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Review

Occurrence, Bioaccumulation, and Risk Assessment of Microplastics in the Aquatic Environment: A Review

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Abstract: Microplastics (MPs) are emerging as environmental pollutants and are widely distributed in aquatic environments. They are characterized by long life cycles, ease of migration, ability to adsorb other environmental pollutants, small size, and ease of ingestion by aquatic organisms, thereby threatening the growth, life, and health of aquatic organisms. MPs are biologically transferable and can accumulate in organisms at high trophic levels via food chains, thereby negatively impacting the ecological environment and human health. Moreover, the bioaccumulation of MPs is an important parameter for scientific risk assessments. This paper reviews the current status of MP pollution and its bioaccumulation in marine, freshwater, and other water environments. Furthermore, it proposes relevant recommendations for future research on the bioaccumulation of MPs in conjunction with previous studies to provide basic support for risk assessment and environmental management.

Keywords: aquatic environment; bioaccumulation; emerging environmental pollutants; microplastics; risk assessment

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1. Introduction

Plastics are widely used in aerospace, military, agriculture, and industry sectors as well as in everyday life because of their light weight, low cost, malleability, and durability. Moreover, plastic products are ubiquitous in our lives, and the demand for plastics has been predicted to reach 33 billion tons by 2050 [1]. Furthermore, although their use is convenient, they cause serious ecological problems. Owing to the expansion of plastic production, its subsequent disposal and recycling are not well-managed, resulting in a huge amount of plastic waste being released into the natural environment [2]. In addition, plastic products can remain stable in the natural environment for a long time and can be broken into small pieces via the action of various external forces to form microplastics (MPs) [3]. The concept of MPs was first introduced in 2004 by Thompson [4]; they were defined as plastic particles and fragments of <5 mm in diameter with different forms (e.g., granular, foam, fragmented, film, and fibrous) and colors (e.g., transparent, red, black, and blue). MPs are mainly composed of the following types of polymers: polyethylene (PE), polypropylene, polystyrene (PS), and polyethylene terephthalate (PET) [5,6]. At present, MPs are found in water [7], soil [8], the atmosphere [9], food [10], and humans [11]. Furthermore, owing to their strong hydrophobicity and nonbiodegradable characteristics, they persist in the environment and can be transported over long distances. A previous study reported that MPs can be ingested by and accumulated in organisms through the food chain, thereby interfering with the normal metabolism and reproduction of organisms [12]. Moreover, it has been reported that MPs enter the digestive tract through ingestion [13] and adhere to

the tissue surfaces of organisms [14]. Furthermore, they can accumulate in various organs, thereby affecting the nutritional intake, growth, development, reproduction, and survival rate of organisms [15].

In summary, MPs can cause serious toxic effects after being ingested by organisms. However, the results of most studies on the accumulation of MPs in organisms have mainly been obtained from indoor exposure experiments. Furthermore, our understanding of the accumulation of MPs in organisms is poor because of the complexity of MP concentrations, types, and particle sizes, as well as the diverse MP ingestion pathways. Therefore, there is an urgent need to investigate the impact of MP bioaccumulation. In this paper, we summarize the results related to the bioaccumulation of MPs in an aqueous environment and propose related recommendations.

2. MP Sources, Distribution, and Hazards

2.1. Sources and Distribution

The sources of MPs are roughly divided into land- and sea-based sources, with land-based sources being the main sources [16]. About 50% of the world's population lives within 50 miles from the coastline, so MPs from the land can easily enter the ocean via rivers and sewage systems, and they can be blown from coastal areas into the oceans [17]. Subsequently, they can be washed up by oceans during storms. Notably, some common detergents, skin products, and industrial raw materials comprise a large number of MP components that can enter wastewater treatment plants through drainage systems. In these plants, only large particles are removed through grates and settling tank systems; therefore, a considerable proportion of small particles, including MPs, can be discharged into river systems [18]. Moreover, a significant amount of clothing microfibers is discharged into washing machine wastewater. MP leakage can also occur during the processing, molding, storage, and transportation of plastic products.

