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A Review of the Sources, Distribution Characteristics and Toxic Effects of Marine Microplastics

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Abstract: Microplastics (MPs) as an emerging pollutant, have garnered significant attention due to their resistance to traditional purification technologies. This paper provides a comprehensive review of the sources, distribution characteristics, and toxic effects of MPs on marine fish. Research indicates that MPs are pervasive in the tissues of marine fish. Direct threats encompass physical damage and chemical toxicity induced by MPs, while indirect threats pertain to the potential influence of MPs on fish physiology and behavior. The paper underscores the necessity for future research to delve deeper into the potential hazards of MPs to halobios, thereby offering a scientific foundation and guiding research direction for the management and governance of marine plastic and microplastic pollution.

1. Introduction

Plastics, as a lightweight, durable and relatively low-cost material, have been widely used around the world due to their unique physicochemical properties. However, this widespread use has also brought about a serious problem - the sharp increase in plastic waste. According to authoritative statistics, the annual production of plastics is growing at an astonishing rate of 3%, and it is estimated that by 2050, its output will reach an astonishing 67.8 million tons [1].

These plastic wastes fragmented into the natural environment (sunlight wind, tide and wave etc), chemically and biologically degraded in Microplastics (MPs), defined as less than 5 mm in diameter [2]. Over time, MPs accumulate continuously in the marine environment and other environments, gradually becoming a new type of pollutant that is difficult to recycle or eliminate.

The presence of MPs not only occupies a large amount of space, but also poses a significant threat to the natural environment. Under long-term weathering and erosion, their surface characteristics may change, making them adsorption and transfer mediums for organic pollutants and heavy metals. These adsorbed pollutants can enter organisms through the food chain, severely affecting the health of the organisms, and even causing damage to the entire ecosystem [3].

Faced with this severe environmental issue, scientists continuously explore and research effective methods for microplastic treatment. With the continuous development of technology, a series of green degradation technologies have emerged, such as s like coagulation, adsorption, filtration, microbial degradation, and advanced oxidation processes (AOPs)[4]. These technologies have to some extent solved the problem of microplastic resistance to degradation, providing new ideas for the management of microplastic pollution.

This review aims to comprehensively and systematically sort out and analyze the sources of microplastic pollution, its harm to the environment, technical means for identifying MPs, as well as the intake of MPs by marine organisms and their resulting ecotoxic effects. Through such research, we hope to gain a deeper understanding of the complexity and severity of microplastic pollution, provide a scientific basis for formulating more effective governance strategies, and contribute our wisdom and strength to solving this global environmental problem.

2. Sources and Distribution Characteristics of MPs

2.1. Source of microplastics

MPs are ubiquitously distributed globally in the world, including soil, ocean, land, atmosphere, and various organisms. The following two sources of microplastics in the current environmental context; primary MPs are defined as plastic species that artificially manufactured and inherently possess microscopic dimensions, including microparticles, microbeads, and microfibers.These minuscule plastic particles pervade our daily lives, evident in common products, for example facial cleansers, medicines, hair spray, toothpaste and body scrubs. During their usage, these products invariably release the embedded microparticles into the environment, thereby contributing to the primary sources of MPs[5]. Secondary MPs derived from larger discarded plastic fragments through processes of physical, chemical, and biological degradation. These larger fragments, including plastic bottles, packaging, foam plastics, agricultural films, tires, marine coatings, and plastic coatings, gradually decompose into minute plastic particles over an extended period due to natural forces like wind and sunlight[6]. The sheer volume of these secondary MPs is immense, and their small size and resistance to degradation pose a more significant threat to the environment.

