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# Living in the Plastizoic Era: A Review of Microplastic Pollution in Aquatic Ecosystems

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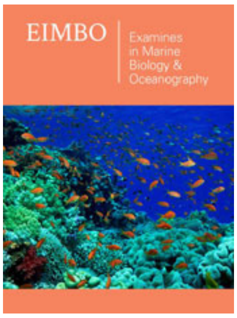


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## Abstract

The mid-20th century witnessed an exponential rise in industrialization world-wide, resulting in widespread plastic product pollution. Microplastic (MP) have garnered significant attention due to their persistence and negative ecological consequences. Here, we review the current state of microplastic pollution research in aquatic ecosystems, highlighting the need for a comprehensive understanding of their impacts. A literature review was conducted using a science database up to the year 2023, identifying 200 manuscripts related to the topic. Data were categorized based on the year of publication, continent, taxonomic domain, type of sample, and the classification of MP to understand research trends and biases in geographical and taxonomic scopes. The analysis revealed a consistent increase in microplastic research publications until 2020, followed by a decline in the two subsequent years. The decline in research publications post-2020 underscores the broader impact of external factors, such as the COVID-19 pandemic, on scientific output. The Europe continent emerged as the leading research region. Most studies predominantly focus on eukaryotic organisms, particularly the Kingdom Animalia, with taxonomic emphasis on Arthropoda and fish. The taxonomic focus on eukaryotic organisms, especially within Kingdom Animalia, may limit a comprehensive understanding of the ecological impact of MP. Hence, these studies primarily concentrated on physical characterization, with marine environments receiving the highest attention. Methodological biases toward water samples, marine environments, and physical characterization suggest a need for more balanced research approaches. This comprehensive review analysis highlights the dynamic trajectory of MP research, emphasizing the importance of global collaboration, balanced taxonomic representation, and the need for increased emphasis on freshwater ecosystems.

**Keywords:** Microplastics; Aquatic pollution; Freshwaters; Review; Life domains

## Introduction

Since the mid-20th century, global plastic production has reached several million tons annually, surpassing an annual output of over two hundred million tons of anthropogenic debris [1,2]. This pervasive form of pollution is widespread and enduring in the Earth's oceans, openly endangering marine life [3]. Mechanical forces and intense weathering contribute to the fragmentation of larger plastic pieces into small particles known as microplastics [4-6]. Microplastics (MP), defined as plastic particles smaller than 5mm, have gained increasing attention as a significant environmental challenge in recent years [7,8]. The ubiquity of MP results from their occurrence in a variety of products ranging from personal care items to textiles, leading to their release into aquatic and terrestrial ecosystems [9]. Their small size and durability contribute to the high persistence in the environment [10].

Plastic waste exhibits a hierarchical classification based on dimensions, delineating macroplastics (>5mm), mesoplastics (5mm to 20cm), microplastics (<5mm), and nanoplastics (<0.1µm) [11]. The classification of MP is typically based on their size and origin, ranging from 1 micrometer to 5 millimeters in diameter [12]. The MP are generally categorized into two groups: primary and secondary [13]. Primary MP, intentionally manufactured at a small scale, include items such as microbeads in cosmetics and microfibers released from synthetic textiles. Secondary MP result from the breakdown of larger plastic items, such as bottles and bags, through weathering and degradation processes [14]. Additionally, the MP are also classified based on their form or shape, including fragments, fibers, filaments, spheres, or films, among other categories [15,16] (Figure 1). Understanding these classifications is essential for studying the environmental impacts of MP, which have pervasive pollutants in aquatic and terrestrial ecosystems, representing potential threats to wildlife ecosystems [17,18]. The occurrence of plastic, particularly in the form of MPs, in both marine and freshwater environments is a growing ecological issue that has gained significant scientific attention [19]. The small size of MP allows for ingestion by aquatic organisms across different trophic levels and with diverse feeding strategies, enabling MP to become integrated into the food webs and accumulate within upper trophic tiers [20].