Marine MPs are one of the sea-based sources of MPs. Although the 1988 International Convention for the Prevention of Pollution from Ships prohibited ships from dumping plastic debris into the ocean, shipping remains a major source of marine plastics owing to the lack of education and enforcement [19]. In addition, coastal tourism, fishing, and marine industries (e.g., aquaculture and offshore oil rigs) are recognized as sources of marine plastics [20]. Notably, plastic products discarded by tourists on beaches or in oceans, plastic floating devices used by the aquaculture industry, and plastic fishing nets and gears used by the fishing industry can enter the marine environment. Plastics entering the marine environment can form secondary MPs. Moreover, the spatial and temporal distribution of MPs in the environment is complex due to the effects of ocean currents, monsoons, and rivers [21]. The frequency of occurrence of MPs varies significantly between regions, as shown in Table 1.

Table 1. Abundance of microplastics in the aqueous environment.

Research Area	Abundance	References
North Pacific Ocean	3260 n/m^3	[22]
East Sea Offshore	0.167 ± 0.138 n/m^3	[23]
North American Great Lakes	43,000 n/km^3	[24]
Geneva Lake	48,146 n/km^3	[25]
Yangtze River Estuary	4137.3 ± 2461.5 n/m^3	[26]
Yangtze River Three Rivers Dam	3407.7×10^3 to $13{,}617.5 \times 10^3$ n/km^3	[27]

2.2. MP Hazards

The impact of MPs on aquatic ecology is greater than that of larger plastics owing to their greater potential bioavailability [28]. This impact is multifaceted. First, MPs accidentally consumed by aquatic organisms are accumulated in the organisms and transferred via the food chain [29], thereby affecting the entire aquatic ecosystem. In a laboratory fish-feeding study by Hoss et al. [30], 100–500 µm precursor particles were placed in the rearing

pools of six juvenile fish species. Their results indicated that all fish ingested MPs, thereby confirming that the fish actively feed on precursor particles. Furthermore, Sharma and Chatterjee [31,32] summarized the effects of MPs on various marine organisms, including intestinal obstruction, satiety inhibition of feeding, imbalance in steroid hormone secretion, delayed ovulation, and infertility. Damage to aquatic animals due to the consumption of MPs, which leads to death in severe cases, can be caused via digestive tract blockage, appetite loss, indigestion, and organ damage. For example, diarrheal and paralytic shellfish toxicities were observed in shellfish exposed to MPs contaminated with algal toxins [33–36].

In addition to the effects of accidental ingestion on aquatic organisms, MPs can affect the photosynthesis of algae and subsequently the primary productivity. Bhattacharya et al. [37] found that MP microbeads adsorbed on the surface of algae hinder photosynthesis owing to electrostatic attraction. This may be attributed to the blockage of light and the obstruction of airflow by MPs.

The mechanisms of the toxic effects of MPs on organisms can be classified as follows: (i) MP exposure causes oxidative stress by affecting the activity of antioxidant enzymes in the body, thereby triggering cell damage and subsequently reducing growth and reproduction rates [38]; (ii) MP exposure can cause neurotoxicity by affecting the activity of acetylcholinesterase in organisms, thereby interfering with the function of the nervous system and causing paralysis and death [39]; (iii) endocrine disruptors in additives and monomers used for producing MPs can affect the development and reproduction of organisms [40]; (iv) MPs ingested by organisms can enter and accumulate in their immune systems and then transfer to tissues and organs, resulting in immunotoxicity [41]; and (v) MPs, which are easily accumulated in the gastrointestinal tracts of organisms, can interfere with the immune system in the intestinal tract and cause local inflammatory reactions [42].

3. Status of MP Pollution in Aquatic Environments

3.1. Occurrence of MP Pollution in Water Bodies

3.1.1. MP Pollution in Seawater

Because of the convenience of use and low costs of plastic products, they are commonly used in our daily lives; however, approximately 4.8 million tons of plastic debris enter the global ocean every year owing to their improper disposal [43]. In the marine environment, these debris are broken into small plastic particles or fragments of <5 mm (which are called MPs) via solar radiation, oxidation, biodegradation, and ocean dynamics [44–46]. Many studies have reported the occurrence of MPs in marine environments, including beaches [47], coastal areas [48], deep seas [49], and polar regions [50]. Moreover, MPs have been widely detected in marine fish, mollusks, zooplankton, mammals, and birds. A significant amount of evidence in the literature has indicated that MPs have various negative effects on marine organisms, such as inhibition of photosynthesis in algae [51] and disruption of energy metabolism in mussels [52], highlighting the potential threat of MP pollution to the entire marine ecosystem. Therefore, in recent decades, the study of MP pollution in the marine environment has gained widespread attention from scientists and the general population.