It is noteworthy that MPs are ubiquitous in the ocean, with statistics indicating that over 80% of marine debris originates from daily plastic discharge[7]. These plastic wastes can infiltrate the marine environment through various means, including sewage treatment system discharges, river transportation, wind dispersion, and surface runoff washout. Furthermore, industries associated with marine activities, such as fisheries, coastal tourism, ship transportation, and the marine industry, contribute significantly to plastic waste generation. This waste is frequently discharged directly onto beaches or into the ocean, thereby exacerbating the issue of microplastic pollution. The pervasive distribution and challenging degradation of MPs have inflicted significant harm on the environment and its inhabitants. These particles can be ingested by marine organisms, thereby impacting their growth and reproductive capabilities. Concurrently, MPs possess the ability to adsorb and transfer various toxic substances, including heavy metals and organic pollutants, which subsequently influences the migration and transformation of these contaminants within the environment. Consequently, addressing the issue of microplastic pollution has emerged as a crucial task within the realm of environmental protection.

2.2. Distribution Characteristics of MPs

The composition and morphology of MPs are crucial for comprehensive studies on their sources, environmental behaviors, and the development of effective treatment strategies. In marine ecosystems, MPs exist in various forms, primarily as sediments, floating objects, and sea salt in different water bodies. Among the constituents of MPs, polyethylene (PE), polypropylene (PP), polyester (e.g., PET), and nylon are predominant. These plastic materials, renowned for their superior physical and chemical attributes, are extensively employed in the production of a myriad of daily commodities and industrial goods. Nonetheless, their resistance to degradation in natural environments renders them persistent once introduced into ecosystems, such as the ocean, where they can persist for extended periods and accumulate.

Table 1: Existence of marine MPs.

Area	Sample Type	Main Component	Particle Size	Shape	Refs.
Yellow Sea of China	Seawater floaters	PET,CE,PE	<5mm	Fiber	[8]
Black Sea	Sediment	PE,PP,Nylon, etc.	<5mm	Particles	[9]
Maowei Sea, China	Sea water depth < 10 cm	PET, PE,EPS	<5mm	Fiber foam	[10]
East Antarctic sea ice	Ice Core	PE,PP,PA,varnish	< 0.35mm	Fragments	[11]
Baltic Sea	Water sample	PE,PP,PET	> 50mm	Thin slice	[12]
Sea of Oman, Iran	Sediment water sample	PE,PET,Nylon	<5mm	Fragment fiber	[13]
Western Mediterranean	Marine Aggregate Float	PE,PP,PS	1.79 ± 1.67 mm	Particles Paint shavings	[14]
Northern Yellow Sea	Surface water sediment	PE,PP,PE / EA	<0.5mm	Fibrous particles	[15]
Mediterranean waters	Surface water	PE,PP,Nylon	> 1 mm	Particles	[16]

Table 1 presents the data, which may illustrate the predominant constituents of MPs in various water bodies. It is evident from the table that plastic elements such as PE, PP, and nylon constitute a significant proportion of MPs. These findings offer valuable insights into the origins of MPs. For instance, PE and PP are frequently utilized in the production of packaging materials like plastic bags and bottles, which are often discarded at random post-use, thereby becoming a primary source of marine debris. Nylon, on the other hand, is commonly employed to create fishing nets, ropes, and other fishing apparatuses. These items can break or be lost during their usage, thus contributing significantly to the marine MPs population. Understanding the composition and morphology of MPs is crucial for accurately assessing their potential environmental impact. Variations in composition can influence degradation rates, adsorption capacities, and other properties within the environment, thereby directly affecting the migration, transformation, and bioaccumulation processes of MPs. Concurrently, comprehending the morphology of MPs can facilitate the development of more effective treatment strategies. For instance, physical methods such as net fishing can be employed to collect floating MPs on the water surface, while more complex techniques like chemical or biological degradation are required for treating MPs deposited on the seabed or soil.

Consequently, a comprehensive examination of the composition and morphology of MPs is crucial for addressing the issue of microplastic pollution. Such an investigation will not only elucidate the origins and environmental behavior of MPs but also facilitate the development of more scientifically sound and effective treatment strategies, thereby safeguarding the health of marine and other ecosystems.

3. The Impact of MPs on Marine Fish

3.1. Direct Ingestion by the Organism

Within the expansive depths of the ocean, fish serve a pivotal role in the ecological chain, with their survival status intimately linked to environmental quality. However, the escalating severity of plastic pollution presents a significant challenge for these marine organisms, as MPs have become a major concern. These minuscule pieces of plastic debris, invisible to the naked eye, can float, settle in ocean water, and are even directly ingested by fish.