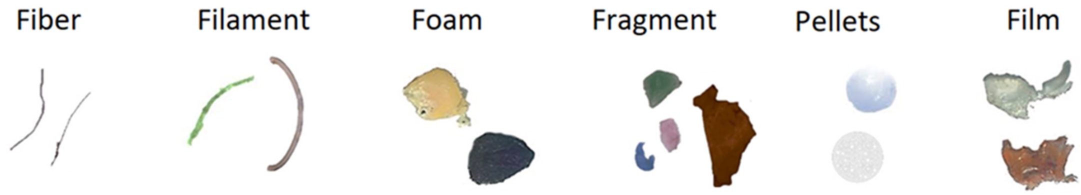


**Figure 1:** Classification of microplastics into six shape-based categories.

The first scientists to draw attention to the occurrence of plastic pellets on the surface of the North Atlantic Ocean did so in 1972, and only a few months later, the ingestion of polyethylene pellets by fish was documented [21]. Subsequent studies have demonstrated that MP can enter ecosystems such as oceans, rivers, and lakes through different pathways such as rivers, ocean currents, and wind over great distances, reaching remote places and deep waters [22]. It is known that nearly 700 aquatic species worldwide have suffered detrimental effects due to the introduction of MP, impacting species such as crustaceans, sea turtles, and penguins among many others [23].

Microplastic particles can be ingested by aquatic organisms, leading to potential bioaccumulation and biomagnification of toxic compounds associated with plastics [24]. Acting as carriers for other pollutants, MP further amplify their potential harm. Studies have found that exposure to MP can result in adverse physiological, behavioral, and reproductive effects [25,26]. These effects, ranging from altered feeding behavior to reproductive impairment, can have cascading impacts on entire ecosystems [27,28]. Thus, short, and long-term exposure to environmental stressors and pollutants such as MP can also impact the gut microbiota, leading to dysbiosis and negative effects on their health [29,30]. The aquatic environment emerged as a severely affected region by MP pollution [31]. Therefore, MPs pollution is considered a prominent topic in ecology due to its adverse consequences on aquatic and terrestrial ecosystems. The objectives of this study were to first, compare the scientific efforts by regions, years, and taxonomic domain, and second, to analyze what were the main targets of these studies. This information will be valuable in expanding our comprehension of MP in aquatic ecosystems and guiding future research.

## Materials and Methods

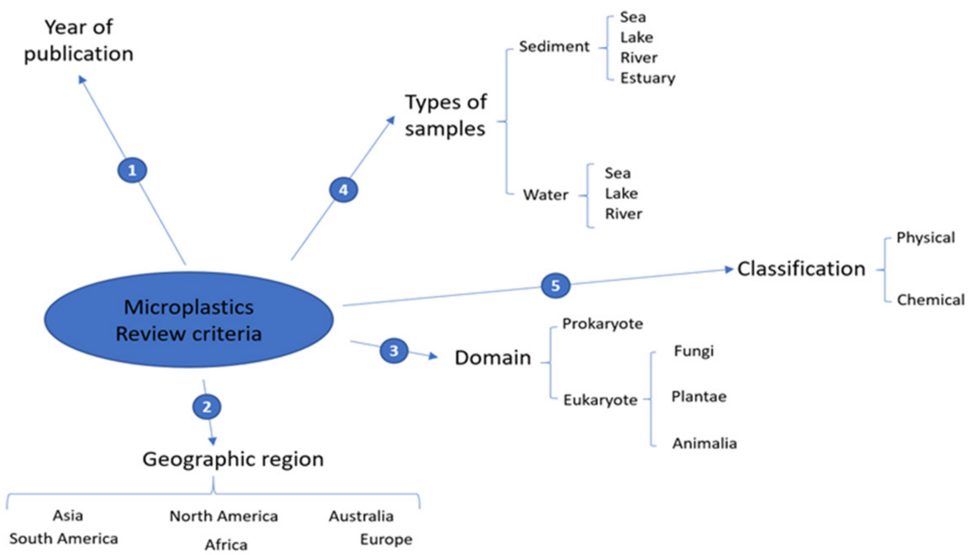


**Figure 2:** Categories used during the literature review process to classify microplastic studies.

A comprehensive literature review was conducted using the Web of Science (WoS) database up to 2023. The advanced search mode retrieved a total of 200 peer-reviewed manuscripts that match the theme of microplastics in aquatic ecosystems. The search focused on the subjects of: 'Microplastic' or 'Microplastic' and 'Aquatic' and 'Marine'. The gathered information was classified the information into categories such as Year, Continent, Taxonomic Domain, Type of Sample, and type of MPs characterization. The Type of Sample category was further divided into water or sediment samples, and the water category was sub-divided into sea, river, lake, estuary, cloud water or snow (Figure 2).

