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Microplastics in aquaculture systems: Occurrence, ecological threats and control strategies

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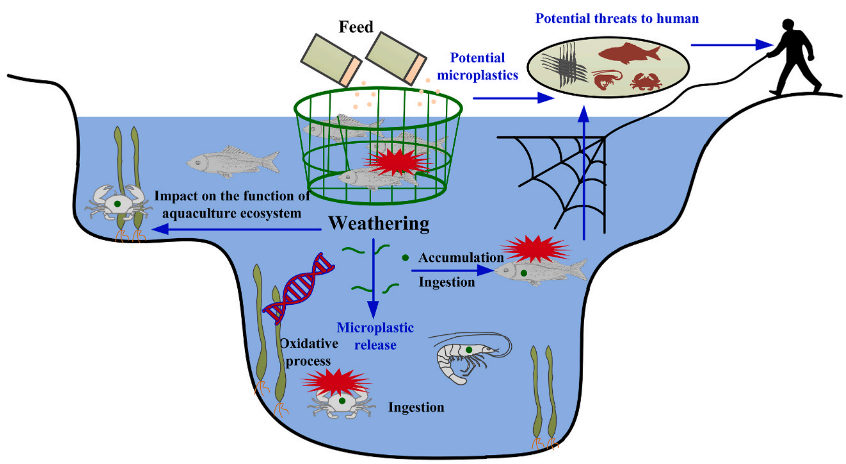
HIGHLIGHT

- Abundance and threats of microplastics in aquaculture environments are reviewed.
- Potential sources of microplastics in products are analyzed.
- Aquaculture environment has become a source of microplastics in natural water bodies
- Removal methods for microplastics in aquaculture environments are discussed

GRAPHICAL ABSTRACT



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ABSTRACT

With the intensification of microplastic pollution globally, aquaculture environments also face risks of microplastic contamination through various pathways such as plastic fishing gear. Compared to wild aquatic products, cultured aquatic products are more susceptible to microplastic exposure through fishing tackle, thus assessing the impacts of microplastics on farmed species and human health. However, current research on microplastic pollution and its ecological effects in aquaculture environments still remains insufficient. This article comprehensively summarizes the pollution characteristics and interrelationships of microplastics in aquaculture environments. We analyzed the influence of microplastics on the sustainable development of the aquaculture industry. Then, the potential hazards of microplastics on pond ecosystems and consumer health were elucidated. The strategies for removing microplastics in aquaculture environments are also discussed. Finally, an outlook on the current challenge and the promising opportunities in this area was proposed. This review aims to evaluate the value of assessing microplastic pollution in aquaculture environments and provide guidance for the sustainable development of the aquaculture industry.

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1. Introduction

The intensification of microplastic pollution in aquatic ecosystems has become the focus of global attention (Shen et al., 2023a; Yu et al., 2023). Sources of microplastics in aquatic environment include terrestrial inputs, tourism, shipping, aquaculture, fishing, and atmospheric sedimentation (Shen et al., 2019a; Somanathan et al., 2022; Xu et al., 2022). The small size range of microplastics (<10 μm) facilitates their accumulation at various nutrient levels through ingestion (Huang et al., 2021). Microplastics have been detected in various organisms (Khoshmanesh et al., 2023). The ingestion of microplastics can lead to various negative physiological effects, including immunotoxicity, reproductive toxicity, and behavioral changes (Kalčíková, 2023). In addition, microplastics sever as carriers of various pollutants, resistance genes, and microorganisms (Dong et al., 2021). Microplastics can also be transferred and bioaccumulated in organisms with high nutrient content.

Aquaculture products are a crucial source of high-quality protein for humans (Wu et al., 2022). The aquatic environment is a crucial material foundation for the survival and development of fishery resources. It provides the necessary living space and appropriate environmental conditions for the growth and reproduction of aquaculture products. Unfortunately, however, current aquaculture environment is contaminated by various pollutants (Mahamud et al., 2022). The use of plastic products brings great convenience to the aquaculture industry. However, over time, these products decompose and break down, releasing microplastics into water bodies and sediments (Vázquez-Rowe et al., 2021). During aquaculture, various materials such as mesh, rope, floating balls, plastic pipes, anti-seepage film for aquaculture pools, and foam packaging boxes are utilized for constructing aquaculture facilities and transporting aquatic products (Le et al., 2022). Fishing gear that is discarded, lost, or disposed of in aquaculture areas can decompose and create different types of microplastics (Xue et al., 2020). After entering natural water bodies, a portion of them will be directly or indirectly absorbed and enriched by aquaculture organisms when raw water enters aquaculture ponds, causing microplastic pollution. At the same time, these microplastics are prone to continuous enrichment and accumulation in the aquaculture water (Xiong et al., 2022) and sediment (Garcés-Ordóñez et al., 2022). Consequently, the quality of aquaculture products is closely related to human health. Pollution of the aquaculture environment and its impact on human health and the quality of aquaculture products should be promptly disclosed.

At present, microplastics have been found in the digestive tracts of various aquatic organisms worldwide, indicating that aquatic organisms are generally contaminated by microplastics (Khoshmanesh et al., 2023). Therefore, it may pose a serious threat to the health of numerous consumers. Exposure to microplastics may result in chronic inflammation and oxidative stress, which are the causes of various chronic complications (Shen et al., 2019b, 2023b). Presence of resistance genes in microplastics may play a crucial role in the carcinogenicity, chemical toxicity, and antimicrobial resistance of the gut microbiota (Dong et al., 2021). All types of evidence indicate that the presence of microplastic pollution in aquaculture environments and products cannot be overlooked. As such, it is particularly necessary to investigate the distribution of microplastics in aquaculture environments and conduct potential risk assessments. This review systematically analyzes the presence of microplastic pollution in aquaculture water bodies, sediment, and products. The degree of bioaccumulation of microplastics in cultured products from different regions is analyzed and compared to that in wild products. The potential impacts of microplastics on pond ecosystems, products, and consumer health are revealed. The strategy for removing microplastics in aquaculture environments is also proposed. Finally, the future research direction is discussed to provide scientific references for the rational use of plastic products and the effective control of microplastics in aquaculture systems.