Notably, the composition of MPs varies greatly according to the region, as shown in Table 2.

Table 2. Differences in the composition of microplastics in different regions.

Research Area	Type of Microplastics	Abundance	References
Atlantic Ocean	49% PA	(1.15 ± 1.45) n/m^3	[53]
North Atlantic Subtropical Circulation System	48% PET and PP	13–501 n/m^3	[54]
Arabian Gulf	PET and PP	43.8–1460 n/m^3	[55]
Chennai Coast	PET and PP	896 n/m^3	[56]
Bohai Sea	51% PE	0.33 ± 0.34 n/m^3	[57]

Note: polyamide (PA); polyethylene terephthalate (PET); polypropylene (PP); polyethylene (PE).

Researchers have also found MPs in estuaries, defined as transition zones between inland and marine ecosystems. Hu et al. [58] reported that the highest abundance of MPs (21520 n/m^3) was found in the Yangtze River estuary, which was significantly higher than that in its adjacent offshore areas. In contrast, the average abundance of MPs in the Pearl River estuary (8902 n/m^3) was significantly higher than that in the Yangtze River estuary (4137.3 n/m^3). These findings suggest that the abundance of MPs in estuarine seawater decreases gradually from the southern to northern regions. This may be attributed to the release of greater amounts of plastic wastes from densely populated and industrialized watersheds in southern China. In conclusion, MPs are commonly found in marine ecosystems, and their pollution has become a global challenge. Therefore, it is important to actively address the common environmental problems to prevent MPs from further damaging marine ecosystems.

3.1.2. MP Pollution in Freshwater

MPs are found in both marine and freshwater environments, such as rivers and lakes. To date, several researchers have detected MPs on the surface water of freshwater lakes and rivers in many European countries. However, the abundance of MPs in rivers, lakes, and reservoirs varies greatly according to the region. In the North American Laurentian Great Lakes, the abundance of MPs in surface water reached an average of 0.43×10^5 particles/km^2 [59]. Notably, the largest accumulation of MPs was found in the German Rhine River (8.93×10^5 particles/km^2) [24]. Currently, studies on MPs in freshwater in China are mainly focused on the Yangtze and Pearl River basins. The highest levels of MP pollution in China are found in estuaries and urban sections of rivers as well as in lakes or reservoirs near large cities. In geographical terms, the Yangtze River basin, Pearl River basin, Three Gorges Reservoir, and other densely populated highly urbanized inland waters are most severely polluted by MPs. This finding indicates the important influence of human activities and economic levels on the environments of city waters [60]. However, MP contamination is also observed in surface waters in remote and sparsely populated areas, such as rivers and lakes on the Tibetan Plateau. This finding indicates that MP pollution is related to human activities and economic development as well as being influenced by runoff and monsoons. In addition, MPs can migrate and spread in different types of water bodies, posing incalculable risks to the freshwater environment and human health [27,61].

By comparing the reported abundance of MPs in surface water in China and other countries around the world, we found that the contamination levels of MPs in the surface water of Chinese freshwater ecosystems were generally higher than those in other countries, as shown in Table 3.

Table 3. Comparison of microplastic abundance in freshwater bodies between China and other countries.