## Result

The number of studies focused on the characterization of Microplastics (MP) in aquatic systems over the years revealed a consistent annual increase in the total number of manuscripts between 2010 and 2018, peaking at 29 publications in 2020. However, a noticeable shift-point occurred in 2021, with a decline to 18 publications. This negative trend continued in 2022 and 2023, with 12 publications each year (Figure 3). An examination of the distribution of publications across geographic regions revealed that the Europe continent emerged as a research powerhouse, consistently leading with an annual average of 6 publications. North America and Asia closely followed, contributing 2 to 4 publications annually; whereas South America, Africa, and Australia exhibited a lower overall contribution, and remained a consistent participant with an average 1.5 publications per year.

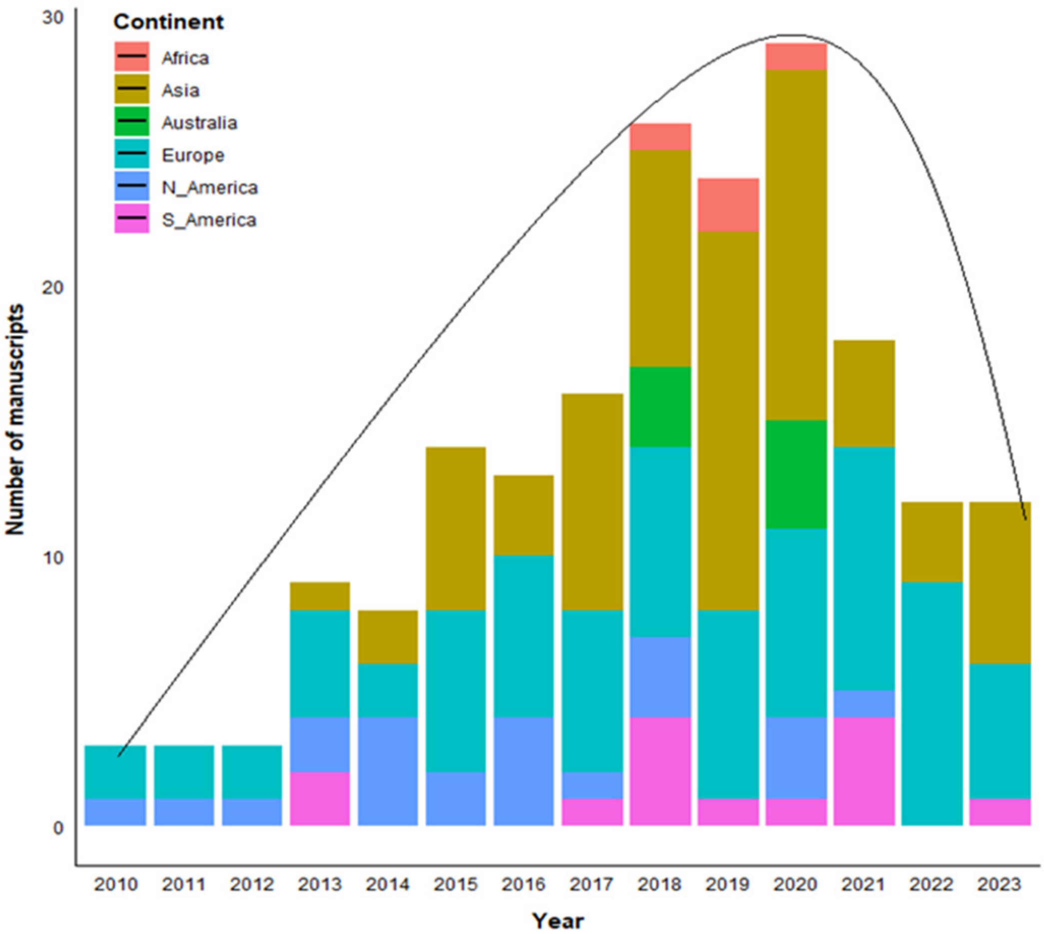


**Figure 3:** Number of published manuscripts by geographic regions through time.

A domain life analysis revealed that the majority of studies related to MP in aquatic ecosystems focus on eukaryotic organisms with 107 published manuscripts, as opposed to 9 manuscripts in prokaryotic organisms. Within manuscript addressing