2. Pollution status of microplastics in aquaculture systems

2.1. Occurrence of microplastics in aquaculture water

The relationship between microplastics and aquaculture systems is extremely complex because the environment of aquaculture systems is variable. After entering the aquaculture system, density becomes a crucial factor in determining their ultimate destination. High-density microplastics are more likely to settle in sediments, while lower-density microplastics are typically distributed in water bodies at various depths. Freshwater and marine water bodies can also influence the distribution of microplastics. Long-term, high-intensity aquaculture activities in enclosed or semi-enclosed environments can result in a significant accumulation of microplastics in water bodies (Table 1). Yu et al. (2023) investigated the abundance of microplastics in aquaculture ponds. The results indicated that microplastics were present in aquaculture water bodies, sediments, and carbs. The majority of microplastics were in the form of fibers, with particle sizes ranging from 100 to 300 μm. Microplastic concentration in water ranged from 4.4 to 10.8 particles/L, while the content range of microplastics in sediment was 28.6–54.3 particles/g dry weight, respectively. Xiong et al. (2022) investigated the distribution of microplastics in aquaculture water bodies during different seasons. In June, the average abundance of microplastics in lakes, rivers, and aquaculture ponds was 167, 129, and 372 particles/m^3, respectively. These figures were 533, 311, and 429 particles/m^3, respectively, in December. In June, microplastic abundance in ponds was significantly higher than that in rivers, and the drainage of aquaculture ponds may increase microplastic pollution in receiving natural water. However, no significant spatial difference in microplastic abundance was observed in December. In another report, Xiong et al. (2021) revealed that the abundance of microplastics in aquaculture ponds for fish, crayfish, and crabs ranged from 87 to 750 particles/m^3, while in lakes it ranged from 117 to 750 particles/m^3. The findings demonstrated that the microplastic content of ponds was higher than that in nearby natural lakes. Ma et al. (2020) studied microplastic pollution characteristics in aquaculture ponds in the Pearl River Estuary. Microplastics were found in all samples of fish pond water, with abundances ranging from 10.3 to 60.5 and 33.0 to 87.5 particles per liter, respectively. The average abundance of microplastics in aquaculture water (42.1 particles/L) was higher than that in ponds (32.1 particles/L). Most of the microplastics were in the form of colored fibers, primarily composed of polypropylene (PP) and polyethylene (PE).

Zhu et al. (2019) the levels of microplastic pollution in aquaculture water and biota in the Maowei Sea. The results indicated that microplastic concentrations ranged from 1.2 to 10.1 particles/L in surface water, 10.1 particles/L in estuarine oyster farms, and 8.8–9.5 particles/L in Qinzhou harbor water. Microplastic abundance in the three tributaries ranged from 2.9 to 4.5 particles per liter. Microplastics were also detected in all collected organisms' bodies, with an abundance of 2–14 particles in fish and 3.2 to 8.6 particles in oysters, respectively. The authors further reported that microplastic pollution in fishery products is an important pathway for human exposure. Song et al. (2023) investigated microplastic pollution in water bodies across various aquaculture methods. Microplastic concentrations in inland model water were 2.5 times higher than those in ocean model water. The hazard indices of microplastics in surface aquaculture water were 655, 390, and 23, respectively, in inland, coastal, and marine aquaculture systems. Microplastic pollution in bivalves in the inland model was significantly higher than in the other two models. The authors emphasized that microplastics could contribute to the transmission of contaminants through the food chain and increase the risk of human exposure in aquaculture systems. Hossain et al. (2023) suggested that the concentration of microplastics in water and sediment of mud crab aquaculture systems was 127.92 ± 149.9 particles/m^3 and 47.5 ± 11.875 particles/g, respectively. Microplastics with particle sizes ranging from 0.05 to 0.5 mm were more commonly found in water

Table 1
Occurrence of microplastics in aquaculture water.

Aquaculture area	Concentration (particles/L)	Particle size (μm)	Characteristics	Reference
Yangtze River Delta	4.4 to 10.8	100–300	Fibers were the main shape (66.77%), followed by fragments (15.7%), films (9.88%), particles (3.49%), and beads (1.16%). PE and PET were the main components.	Yu et al. (2023)
Neijing River, China	0.1–1.167 (June) 0.2–0.6 (December)	<500	PE, PP, PET, PS, and PA were identified. Microplastic abundance in ponds was significantly higher than that in rivers.	Xiong et al. (2022)
Honghu Lake, China	87–750 particles/m^3	<100	PP, PET, and PE were the first three predominate types of polymers. PP was predominant in the crayfish ponds and fish ponds, whereas PET was predominant in the natural lake.	Xiong et al. (2021)
Pearl River Estuary, China	33.0–87.5	<1000	Most microplastics were in the form of colored fibers, mainly composed of PP and PE.	Ma et al. (2020)
Maowei Sea, China	10.1	<1000	PES, PP, PE, PA, PS, POM, PU, PBT were identified. Fiber, flakes, foam, and fragments, were observed.	Zhu et al. (2019)
South China Sea	127.92 ± 149.9 particles/m^3	>50-500	Fibrous (72.17%) and transparent (59.37%) were the dominate shape.	Hossain et al. (2023)
Hainan, China	523 particles/m^3	<2000	The most common type was foam (91%), followed by fibers (6%), films (2%) and fragments, and the white was dominant (92%).	Lin et al. (2022)
Foshan City, China	288.53 ± 74.27	0.5–1 mm	The proportions of four shapes from large to small are: fiber (96.74%) > film (1.58%) > pellet (1.19%) > particle (0.49%).	Li et al. (2022c)
Chao Phraya River Estuary, Thailand	48 ± 8 particles/m^3	50–300	Fragment shapes and types of PP, PE were predominant. Colored microplastics account for lower proportions with the predominance of blue (14.5%) and green (7.7%).	Ta and Babel (2020)
Mekong River Delta, Vietnam	53.8 ± 140.7 particles/m^3	1235	Fibers were predominant shapes of microplastics. Six colors were observed over the river system. Blue fibers (50%–69%), followed by red and white.	Kieu-Le et al. (2023)