Research Area	Abundance	References
Three Gorges Reservoir (China)	1597–12,611 n/m^3	[62]
Dongting Lake (China)	900–2800 n/m^3	[63]
Hong Lake (China)	1250–4650 n/m^3	[63]
Middle and Lower Yangtze River (China)	500–3100 n/m^3	[64]
Tai Lake (China)	3400–25,800 n/m^3	[58]
Seine River (France)	0.28–0.47 n/m^3	[65]
Qusi Lake (Italy)	2.68–3.36 n/m^3	[66]
Bolsena Lake (Italy)	0.82–4.42 n/m^3	[66]
Antus River (Portugal)	58–193 n/m^3	[67]

Our literature review revealed that MPs are prevalent in freshwater ecosystems in China and that MP pollution is the most serious in estuarine and inland waters located in urban areas. However, the current state of MP contamination in Chinese freshwater ecosystems can mainly be attributed to poor management and lack of suitable laws and regulations. Despite the growing interest in MP contamination and the fact that it has recently become a topic of interest in environmental research, many scientific questions remain unanswered. Therefore, there is an urgent need to investigate and prevent MP pollution in Chinese freshwater bodies.

3.2. MP Pollution in Sediments

In addition to freshwater and seawater environments, sediments are important sinks for MPs in aquatic environments. Sediments in the global aquatic environment are partially contaminated with MPs, with hundreds or thousands of MPs per kilogram of sediment [68]. The abundance of MPs in sediments varies among different water environments, as shown in Table 4.

Table 4. Microplastics in the sediments of different waters.

Research Area	Abundance	References
Rhine River	228–3763 n/kg	[53]
Yangtze River Estuary	20–340 n/kg	[54]
South China Sea Inshore Beach	216–608 n/50 g	[55]
North River Basin Coastal	178–544 n/kg	[56]
Bohai Offshore	102.9–163.3 n/kg	[57]
Taihu Lake Coast	11.0–234.6 n/kg	[58]

In addition to water bodies, sediments in aquatic environments are reservoirs of MPs [69]; moreover, they act as settling tanks and a secondary source of MP pollution. This is because sediments in the aquatic environment are subjected to various effects related to sedimentation, density, and co-sedimentation [70]. This indicates that after accumulation in the sediment, MPs can be resuspended in the water and combined with other pollutants or can release toxic substances when the environment is changed or biologically disturbed [71]. Therefore, the potential impact of MP pollution on water ecosystems is a growing concern.

3.3. MP Pollution in Wastewater Treatment Plants

At present, the research on MPs has been conducted in conventional areas, such as marine surface water, deep seawater, freshwater, and sediments, as well as in other areas, such as sewage treatment plants. Wastewater treatment plant discharge is an important route for MPs to enter the natural environment [72]. Mason et al. investigated 17 different wastewater treatment plants in the USA and reported that each plant discharged 0.05 MP particles/L of effluent on average, with an average MP discharge of over 4 million n/d per plant, and high population density was correlated with high daily MP discharges from plants [73]. Furthermore, Habib et al. and Hoellein et al. found that the number of MPs

in water downstream of wastewater plants was much higher than that in the upstream and seawater sampling sites. They also found that large amounts of MPs were trapped in the activated sludge of wastewater plants, and most MPs were possibly still trapped in residual sludge after process treatments [74,75].

Recently, studies on MPs in urban wastewater treatment plants in China have focused on only a few cities, such as Beijing [76] and Wuhan [77]. Furthermore, these studies mainly focused on the physical properties and assignment tendencies of MPs in wastewater treatment plants; accordingly, the data on MP emissions from wastewater treatment plants are not comprehensive. Further research into ways to reduce MP emissions from wastewater treatment plants and treatment processes that are most effective for MP removal is needed.

4. MP Uptake by Aquatic Organisms

The ingestion of MPs by organisms has been reported in many studies, and some of the ecological effects of the ingestion are shown in Figure 1. Zooplankton, the main consumers of MPs, ingest high concentrations of MPs, leading to a risk for organisms at high trophic levels, including crustaceans, fish, and birds, via the food web [78]. Notably, fish, as intermediate members of the food chain, can ingest MPs both directly and indirectly by feeding on organisms containing MPs [79,80]. MPs have been detected in both the gills and skin of fish [81].