eukaryote, a further classification into specific kingdoms, results revealed a total of 94 manuscripts attributed to Kingdom *Animalia*, and 11 to the Kingdom *Plantae*, while Fungi and Unicellular eukaryotes were less represented with only 1 manuscript published in each group. These data offer insights into the distribution of manuscripts across different kingdoms within both prokaryotic and eukaryotic domains (Figure 4A). The analysis within Kingdom *Animalia* revealed that *Phylum Arthropoda* stands out as the most studied group, with 35 studies, followed by the fish Clade with 32 publications. *Phylum Mollusca* also exhibited a substantial presence, contributing 18 manuscripts, whereas *Phyla Cnidaria* and *Echinodermata*, and the classes *Aves* and *Mammalia* had a lower representation. The less represented clade was the Class Reptilia with only 1 manuscript (Figure 4B).


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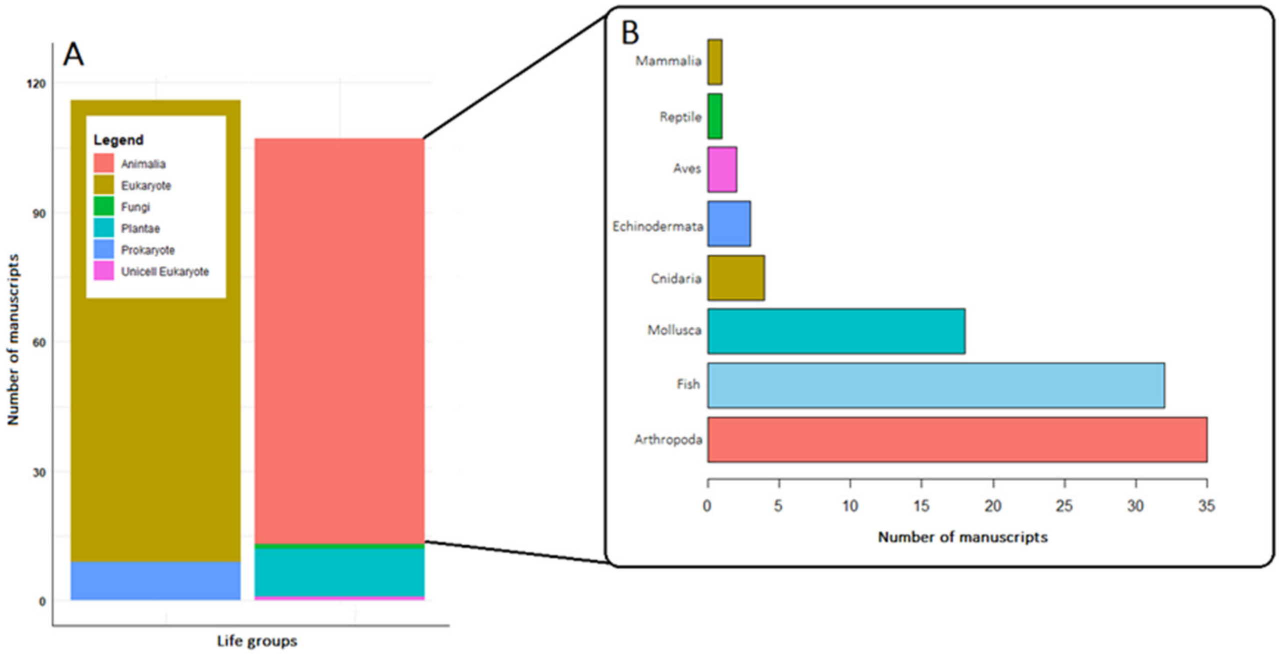


**Figure 4:** Overall number of manuscripts by life groups from data between 2010 to 2023. Panel A represents the number of manuscripts by Domains (first column) and by kingdoms (second column). Panel B represents the number of manuscripts within the Kingdom Animalia.