samples, whereas larger particles (>1–5 mm) were more frequently observed in sediment samples. The author suggested that the hazard level in water was Level I, while the hazard level in sediment was Level II.

Lin et al. (2022) investigated microplastic pollution in the aquaculture environment of Hainan Island. The findings indicated that the concentration of microplastics in seawater samples was measured to be 523 particles/m3. The average abundance of microplastics in fish was 7.1 particles per individual, with the majority (99%) being found in the gastrointestinal tract. The content of particles in soft tissues was 0.36 ± 0.81 particles per individual. The bioaccumulation of microplastics is influenced by environmental pollution. Li et al. (2022c) found that the concentration of microplastics in grass carp aquaculture ponds was 288.53 ± 74.27 particles/L. These microplastics were primarily composed of fibers. The microbial community on microplastics showed higher diversity than in water, indicating that microplastics provide a unique habitat within the ecosystem. Ta and Babel (2020) investigated the distribution characteristics of microplastics in sediment and surface water in the aquaculture zone of the Mekong River estuary in Thailand. Microplastic abundance was 48 ± 8 particles/m3 and 39 ± 14 particles/kg in surface water and sediment, respectively. Due to the fact that the estuary is a vital aquaculture area in Thailand, therefore, microplastics could seriously affect human health. Recently, Kieu-Le et al. (2023) also reported that microplastics in the whole Mekong Delta region of Vietnam 53.8 ± 140.7 particles/m3 in water and 6.0 ± 2.0 particles/g dry weight in sediment, respectively. The dynamic flow regime is the key factor affecting the concentration of microplastics in aquaculture areas.

2.2. Occurrence of microplastics in sediments

In addition to sedimentation caused by high density, waves, tides, and microbial colonization also contribute to the deposition of microplastics in the sediment (Table 2). The pollution status of microplastics in offshore sediments globally cannot be underestimated (Shen et al., 2020b; Zhang et al., 2019). Microplastics in sediments are primarily concentrated on fibers and foam in most areas (Belontz et al., 2022) This is mainly due to the widespread use of fishing nets. Broken fishing nets and foam buoys will produce fiber and foam microplastics (Nunes et al., 2023). Flow velocity, particle size, and aquaculture activities are all factors that influence the content of microplastics in sediments (Perumal and Muthuramalingam, 2022).

Wu et al. (2020) investigated the characteristics of microplastic pollution in sediment and typical commercial species. Microplastic abundance in sediment was related to aquaculture activities, with a content of 51–88 particles/kg dry weight and ranging from 0.5 to 2 mm. Microplastics were observed in all species, with a range of 0.95–2.1 particles per individual. Among the species studied, shrimp (*Parapenaeopsis hardwickii*) showed a lower potential for accumulating microplastics compared to other species. Le et al. (2022) evaluated the presence of microplastic pollution in aquaculture sediments. The microplastic content in two surface sediments ranged from 2767 ± 240 to 2833 ± 176 particles/kg dry weight. PP and PE were the two main polymers, primarily derived from aquaculture activities. Liu et al. (2023a) evaluated the pollution of microplastics in a natural mariculture area, and the findings indicated that the microplastic content was 4765 ± 116 particles/kg dry weight in sediment, predominantly consisting of black fibers.

From the offshore culture area to the estuarine culture area, the microplastic content in sediment gradually increased. Furthermore, it was found to be positively correlated with the abundance of microplastics in the intestinal tract of *Trachinotus ovatus*. Jorquera et al. (2022) investigated the distribution of microplastics in sediments from 35 sites in the Chilean Sea of Patagonia. The study found that the average microplastic content was 72.2 ± 32.4 particles/kg dry weight. About 40% of the variation in microplastic concentration is determined by the level of local production activities. Garcés-Ordóñez et al. (2022) reported that the abundance of microplastics in sediment near Santa Marta Island ranged from 0.0 to 3.1 particles/kg. The most common types of microplastics found were fibers and fragments, with PP, PE, and HDPE being the most prevalent polymers. Additionally, microplastics were observed in the digestive tracts of approximately 21.1% of fish species. The microplastics found in the water, sediment, and digestive tract displayed similar characteristics and showed statistically significant correlations. The authors further indicated that microplastic concentrations were higher near estuaries and in urban areas with a high density of fishing activities and aquaculture infrastructure. Nawar et al. (2023) showed that the microplastic content in the water and sediment samples of Pasur River was 2.66 × 10^3 particles/L and 1.57 × 10^5 particles/kg, respectively. Chen et al. (2022b) have revealed that the abundance of microplastics in seawater aquaculture ponds and offshore waters was 49.2 ± 35.9 and 17.1 ± 9.9 particles/kg dry weight, respectively. Chen et al. (2022b) have revealed that the abundance of microplastics in seawater aquaculture ponds and offshore waters was

Table 2
Occurrence of microplastics in sediments.