Fish may ingest MPs either during foraging activities or by preying on marine organisms that have already assimilated these particles. Once internalized, MPs accumulate progressively in the fish's digestive system, presenting a significant health risk. Chronic exposure to MPs can lead to obstructions in the digestive tract, disrupting the standard feeding and digestion processes. Moreover, there is a potential for MPs to induce damage to the internal organs of the fish, thereby impairing its physiological functions.

Beyond inflicting damage to the digestive system of fish, MPs may also exert detrimental effects on their reproductive and endocrine systems. Certain studies have indicated that harmful substances present in MPs can disrupt the endocrine system of fish, potentially leading to endocrine disorders. Furthermore, these MPs may inflict damage on the reproductive system of fish, diminishing their reproductive capacity and significantly impacting the balance of marine ecology.

For humans, the consumption of these microplastic-ingested fish could potentially become a popular delicacy. However, the ingestion of fish meat contaminated with MPs may lead to the entry of these minuscule plastic fragments into our bodies, thereby posing potential health risks. Existing research indicates that long-term exposure to MPs can induce adverse reactions within the human body, including inflammation and immune system anomalies, and may even elevate the risk of cancer [17]. It is pertinent to note that the influence of MPs on fish extends beyond mere quantity, with particle size playing a pivotal role. Research indicates that under specific conditions, smaller MPs are more readily ingested by fish due to their resemblance to food particles. This ingestion can be problematic as these minute plastic fragments may more easily penetrate the blood-brain barrier of fish, subsequently infiltrating their brains and inflicting damage upon their nervous system. Such damage could potentially lead to neurological dysfunction in fish, thereby disrupting their normal behavior and life [18].

3.2. Release Toxic Substances

These minuscule plastic fragments are perpetually exposed to a myriad of physical and chemical interactions within the marine environment over extended periods. Through prolonged abrasion in water, facilitated by waves, tides, and marine organisms, unreacted monomers and oligomers, along with chemical additives incorporated into plastics to confer specific properties, gradually leach out from the materials. Additives such as polybrominated diphenyl ethers (PBDE), phthalates, nonylphenols (NP), bisphenol A (BPA) and brominated flame retardants are extensively incorporated into plastic products during manufacturing to imbue them with superior antioxidant properties, corrosion resistance, and flame retardancy[19][20]. However, these additives are progressively released into the marine environment as plastics age, suffer damage, and degrade. Research has identified the presence of flame retardant hexabromocyclododecane (HBCD) in polystyrene (EPS) debris marine litter across 12 global regions, including India. This discovery has elicited concern among scientists due to HBCD's common usage as a flame retardant in plastic products such as EPS, designed to enhance their flame resistance. However, certain manufacturing factors can lead to potential migration of unpolymerized raw materials and additives from these products into the environment during use or disposal[21].The leakage of these additives and monomers from MPs presents not only a potential hazard to marine ecosystems, but also the possibility of transference to higher organisms, including humans, via the food chain. Consequently, monitoring and research into MPs and their leachates are crucial for comprehending the environmental and biological impacts of plastic pollution, as well as for devising effective governance strategies.

