businesses may save expenses, increase customer loyalty through deposits and incentive programs, and adjust to the needs of each person by implementing reuse models (Lendal & Wingstrand, 2019). Using reusable packaging, as demonstrated by the largest dairy firm in Austria, Berglandmilch, may save packaging costs and enhance sales and profits by replacing eleven single-use bottles. The reuse approach has been quite successful, mostly because of public opinion and financial incentives (Eriksen et al., 2018). However, recycling is required to lessen the amount of plastic trash in the environment in industries that prioritize hygienic and health regulations as well as a desire for new packaging materials (Nafea et al., 2024).

Recycling benefits society and the environment by lowering emissions and conserving energy and resources (Prata et al., 2019). About 130 million kJ of energy may be saved by recycling one ton of plastic garbage (Garcia & Robertson, 2017). Because of the current recycling process's high costs and limited efficiency, fewer than 9% of all plastic garbage gets recycled (Nafea et al., 2024). For consumers or centers to separate plastics before they are treated further through mechanical or chemical recycling, the trash collecting step is essential (Nafea et al., 2024). Even though mechanical recycling is frequently used, the recycled plastic's quality is inferior to the original, eventually making it unsuitable for recycling (Jeswani et al., 2021). Although chemical recycling is a novel method that disassembles polymers into their component molecular components before reassembling them into their original materials, it is not frequently employed for extensive recycling (Rizos et al., 2023). Upcycling, which highlights the identification of inherent value in plastic trash, is thus developed as an extra and more appealing choice to get over the problems with recycling methods (Rorrer et al., 2019). The phrases "recycling" and "upcycling" have been used interchangeably in various publications since many upcycling techniques are developed based on recycling techniques and some routes may overlap (Nafea et al., 2024).

However, the effectiveness of upcycling in decreasing environmental plastic and microplastics depends on a number of factors, including the scalability of upcycling processes, the quality and market demand for upcycled items, and the energy and resources necessary for the upcycling process (Rorrer et al., 2019). Therefore, plastics can be utilized as feedstock for energy recovery when it is not viable to reuse, recycle, or upcycle plastic goods. Fuels similar to gasoline may be produced from polymers through chemical methods like pyrolysis or cracking (Thahir et al., 2019). Other choices for complete energy recovery and waste reduction

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include oxidation to create heat, steam, or electricity (Chow et al., 2021).

9. Conclusion

A major threat to human health, food webs, and biodiversity, microplastics are becoming a common contaminant in aquatic environments. Their ecological effect is increased by their tenacity and capacity to serve as carriers of viruses and hazardous chemicals. To achieve effective mitigation, the 4R concept must be applied in conjunction with better waste management, biodegradable substitutes, and creative recycling or upcycling techniques. But a lot of information is still lacking, especially when it comes to long-term health impacts and ecosystem-level repercussions. To protect marine habitats and human health, addressing microplastic contamination requires concerted international effort, more robust regulations, and public involvement.

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