Aquaculture area	Content (particles/kg)	Particle size (μm)	Characteristics	Reference
Xiangshan Bay, China	51–88	500–2000	Fibers were the most common type of microplastics and accounted for 94.66%. Films and fragments only contributed 3.82% and 1.53%.	Wu et al. (2020)
Hanoi city, Vietnam	2767–2833	<1000	Fibers were dominated microplastic shape, followed by fragment. For fibers, green, white, black and red were most detected. PE and PP were the most common polymers.	Le et al. (2022)
Beibu Gulf, China	4765 ± 116	20–50	Fibers (48.35%) were the most common shape in sediments, followed by fragments (27.99%), and pellets (15.72%). Black had the highest abundance (39.82%).	Liu et al. (2023a)
Inner Sea of Chiloé, Chile	72.2 ± 32.4	200	Fibers being the most abundant particles (88%), followed by fragments (10%) and films (2%). For fibers, the most observed colors were transparent (24%). PET and acrylics were the most abundant polymers.	Jorquera et al. (2022)
Colombian Caribbean	0.0–3.1	500	PP, PE and HDPE were the most abundant polymers. Fibers were the most abundant, followed by fragments, films, foams and granules.	Garcés-Ordóñez et al. (2022)
Pasur River, Bangladesh	1.57×10^5	<500	Fragments were dominant in the sediment samples. Black and brown were dominant, ranging between 23 and 39% and 18–23% particles, respectively.	Nawar et al. (2023)
Qingduizi Bay, China	49.2 ± 35.9	2000–5000	Four shapes of microplastics were observed: fiber, pellet, fragment, and film. The spatial distribution showed a downward trend from the inside to the outside.	Chen et al. (2022b)
Dongshan Bay, China	31–971	<1000	The dominant type, color, and shape were PES and PET, black and white, and fiber. The distribution patterns and hotspots of sedimentary microplastics reflected a deep human footprint.	Pan et al. (2023)

49.2 ± 35.9 and 17.1 ± 9.9 particles/kg dry weight, respectively. Recently, Pan et al. (2023) investigated the presence of microplastic pollution in the estuary beach and near-shore sediments of Dongshan Bay, located in southeast China. Microplastic abundance in surface sediments showed spatial heterogeneity, ranging from 31 to 971 particles/kg dry weight. The high concentration of microplastics on the Midwest coast seems to be caused by increased human activity. The distribution patterns and hotspots of microplastics in sediment indicate a significant impact from human presence.

2.3. Occurrence of microplastics in aquaculture products

Microplastic pollution in aquaculture products cannot be ignored, as environmental microplastics can have a significant impact on the quality and quantity of these products. Kılıç (2022) examined the microplastic feeding status of commercially important species (*Oncorhynchus mykiss rainbow trout, Dicentrarchus labrax European Sea bass, and Sparus aurata Gilthead Sea bream Linnaeus*) from Turkey. Microplastics have been observed in the digestive tracts of approximately 50%–63% of fish. Because fish consumption is an important pathway for microplastics to enter the human body, the findings revealed a potential danger to humans. Ta et al. (2022) found that microplastics were observed in the bodies of *Tegillarca granosa* in aquaculture farms and sales markets, with a content of 6 ± 1 and 11 ± 5 particles, respectively. The microplastic content in mussels from Talaad Thai market and Sriracha Fishery Research Station products was 96 ± 19 and 11 ± 7 particles, respectively. The microplastic content of bivalve samples from the market was much higher than that of samples from farms. This difference could be attributed to the potential contamination of microplastics during the packaging and transportation process. The accumulation of these organisms resulted in biomagnification, thereby affecting human health.

Microplastics have commonly been found in various coastal areas. During the process of artificial aquaculture in ponds, microplastics are released when food dissolves in water. A study conducted by Zhang et al. (2020) has revealed that the average concentration of microplastics in the gastrointestinal tract of commercial fish was 5.4 particles per individual. Another similar study carried out by Teng et al. (2019) showed that the concentration of microplastics in oysters was 2.93 particles per individual. Lv et al. (2019) found that microplastics were detected in eels, loaches, and crayfish, with an average content of 1.7 ± 0.5 particles/individual. Microplastics in water, soil, and animal samples increased from the non-rice stage to the rice planting stage. Additionally, there was a correlation between the abundance of microplastics in aquatic animals and that in farmland soil. The authors further suggested that microplastics in rice-fish farming ecosystems may affect food safety and pose an increased threat to human health. Recently, Yu et al. (2023) also indicated that the microplastic content in crabs was 23.9 ± 15.9 particles per individual, with the highest concentration found in the crab intestinal tissue. Meanwhile, the presence of microplastics in the bodies of crabs was positively correlated with their body weight, suggesting the occurrence of bioaccumulation and potential risks associated with ingestion. Furthermore, a notable positive correlation was observed between the presence of microplastics in products and their impact on the local aquatic environment. Qu et al. (2018) demonstrated that the concentration of microplastics in aquaculture water, sediment, and products were 0.2–0.6 particles/L, 30–80 particles/g wet weight, and 2.3–7.3 particles/individual, respectively. Microplastic pollution around artificial reefs can primarily be attributed to fishing activities in the area, while the intake of microplastics is influenced by the level of microplastic pollution in sediments. Generally, closed or semi-enclosed environments prevent the spread of microplastics, resulting in a rapid increase in the concentration of microplastics in aquatic food. Factors such as the level of microplastic pollution in water, the eating habits of aquatic animals, and variations in individual traits may result in variations in microplastic residues in aquatic animals in both aquaculture systems and natural water bodies (Wu et al., 2022).