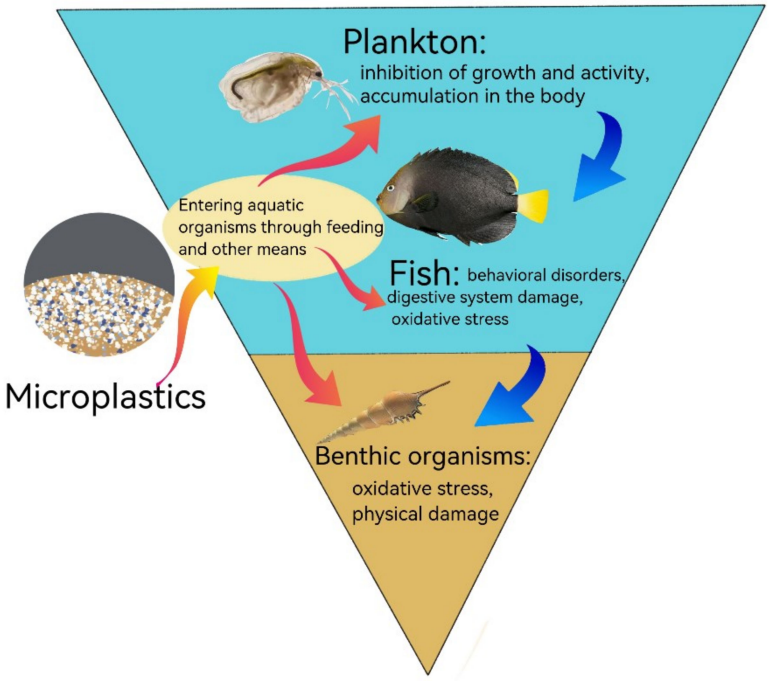

Figure 1. Diagram of the biological effects of MPs in the aquatic environment.

4.1. MP Uptake by Zooplankton

Many studies have reported that MPs can be ingested by zooplankton in their natural environments. Desforges et al. [82] compared the MP intake of two zooplankton species in the Pacific Ocean and reported that both Daphnia magna and krill can ingest MP particles, and the number of MPs ingested by krill was significantly higher than that ingested by D. magna. Sterr et al. [83] evaluated the fish fry in the English Channel and found that 2.9% of the fry had ingested MPs. Sun et al. [84] investigated the uptake of MPs by zooplankton populations in the northern South China Sea, and their results revealed that MPs were present in copepod zooplankton, jellyfish, shrimp, and fish fry. Furthermore, Sun et al. [85] investigated the bioconcentration and enrichment rate. Their results revealed that the bioconcentrations of copepod and pteropod zooplankton were 0.13

and 0.35 particles per zooplankton, respectively, and the intake of MPs showed a decreasing trend (omnivore > carnivore > herbivore), which was influenced by the feeding mode.

In summary, MPs in water bodies can be ingested by zooplankton, and the bioavailability of MP particles is determined by the species and feeding habits of zooplankton. Furthermore, MPs can enter higher trophic levels through the food chain and eventually endanger human life and health.

4.2. MP Uptake by Fish

Given that fish are the most important aquatic organisms consumed by humans, MP contamination of fish is an emerging food security and human health concern. Therefore, this contamination and its possible effects require special attention. In particular, MPs were detected in the stomachs of 16.8% of the dogfish in Mediterranean waters, and more filamentous MPs were found in the heavy MPs in the food they consumed, suggesting that dogfishes can bioaccumulate MPs by consuming foods containing MPs [86]. In a previous study, MPs were detected in fish cultured in Xiangshan Bay, and the study results indicated that MPs were distributed in the intestine and stomach instead of the fish flesh [87]. However, MPs can also be attached to the skin of fish or transferred to other tissues, such as the gills, liver, and muscles [88]. Wright et al. [89] reported that very fine plastic particles may enter the circulatory or lymphatic systems through living cells, leading to the dispersion of MPs throughout the body.

As many fish are visual predators, plastic particles that look similar to their natural prey may be ingested by them. A previous study [11] reported that white MP particles are more likely to be ingested by juvenile goby than black and red MP particles because the food commonly eaten by goby is white brine shrimp. Accordingly, juvenile goby may consider white MP particles brine shrimp, thereby leading to a higher intake of white MPs. Therefore, the size and color of MPs can influence the probability of their ingestion by fish. However, there is still uncertainty about the potential mechanisms underlying the selective feeding behavior of fish for MPs. In summary, MPs can be ingested by fish in the natural environment and accumulate mainly in the intestine. MPs are mainly detected in the form of fibers and fragments, consistent with the results of the shapes of MPs detected in the aquatic environment, and they are more likely to accumulate in fish in relatively confined waters.