3.3. Toxic Effects as Carriers of Toxic and Harmful Substances

The expansive surface area of MPs confers upon them a robust adsorption capacity. This unique property allows MPs to act as sponges, absorbing and concentrating a variety of pollutants, including harmful heavy metals and organic contaminants from adjacent water bodies, for instance, MPs have the capacity to adsorb a broad spectrum of pollutants, encompassing heavy metals such as lead, cadmium, and copper, in addition to organic contaminants like polychlorinated biphenyls, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, and dioxins. The interaction between these pollutants and MPs results in a compound pollution effect[22]. This not only enhances the persistence and mobility of the pollutants but also escalates their potential hazard to marine organisms and ecosystems. More significantly, MPs serve as vectors for these pollutants, facilitating their transportation to every corner of the ocean and beyond. This extensive transmission capability renders MPs a global source of pollution, inflicting enduring damage on the health of marine ecosystems[23]. MPs are susceptible to inadvertent ingestion during feeding activities, which can cause abrasion and ulceration in the digestive tract of the fish. Once ingested by fish. Furthermore, they can induce pseudo-satiety in the fish, leading them to believe that there are consumed an adequate amount due to the large volume of MPs ingested. This subsequently reduces their intake of other essential nutrients. Furthermore, MPs have been found to induce detrimental effects in fish, such as oxidative stress, which can severely impair their physiological functions. These pollutants may potentially damage the reproductive ability of fish, leading to a decrease in their reproductive ability and subsequently a decrease in population size. [24,25]

4. Conclusions and Outlook

In recent years, the extensive production and utilization of plastics have become an integral component of contemporary society. However, this has also precipitated significant environmental issues. The pervasive use of plastics has led to a surge in microplastic concentrations within various environments, including land, atmosphere, and ocean, thereby exerting immense pressure on the ecosystem. The management of MPs is challenging due to their intricate composition, varied morphology, and distinctive chemical properties. These attributes render the degradation process of MPs in the environment exceedingly slow, often necessitating decades or even thousands of years. Upon ingestion by organisms, MPs are transferred up the food chain and ultimately accumulate within the human body. This accumulation of a significant number of plastic particles presents a potential health risk to humans. However, due to the complex and variable nature of the environment in which MPs reside, conducting comprehensive research and monitoring on them is challenging. The composition, shape, concentration, and other characteristics of MPs are difficult to measure accurately, resulting in a limited understanding of their behavior patterns in the environment. To more effectively confront the challenges posed by MPs, this paper advocates for comprehensive research in the following areas:

(1) Develop standardized sampling and detection methodologies. Given the varied forms of MPs across different environments, it is imperative to devise specific sampling techniques for each setting. For instance, in aquatic contexts, various trawling techniques can be employed based on the

water depth to gather MPs. In solid sediment samples, identification can be achieved through direct visual inspection and alternative methods. Furthermore, given the intricate and multifaceted origins and compositions of environmental MPs, there remains an absence of a universally accepted identification technique. Consequently, we must employ cutting-edge technologies such as microscopes, infrared spectroscopy, and Raman spectroscopy for either qualitative or quantitative assessments. Additionally, establishing a standard spectral database will enhance the precision and dependability of detection.

(2) Implement a comprehensive dynamic monitoring system. Currently, research concerning the distribution and origins of MPs predominantly focuses on specific regions, thereby lacking global representativeness. To thoroughly comprehend and evaluate the prevalence, dissemination, and evolving trends of MPs globally, it is imperative to institute a broad dynamic monitoring system. This system should be capable of real-time tracking of microplastic distribution and concentration across diverse sectors, while also facilitating the collection, analysis, and prompt dissemination of pertinent data. Such a system would enable a more precise evaluation of the risks posed by MPs to marine life or humans, thereby providing a scientific foundation for the development of effective governance strategies.

(3) Evaluate the risk of MPs to marine life and humans. MPs, acting as carriers, may transport pollutants, particularly toxic substances, thereby posing potential threats to both marine organisms and human health. Consequently, it is imperative to concentrate on the biological effects of MPs and their toxicological mechanisms. This encompasses understanding how MPs are absorbed by organisms, distributed, metabolized, and the potential biological effects and toxicity they may induce. Simultaneously, attention must be given to the toxicological research of monomers, additives, etc. released by MPs themselves to fully comprehend the impact of MPs on the environment and organisms. In conclusion, addressing the MPs issue necessitates a multifaceted approach involving comprehensive research and monitoring. By developing standardized sampling and detection techniques, implementing extensive dynamic monitoring systems, and evaluating the risks posed by MPs to marine life or humans, we can gain a deeper understanding of microplastic behavior in the environment and their subsequent impact on ecosystems. This knowledge will provide a scientific foundation for devising effective governance strategies.

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