2.4. Sources of microplastics

Aquaculture is a complex aquatic ecosystem, and the sources of microplastics are diverse. Firstly, plastic tools would inevitably cause microplastic pollution in aquaculture environments. Fig. 1 illustrates the primary sources of microplastics in aquaculture systems. Owing to weathering, plastic fishing nets can produce microplastics (Yu et al., 2023), thereby causing microplastic pollution in aquaculture ponds (Xiong et al., 2021). A study performed by Wright et al. (2021) has revealed that abandoned, lost, or otherwise discarded fishing nets are a significant source of microplastics in aquaculture environments. Their decomposition can produce 1227 ± 431 microplastics/m^2, with fishing nets (49%) and ropes (40%) contributing the most. Another similar study carried out by Zhang et al. (2021b) reported that fishing nets/ropes are an underestimated source of microplastics in marine fishing activities, particularly in marine aquaculture. Microplastic concentration in marine aquaculture areas was 11.49 particles/m^3, which was significantly higher than the 1.57 particles/m^3 found in other non-aquaculture areas. Simultaneously, the loss of fishing gear and ropes can appear to be out of control in aquaculture areas and contribute to microplastic pollution in aquaculture (Fig. 1).

Secondly, the exchange of water bodies in the closed aquaculture process is also a potential pathway for microplastic input (Fig. 1). Pond aquaculture is the most important mode of freshwater aquaculture, followed by lakes, rivers, and other modes of aquaculture (Wu et al., 2022). Microplastics can be transported to aquaculture ponds, leading to an increase in the background value of microplastics in the water. In addition, the improper disposal of plastic packaging for pesticides and fertilizers can also contribute to the generation of secondary microplastics in ponds (Wu et al., 2023). Chen et al. (2018) found that mariculture activities may be a significant contributor to microplastic pollution. The study revealed that microplastics generated by mariculture were being transported from coastal bays to the open sea. Chen et al. (2022a) also suggested that high concentrations of microplastics were observed in water used for oyster farming. Social development, agricultural structure, and aquaculture scale affect local levels of microplastic pollution.

Thirdly, microplastics can also enter aquaculture systems through feed (Fig. 1). A study done by Hanachi et al. (2019) revealed that fish meal contained microplastics, which showed a positive correlation with the levels found in cultured carp. Another report performed by Yao et al. (2021) indicated that the microplastic content in fish meal ranged from 10 to 54 particles/kg, while the average content in shrimp meal was 107 particles/kg. Moreover, crabs and fish primarily feed on algae and phytoplankton. It is important to note that feeding on algae can also lead to the ingestion of microplastics. The plastic products used in water plant cultivation, crab seedling placement, feeding management, and final harvesting all contribute to a certain amount of microplastic pollution in the river crab pond. Recently, Peller et al. (2021) found that fresh, large, branched algae can bind to microplastics through adsorption and physical entanglement. Meanwhile, Li et al. (2022b) also reported that large algae can capture and intercept microplastics through entanglement, adhesion, encapsulation, embedding, and epidermal biological capture. The widespread presence of both organisms can impact the functioning of the aquatic ecosystem and subsequently influence the transfer of nutrients and energy along the food chain.

Fourthly, atmospheric sedimentation and runoff are also a key source. The discarded wastes are transported to the surrounding environment through wind or water flow (Zhang et al., 2021a). Piñon-Colin et al. (2020) demonstrated that surface runoff was a vital route for microplastics to enter the aquatic environment. Wright et al. (2020) showed that the deposition rate in the atmosphere ranged from 575 to 1008 particles/(m^2·day). Brahney et al. (2020) also found that the average deposition rate of plastic in protected areas was 132 particles/(m^2·day). Although research on the deposition of microplastics in the atmosphere is still limited, in increasingly polluted environment, microplastics transported to aquaculture areas through this pathway cannot be ignored.

Overall, microplastics can be transported through various pathways in aquaculture systems. No matter which method is used, only the potential sources of microplastics can be determined. More accurate source tracking will depend on advancements in understanding the formation process and transport mechanisms. It is important to be vigilant about the presence of microplastics in aquaculture systems, as they can cause low animal growth rates, impaired reproductive function, neurotoxicity, poor eating habits, oxidative stress, decreased metabolic rates, and increased mortality rates in organisms. If these threats are not contained, microplastic pollution is likely to negatively impact aquaculture production. Therefore, the negative impact of microplastics on aquaculture cannot be overstated.

3. Impacts of microplastics on aquaculture systems

3.1. Impacts on aquaculture environment

Microplastics can act as carriers of pollutants, and their long-term and stable presence in aquaculture systems can lead to environmental degradation. Once microplastics are ingested by organisms in the fishery, pollutants can be gradually released under specific conditions. A research performed by Avio et al. (2015) revealed that microplastics could significantly enhance the uptake of polycyclic aromatic hydrocarbons by *Mytilus galloprovincialis*. In addition, microplastics can have a significant impact on the abundance of phytoplankton in aquatic ecosystems. The aggregation of microplastics and algae changes the density of microplastics, and the sinking aggregation affects the synthesis of dissolved organic carbon and the transport of microplastics in aquatic environments (Shen et al., 2023a). Vertical migration of microplastics can lead to their widespread distribution from surface water to sediments, thereby disrupting and disturbing the balance of ecosystems.