Studies focusing on the characterization of MP in water rather than in sediment samples showed that from a total number of 200 manuscripts analyzed, 164 studies analyzed the occurrence of MP in both water and sediments. However, 79.3% of manuscripts focused on water samples, while only 20.7% analyzed MP in sediment samples. Most studies on MP concentrated on the sea, followed by studies in rivers, while lakes and estuaries received less attention, accounting for only 6.15% of the publications between 2010 and 2023 within water samples. Additionally, studies with sediment samples showed a pattern similar to that observed in studies with water samples, with marine samples being the most commonly studied environment once again, and estuaries being the least explored (Figure 5). Microplastic samples are typically characterized both physically and chemically. Results from 2010 to 2023 reveal that physical characterization takes the lead, comprising 64.8% of the studies and emphasizing the physical attributes of MP particles, while chemical characterization constitutes 11.5% of the total number of publications. Studies that integrate both chemical and physical characterization account for 45.7%. A few studies that did not focus on the characterization of MP, or the characterization method was not explicitly specified, representing 7.8% of the publications.

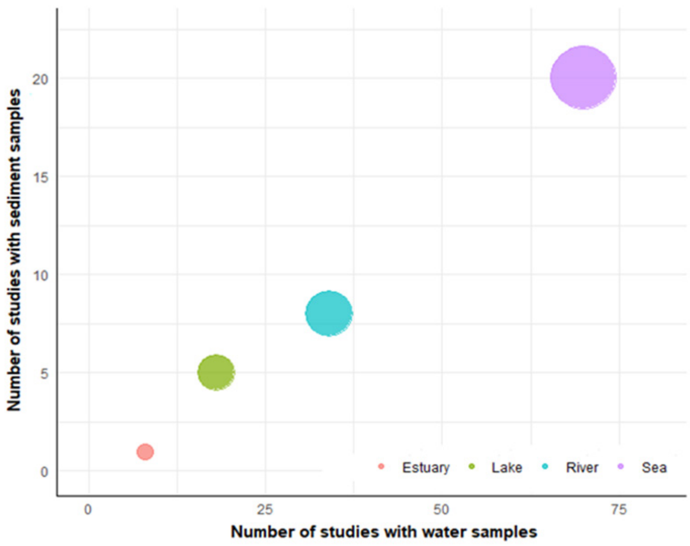


**Figure 5:** Number of microplastic research carried out on water and sediment samples between 2010 to 2023.


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## Discussion

### Temporal trends and regional disparities

The trajectory of microplastic research in aquatic ecosystems has witnessed notable shifts, as evidenced by the publication trends observed until 2023. The steady increase in studies characterizing microplastics from 2010 to 2018, peaking at 29 publications in 2020, reflects the growing recognition of the importance of this hot topic for aquatic ecosystems [32-34]. However, the subsequent decline in 2021 and the continued decrease in 2022 and 2023 raise questions about the factors influencing this downturn. The most likely cause of this decline is attributed to the impact of the COVID-19 pandemic. Meta-research gathering publications in peer-reviewed journals have shown that the rise of the COVID-19 was accompanied by a substantial decrease of published research [35,36]. The fluctuations in research output indicate the need for resilience in the face of unforeseen challenges and the importance of adapting research strategies to global circumstances. The regional distribution of research across geographic regions reveals Europe consistently leading in the annual average of publications. Following closely are North America and Asia, contributing two to four publications annually. In contrast, South America, Africa, and Australia exhibit a lower overall contribution [37,38]. The dominance of Europe could be related to a robust research infrastructure, more funding, and a well-established collaborative culture. Notably, questions arise about the challenges and opportunities faced by regions with lower publication rates, such as South America, Africa, and Australia. Our results underscore the potential impact on global knowledge distribution, suggesting prompt consideration of how increased international collaboration, policy adjustments, and technological advancements could mitigate disparities and foster a more equitable global research panorama [39,40]. Examining the role of cultural and societal factors in shaping research productivity will provide insights into the nuanced dynamics influencing current regional disparities.