4.3. MP Uptake by Other Aquatic Organisms

At present, studies on the ingestion of MPs by aquatic organisms in the natural environment have mainly focused on fish and relatively few other species. Researchers who reviewed the number of MPs ingested by marine mussels reported that the numbers reached 0.2 ± 0.3 pieces/g in mussel tissue [90]. Santos et al. [91] investigated the accidental consumption of MPs by juvenile sea turtles, which can lead to their death by blocking the gastrointestinal tract. They found that the concentration of MPs in the gastrointestinal system of green sea turtles was 47.5 items per turtle.

In conclusion, most aquatic animals can ingest MPs, and this ingestion is greatly dependent on the size of MPs and predatory habits of the organism. Therefore, the environmental risks caused by MPs to aquatic organisms are very serious and pose a danger to human lives.

5. Accumulation of MPs by Aquatic Organisms

5.1. Bioaccumulation of Marine MPs

MPs can enter organisms through various pathways, and the most common pathway is ingestion by animals through the digestive tract and accumulation in the body. Katrina et al. [92] found that sea urchin larvae are exposed to PE excreted MPs from their stomachs within few hours of ingestion. Brillant et al. [93] evaluated the uptake of different-sized MP particles in the stomach and intestines of sea scallops. They found that less dense MP particles were more likely to be retained in the organism. VonMoos et al. [94] exposed

purple mussels to 0–80 µm PE and found that in addition to accumulation in the gills, particles were transferred to the stomach and digestive glands. Moreover, MPs can be transferred to the circulatory systems of mussels through the intestinal or digestive tract. Browne et al. [95] reported that PS particles accumulated in mussels within 12 h and were transferred from the intestine and digestive tract to the circulatory system within three days of being ingested, and MPs were detected in the blood lymph fluid and blood cells of the mussels. Furthermore, MPs pose a greater threat to large marine mammals, especially large filter-feeding marine animals that are prone to ingesting MPs. For example, humpback whales feed by filtering small particles from large volumes of water, and some studies have detected MPs (size, 0.1–17 cm) in their gastrointestinal tracts [96]. Elisa et al. [97] examined 107 harbor seals in the Netherlands and detected MPs in the gastrointestinal tract of 12.2% of the seals.

A previous study reported that MPs are biologically transported and can be enriched in organisms at higher trophic levels as they pass through the food chain, ultimately affecting human health [98]. High trophic-level organisms in the food chain can indirectly ingest MPs by preying on low trophic-level organisms that contain MPs; therefore, nutrient transfer may be an indirect pathway for MP ingestion [99]. Farrell et al. [100] investigated the trophic transfer of MPs from mussels to green crabs. After feeding green crabs with mussels exposed to 0.5 µm PS, MPs entered the hemolymph tissue of the green crabs, and the number of MPs in the hemolymph was the highest after 24 h. Furthermore, MPs were detected in the stomach, hepatopancreas, ovaries, and gills of the green crabs, and their number gradually decreased with time. Setala et al. [101] fed mysid shrimps with copepod zooplankton exposed to 10 µm PS MPs, and MPs were detected in the gut of all mysid shrimps after 3 h. This suggests that MPs can be transferred from lower to higher trophic levels via zooplankton.

5.2. Bioaccumulation of Freshwater MPs

MPs can also be ingested and accumulated by freshwater organisms. Xiong et al. [102] reported that goldfish ingested MPs when fish food and MPs were wrapped together, which could damage their digestive tract. Moreover, they reported differences in the retention times of different types of MPs in goldfish. Evidence of MP accumulation in freshwater fish has also been found in field sampling surveys. In addition to fish, freshwater zooplankton, freshwater bivalves, benthic macroinvertebrates, and other freshwater taxa can ingest and accumulate MPs [103]. Furthermore, Hu et al. [104] found that MPs are accumulated in tadpoles.