Additionally, the extensive use of antibiotics in aquaculture leads to an increase in the concentrations of antibiotic resistance genes (ARGs) in water (Dong et al., 2021). Microorganisms in aquatic environments may develop resistance, and these genes can be transported through the migration and spread of microplastics (Tan et al., 2019). Microplastics increase the concentration of ARGs and the potential risk of antibiotic failure in aquaculture environments. Microplastics also affect microbial communities and carbon nutrient cycling, which may indirectly impact the production of aquaculture systems. The accumulation of microplastics and ARGs in aquaculture systems would enter the receiving

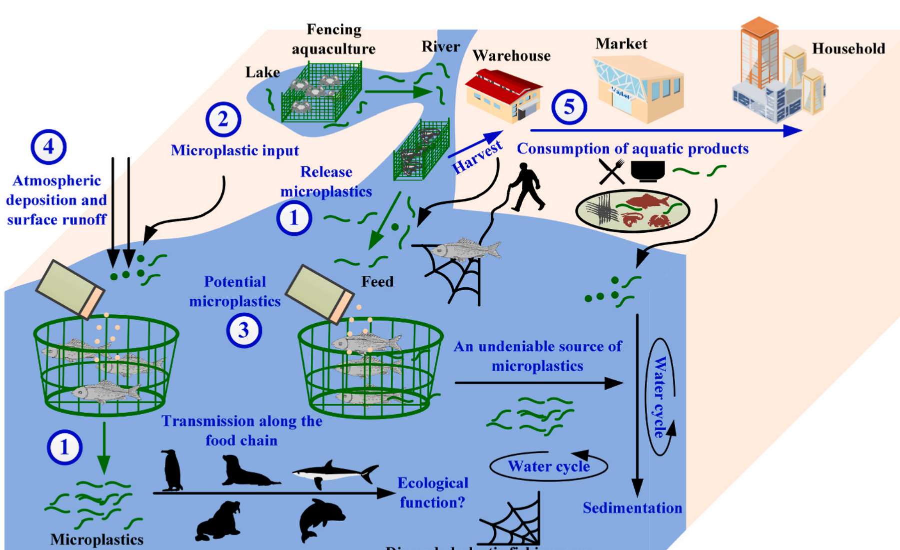

Fig. 1. Main sources of microplastics in aquaculture systems.

water through the effluent. Consequently, microplastics and resistance genes generated during aquaculture could potentially be sources of such pollutants in the surrounding waters.

3.2. Impacts on aquaculture products

These products are the primary source of human nutrition and energy acquisition. However, the persistent presence of microplastics and pollutants negatively impacts their quality. Fig. 2 illustrates the potential impact of microplastics on aquatic organisms. Wang et al. (2022b) reported that the ingestion of feed contaminated with microplastics is a significant pathway for microplastics to enter aquaculture organisms. After ingestion, microplastics were found to accumulate at higher concentrations in farmed *Salmon salar* and *Procambarus clarkia*. The accumulation and retention of microplastics can lead to false food satiety, causing blockage in the digestive system and resulting in structural and functional damage. This, in turn, can affect nutrition and growth (Mahamud et al., 2022). Kim et al. (2022) demonstrated that nanoplastics adsorbed onto the cell walls of microalgae gradually transferred to organisms at higher trophic levels. The presence of microplastics reduced the abundance of Lactobacillus in the digestive tract of grass carp, and significantly decreased the activities of antioxidant enzymes in the intestine. Microplastics not only limit the feeding behavior of *Tripneustes gratilla* (Kaposi et al., 2014), but also reduce the water filtration rate of *Mytilus edulis* (Woods et al., 2018). Nan et al. (2022) conducted a study on the bioaccumulation and in vitro and in vivo toxicity of nanoplastics on Eriocheir sinensis. The findings indicated that nanoplastics can be internalized by crab blood cells, resulting in imbalanced expression of genes related to glucose metabolism. This leads to abnormal cell apoptosis and glucose metabolism disorders. Exposure to nanoplastics can lead to alterations in the antimicrobial immunity of crabs, such as changes in the expression of antimicrobial peptides, survival rate, and bacterial clearance rate. Micro/nanoplastics may also be transferred to the liver, inducing hepatotoxicity and endocytosis/phagocytosis. Lu et al. (2016) also found that after 7 days of exposure, microplastics induced metabolic changes, oxidative stress, and lipid accumulation in the liver of fish. It disrupts the synthesis and transport of phospholipids by altering the levels of choline, phosphatidylcholine, and cholesterol, thereby hindering lipid metabolism (Fig. 2).

In addition, microplastics can also enter aquatic organisms through their gills (Wesch et al., 2016). The microplastics intercepted and accumulated in the gills may cause fish hypoxia, gill infection, and death (Jabeen et al., 2018). A study carried out by Barboza et al. (2020) has revealed that microplastics increase oxidative stress through the overexpression of acetylcholinesterase activity in the brains of fish. This can lead to changes in the nervous system and an increased demand for energy. These phenomena may reduce the adaptability of individual fish, making them more susceptible to diseases and nonpathogenic factors. Moreover, microplastics with small particle sizes can cause damage to the brain (Schür et al., 2019). Additionally, the accumulation of microplastics significantly reduces the respiration and excretion rates of aquatic organisms, leading to a decrease in feeding and absorption efficiency (Jiang et al., 2022). Similarly, Wang et al. (2022c) investigated the enrichment of microplastics in juvenile loach fish (*Paramisgurnus dabryanus*) and examined their effects on growth and liver tissue morphology. Microplastics were found to accumulate in the liver, intestine, and gills, with a higher level of enrichment observed in the liver compared to the gills and intestine. The survival rate, weight gain rate, and specific growth rate of loach larvae were significantly reduced. The activities of superoxide dismutase, catalase, glutathione peroxidase, and acetylcholinesterase decreased as the exposure time prolonged. These factors could potentially lead to changes in the nervous system and an increased demand for energy, ultimately reducing the adaptability of individual fish (Fig. 2).