### Taxonomic focus and ecological implications

While the oceans constitute the vast majority of the Earth's surface, our understanding of marine biodiversity lags significantly behind that of terrestrial systems [41]. The accumulation of plastic in the environment, has resulted in adverse effects on aquatic ecosystems and the associated fauna [42] An examination of taxonomic and ecological dimensions in microplastic studies emphasizes a concentration on eukaryotic organisms, particularly within Kingdom Animalia. The preeminence of Arthropoda and fish in research [43,44] (Griffith et al. 2023) reflects the practical challenges associated with studying smaller organisms and the potential biases in sampling methods. The overarching emphasis on eukaryotic multicellular organisms, especially within the animal kingdom, may skew our understanding of the broader ecological picture. However, floating microplastic fragments can host a diverse fauna of encrusting small organisms, such as, fungi, parasites, bacteria, diatoms, and other small organisms. For example, the occurrence of Vibrio inhabiting microplastic particles was recently discovered a genus of bacteria that can potentially cause human health problems [45]. Parasites can exploit microplastics as a means of transportation, as demonstrated in recent research where three parasites: Toxoplasma gondii, Cryptosporidium parvum, and Giardia enterica. These species could effectively attach to microplastics [46]. This finding represents a serious concern for humans, but also for the wild fauna.

### Methodological imbalances in microplastic research

This study emphasizes a significant bias towards research on microplastics in water samples, with 79.3% of manuscripts concentrating on water compared to only 20.7% on sediment samples. Furthermore, within water samples, most of the studies with microplastic were skewed towards marine environments, leaving estuaries, lakes, and rivers relatively understudied [47-49]. This bias raises questions about the comprehensiveness of our understanding of microplastic distribution across diverse ecosystems and calls for a more balanced research approach. On the other hand, methodological approaches in microplastic research have predominantly focused on physical and chemical characterization. The prevalence of physical characterization, comprising 64.8% of studies, may indicate a bias towards morphological aspects. Chemical characterization, although providing essential insights into composition and potential toxicity, constitutes only 11.5% of the total publications. The integration of both methods in 45.7% of studies will be highly effective for a holistic understanding [50].

In contrast to marine environments, there has been comparatively less research into the concentration of microplastics in freshwater environments [4,37,51,52]. Studies focused on microplastic pollution have predominantly centered on marine ecosystems, leaving freshwater ecosystems relatively understudied [53]. This knowledge gap is noteworthy as freshwater environments, including rivers, lakes, and streams, play a crucial role in supporting biodiversity and serving as primary sources of drinking water for human populations [54,55]. Addressing this disparity in research attention is essential for gaining a comprehensive understanding of the distribution and potential ecological implications of microplastics, as well as for formulating effective strategies to mitigate their impact on freshwater ecosystems [56,57].

## Conclusion

This comprehensive analysis of MP literature review has helped us see the field's evolution, regional disparities, and areas of concentration. As the global scientific community addresses the complex challenges raised by MP pollution, this critical examination provides a roadmap for future research priorities, emphasizing the importance of global collaboration, and a more balanced research effort of MP impact on different life groups. To enhance our understanding of microplastic distribution across diverse ecosystems, it is imperative to explore understudied environments, integrate chemical characterization methods, and foster a more inclusive research agenda that addresses the ecological implications beyond marine environments. It is crucial to adopt a global perspective while implementing initiatives to mitigate environmental risks from plastic pollution in the "Plastizoic Era". A comprehensive strategy that combines legislative measures with the enhancement of ecological awareness through

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educational programs is likely the optimal solution for resolving these environmental challenges. Both the public and the scientific community share responsibility to advocate for shifts in the attitudes of governments and businesses toward MP pollution. It is unequivocal that immediate attention is required to address environmental hazards impacting ocean biodiversity, particularly the urgent matter of plastic debris pollution. Combatting the pervasive threat of MP pollution demands a concerted effort employing diverse technical measures. Enhanced filtration systems deployed within wastewater treatment plants can effectively intercept MP before they infiltrate water bodies. Concurrently, fostering the development and adoption of biodegradable plastics and alternative materials could mitigate the persistence of MP waste in the environment. New technologies will hold promise for targeted removal and degradation of MP from aquatic ecosystems, contributing to cleaner water sources. Strengthening waste management infrastructure to optimize recycling, collection, and disposal processes will be essential for minimizing MP leakage into aquatic ecosystems, thereby mitigating the detrimental impacts of MP pollution on the environment and human health.

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