5.3. Factors Affecting the Bioaccumulation of MPs

MPs can be ingested in the aquatic environment by various organisms, such as plankton, fish, birds, and mammals, and they can accumulate in the aquatic food web. This review established four factors influencing the bioaccumulation of MPs: Exposure concentration, particle size and shape, polymer type, and biological characteristics. First, increasing the exposure concentrations of MPs in the environment tends to increase the effectiveness of their bioaccumulation. Revel et al. [59] reported that exposure to high levels of PS alone resulted in the accumulation of MP in the digestive tract of mussels. Second, the particle size of MPs significantly affects the extent of their accumulation in organisms; it has been reported that the MP accumulation capacity of organisms increases with the decreasing size of MPs [105]. For example, compared with 20.6 and 30.6 µm PS MP particles, the percentage of 7.3 µm PS MP particles accumulated in *Acartia clausi* was higher [106]. Moreover, differences in the shapes of MPs affect the extent to which they bioaccumulate at different trophic levels and occupy different habitats [107]. For example, fibers and films are less dense, float easily, and are difficult to sink; hence, they are more likely to be ingested by pelagic organisms, such as phytoplankton and zooplankton. In contrast, amphipods, mollusks, and echinoderms are more likely to ingest spherical MPs denser than water [108]. Third, the type of polymer determines the density of MPs, and the

density of MP particles directly affects their trajectory, sedimentation rate, and distribution area and thereby their accumulation in different organisms. For example, low-density MPs usually float on the surface of the water column and are easily ingested by plankton, whereas high-density MPs are often found in benthic invertebrates [109]. Fourth, because different organisms have different feeding patterns, the degree and ability to recognize the color and particle size of foods vary greatly, and these differences lead to a wide variation in the number and type of MPs ingested by organisms in the environment [110].

In general, the physicochemical properties of MPs lead to differences in the bioaccumulation of MPs. However, although the number of studies on MP accumulation in aquatic organisms is increasing, most indoor studies remain biased toward specific types or certain particle size ranges of MP particles and high exposure concentrations. Therefore, they lack the evaluation of correlation and coupling with exposure scenarios in real-field environments. Therefore, in the future, more attention should be paid to the selection of environmentally representative variables in studies on the interaction of MPs with aquatic organisms. This would provide a more scientific basis for assessing the bioaccumulation and toxic effects of MPs.

6. Ecological Risk Assessment of MPs

Currently, MPs are ubiquitous in the environment. To comprehensively reduce the risk of MP pollution and develop control measures, ecological risk assessment of MPs is an important scientific basis. Therefore, research on the ecological risk assessment of MPs has received increasing attention from researchers, and currently, the most applied ecological risk assessment methods are the risk quotient (RQ) and probabilistic risk evaluation methods.

6.1. The RQ Method

The first environmental risk assessments of water bodies were based on the toxicity data of freshwater organisms, and the species sensitivity distribution method was used to calculate the RQ of MPs in freshwater, which was determined using the predicted no-effect concentration (*PNEC*) values [111]. A lognormal model was used to fit a species sensitivity distribution (SSD) curve and calculate 5% hazard concentration (HC_5). This requires fitting the no-observed-effect concentration (NOEC) of different species to the curve for MPs and then finding the concentration at the 5% position of the proportion of affected species. Subsequently, *PNEC* is derived from the following formula:

$$PNEC = \frac{\mathrm{NOEC}}{\mathrm{AF}} \text{ or } PNEC = \frac{\mathrm{HC_5}}{\mathrm{AF}} \quad (1)$$

where HC_5 is divided by an assessment factor (AF), ranging from 1 to 5, and the AF generally takes the value of 1 [112]. The probability distribution of the *PNEC* values is calculated from the NOEC, and the measured environmental concentration is the measured abundance of MPs at each sample site.