The presence of other pollutants, such as refractory organic pollutants, heavy metals, and resistance genes, can impact the ecological effects of microplastics on aquatic organisms (Fig. 2). Avio et al. (2015) found that the presence of microplastics obviously increased the absorption of polycyclic aromatic hydrocarbons by *Mytilus galloprovincialis*. Akhbarizadeh et al. (2018) revealed that there was a strong linear relationship between microplastics and heavy metals in fish muscles in the northeastern Persian Gulf. Xin et al. (2021) investigated the bioaccumulation of TiO_2, triclosan, and ZnO in aymonieri through the algae *Asterococcus superbus*. The bioaccumulation of triclosan varied with

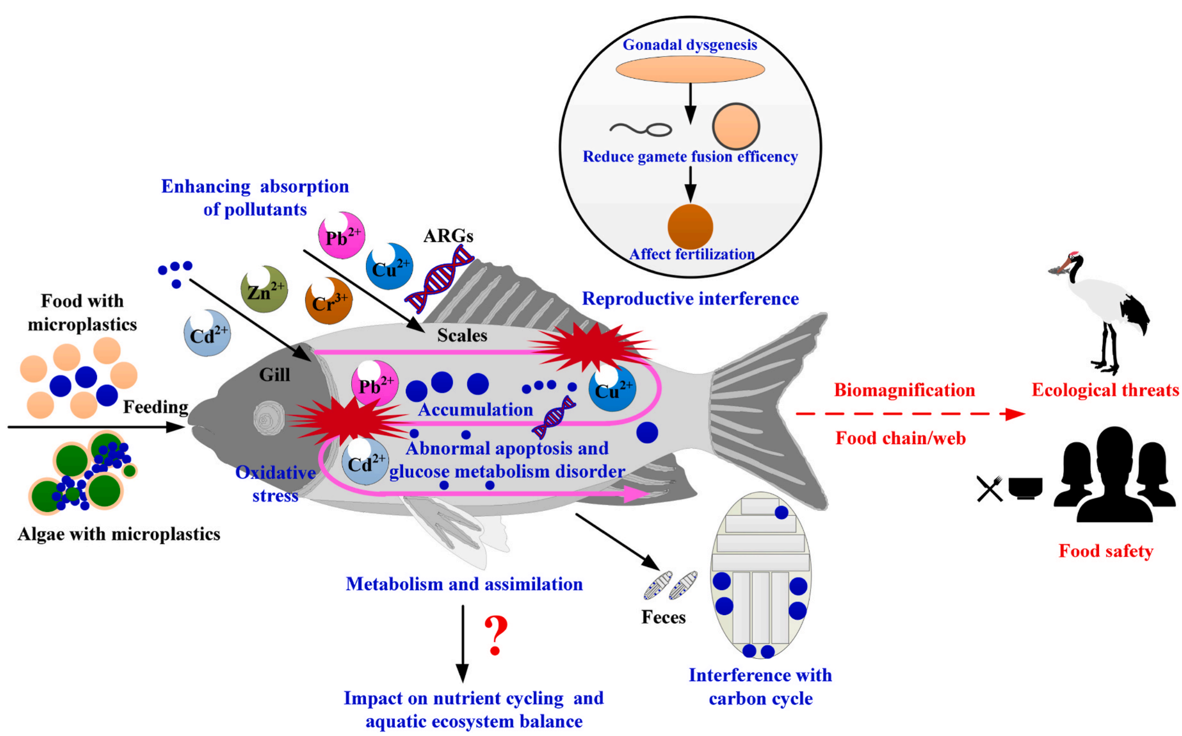

Fig. 2. Potential impact and ecological risks of microplastics on products in aquaculture environments.

changes in algal biomass, while the bioaccumulation of Ti and Zn varied with the content of lipids and proteins in algal cells. TiO_2 was primarily accumulated in fish muscles, while ZnO was predominantly enriched in gills. Zuo et al. (2022) found that Cd^{2+} did not influence microplastic accumulation in the gut. However, they discovered that heavy metal-induced brain lipid peroxidation may cause abnormal motor behavior in fish.

Plastic additives also have an impact on aquatic organisms (Fig. 2). A study done by Han et al. (2022) reported that bisphenol A had toxic effects on the gonadal development of white-legged shrimp. Additives can reduce the efficiency of gamete collision and fusion, thereby hindering the successful fertilization of bivalves. Similarly, another report carried out by Sussarellu et al. (2016) indicated that microplastics and additives had a significant negative impact on the energy absorption and distribution, as well as the reproductive health of oysters. Bonfanti et al. (2021) pointed out that additives can delay fish hatching, thereby affecting subsequent larval development stages.

All in all, the increasing levels of microplastic pollution in aquaculture environments have become a significant threat to aquatic products. Microplastics can cause organisms to experience toxic effects, such as dysplasia, reproductive system disorders, and neurological damage. However, it is still unclear whether they pose a threat to the balance of aquatic ecosystems through the transmission of the food chain. In addition, the coexistence of other toxic substances also enters the fish body through the ingestion of microplastics, which can lead to a series of adverse reactions. Due to the development of aquaculture, the abundance of microplastics in the aquatic system may continue to increase in the future. The environmental and ecological risks associated with this cannot be ignored.

4. Threats to food sustainability and safety

4.1. Threats to ecological sustainability

The impacts of microplastics and pollutants on the reproductive function of aquatic organisms result in a significant decrease in the population, which in turn affects the yield and quality of the products (Sussarellu et al., 2016). The larvae are also an important economic resource, and their quality is influenced by many factors (Chen et al., 2021). Okada et al. (2014) reported that the survival rate of juvenile Pacific bluefin tuna after 30 days in sea nets was as low as approximately 50%. Additionally, they found that 21.9–42.9% of the deceased fish had foamed plastic garbage and wood in their bodies. Tongo and Erhunmwunse (2022) reported that exposure to microplastics can lead to a decrease in swimming speed, travel distance, and movement mode of *Clarias galliepinus*. Microplastics in the gastrointestinal tract increased with higher exposure concentrations, and fish are unable to recognize and avoid ingesting microplastics.