The potential ecological risk of MPs detected in freshwater has been assessed using the RQ method, which has also been used to assess the risk of MPs in the marine environment [113], as shown in the following formula:

$$\mathrm{RQ} = \frac{MEC}{PNEC} \quad (2)$$

However, the *PNEC* value used in Formulas (1) and (2) does not consider the ecological impact of MPs that are composed of different types of polymers on water bodies. Therefore, the formula is modified using the polymer hazard index (S_i) [114,115], and if multiple copolymers are present, the average value of each polymer is used to calculate S_i. At this point, the risk characterization ratio (RCR) is used to analyze the degree of ecological pollution by MPs, which can be divided into four classes: $0 < \mathrm{RCR} \leq 1$, no significant risk; $1 < \mathrm{RCR} \leq 10$, low ecological risk; $10 < \mathrm{RCR} \leq 100$, medium ecological risk; and $\mathrm{RCR} > 100$,

high ecological risk. The estimates are based on the concentration of MPs, diversity of the MP polymer composition, and hazards and risks posed by individual MP polymers. Everaert et al. [113] combined MP toxicological data to use a risk description ratio for the risk assessment of MPs. Adam et al. [112] evaluated the ecological risk assessment in freshwater AF_{ssd}, which was taken as 1, and the probability distribution of *PNEC* was calculated from NOEC; the obtained plurality of *PNEC* was 7.4×10^5 n/m^3. Similarly, Zhang et al. [116] obtained the *PNEC* of the water body as 4920 n/m^3 by fitting the SSD curve. Li et al. [117] conducted an ecological risk assessment of MP pollution in 13 typical rivers in China using the RQ approach based on species sensitivity distributions.

6.2. Probabilistic Risk Evaluation Method

Probabilistic risk evaluation demonstrates the results of risk calculations in the form of probability distributions for factors such as differences in the spatial and temporal distribution conditions of exposure and interspecies and intraspecies individual sensitivity differences. Probabilistic risk assessment accounts for the uncertainty and stochasticity of exposure and effects and considers the variability of exposure concentrations and species sensitivity distributions during ecological risk assessment. This can better describe the likelihood of exceeding effect thresholds and the risk of adverse effects. The most commonly used method is the probability density function overlapping area method. This method involves placing the probability density curves of exposure concentrations and toxicity data in the same coordinate system using the maximum environmental exposure concentration and the toxicity data of the most sensitive organisms as boundaries; moreover, it involves determining the area of the overlapping part of the curve with this boundary to represent the risk of the compound to aquatic organisms [118]. In cases where the mean value of the exposure concentration distribution curve is smaller than that of the toxicity data distribution curve, the overlap area is directly related to the risk level. The advantage of this method is that the probability density curves of exposure concentration and toxicity data are easier to obtain, and the overlapping area can visually reflect the level of risk. Shen et al. used the probability density overlap area method to evaluate the ecological risk of MPs in major water systems in China [119].

7. Conclusions

This paper reviews the sources and hazards of MPs, current status of MP pollution in aquatic environments, uptake and accumulation of MPs by aquatic organisms, and factors affecting the bioaccumulation of MPs. This paper also reviews the current research on the ecological risk assessment of MPs in the aquatic environment and focuses on two approaches, the RQ method and probabilistic risk evaluation method. MPs are commonly found in the environment and have been detected in many organisms. However, current research on the accumulation of MPs in organisms is still in the initial stages.

8. Future Directions

To initiate in-depth research of MPs, future studies should be conducted based on the following aspects:

(1) To better assess the pollution of water environments by MPs, we should continue to conduct continuous surveys and research on multiple water bodies and environments to gradually form a point-line surface research model.

(2) Current research on the toxicity of MPs is mainly at the laboratory stage, and there is a lack of research on the toxic effects of MPs in a complex real environment. Laboratory results cannot indicate the influence and synergistic effects of complex environmental factors and other substances on MP pollution, and the toxic effects of MPs in the real environment need to be evaluated. Moreover, the physical and chemical properties of MP particles (i.e., particle size, shape, and polymer type) and different feeding behaviors of organisms need to be considered in the investigation of the bioaccumulation of MPs under real environmental conditions.

(3) Owing to the unique physicochemical properties of MPs and their adverse effects on aquatic organisms, there is a need to develop a long-term impact assessment system for MPs in the ecosystem. Based on the comprehensive use of MP ecotoxicity data and environmental exposure histology information, it is also necessary to strengthen research on the pathways, risks, and hazards of MPs in the human body as well as systematically assess the health risks of MPs in different populations.

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