According to reports, global aquaculture production has reached 82 million tons, accounting for 46% of global production (Chen et al., 2021). Undoubtedly, aquaculture products will become a key source of human food and protein. Problematically, the intensification of microplastic pollution in aquaculture environments poses a significant problem, as it causes food safety issues and affects the sustainable development of fisheries. Additionally, it has incalculable impacts on socio-economic development (Iheanacho et al., 2023). Girard and Pérez Agúndez (2014) reported that the high mortality rate has seriously questioned the sustainability of the industry and had a significant impact on the economy. Food safety is an important issue. While humans consume seafood, they also inadvertently consume micro/nanoplastics. However, the actual impact of consuming these micro/nanoplastics on human health remains unclear. It must be faced that microplastic pollution inevitably poses risks to humans and the ecology. As such, priority must be given to the sustainable development of fisheries in order to safeguard the fundamental interests of humanity and the ecological environment.

4.2. Threats to human health

Existing research has shown that microplastics have been detected in both wild fish and aquatic products (Walkinshaw et al., 2020). The probability of microplastics entering the human body through edible products has been demonstrated (Li et al., 2022a). It is generally believed that the intake of microplastics can be reduced by removing the digestive tract and gills, which are not commonly consumed by humans, from aquatic products (Toussaint et al., 2019). Unfortunately, for shellfish and small fish, they are typically consumed as a whole as food. Senathirajah et al. (2021) demonstrated that people worldwide consume an average of 0.1–5 g of microplastics per person per week. Aiguo et al. (2022) investigated the accumulation of microplastics in various fish species. The findings indicated that microplastics accumulation varied significantly based on water depth, feeding habits, and diet. The omnivorous fish that inhabit the bottom have the highest intake of microplastics, while the intake of herbivores in the middle benthic layer and upper layer is the lowest. Microplastics entering the human body can have adverse effects on human health. Tan et al. (2020) found that microplastics can interact with lipid droplets and lipase. Due to their high hydrophobicity, microplastics reduce the bioavailability of lipid droplets by forming heterogeneous aggregates. Microplastics not only can cause oxidative stress, inflammatory damage, and endogenous metabolic changes in cells (Kamalanathan et al., 2021), but they also interact with the immune system (Mahamud et al., 2022). The medical evidence related to persistent organic pollutants and human diseases is conclusive, including cancer, tumors, nervous system diseases and defects, reproductive system diseases, and other diseases in both humans and wild animals (Yang et al., 2022). Oxidative stress is a toxic effect caused by microplastics, which may be attributed to the presence of different functional groups in microplastics. When the body is unable to regulate excessive oxidative stress, it inhibits the function of antioxidant enzymes, which can lead to liver damage and metabolic disorders (Cui et al., 2021). Microplastics entering the human body can impair immune function, potentially leading to autoimmune diseases or immunosuppression. The occurrence of autoimmune diseases may be caused by several mechanisms, such as the release of immune modulators and the activation of immune cells (Mamun et al., 2023).

Additionally, microplastics can also accelerate the spread of pollutants along the food chain in aquaculture environments (Fig. 1). Human consumption of contaminated products may accelerate the spread of heavy metals and toxic organic compounds, leading to a series of symptoms and diseases (Cortes et al., 2021). Wang et al. (2020) showed that microplastics ingested by low-trophic organisms can be transferred to products that are directly consumed by humans, resulting in an increase in trophic levels and an enrichment effect. Liu et al. (2022b) found that the co-exposure of iron and microplastics exacerbated cognitive impairment by disrupting brain iron homeostasis and inducing ferritin degeneration in brain regions related to cognition. The co-exposure also led to significant iron overload and cognitive impairment, as well as increased lipid peroxidation and inflammation associated with iron deficiency. Microplastics that enter the human body cannot be cleared in a timely manner, leading to chronic inflammation (Prata et al., 2020). Although there is currently limited research on microplastics in humans, the issue of microplastic pollution has compelled us to take notice of this phenomenon. Recently, a study performed by Liu et al. (2023b) suggested that the use of bottles and plastic toys could potentially expose lactating infants to harmful substances. Leslie et al. (2022) reported that microplastics have been detected in human blood.

Moreover, microplastics can accelerate the diffusion and transmission of resistance genes. The use of antibiotics in aquaculture is unavoidable, and microplastics have a higher affinity for antibiotics, which accelerates the bioaccumulation of antibiotics. In terms of human health, consuming food contaminated with antibiotics may pose risks (Wang et al., 2021c). The abundance and composition of gut microbiota are influenced by the host's diet, medication, body weight, and overall metabolic status. Resistance genes affect the gut microbiota by altering the specific conditions of the gut. At the same time, environmental pollutants can also alter the composition of intestinal flora and impact the immune system, thereby contributing to obesity and diabetes (Dong et al., 2021).

Problematically, microplastics accompany products throughout their entire lifecycle, from birth and development to harvesting, transportation, and consumption. As a result, they enter the consumer market and have a long-term impact on the human body. With the increasing detection of microplastics in aquatic products, it is evident that the issue of microplastic pollution has become a global phenomenon. How to address the escalating issue of microplastic pollution and its wide-ranging consequences is a global challenge that requires immediate attention. At present, there is no evidence to suggest that consumers have a negative impression of aquaculture products contaminated with microplastics. Some key issues still require further research. What is the probability of micro/nano plastics entering human organ tissues and cells through consumer products? What are the chronic hazards of long-term human exposure to microplastics? Consequently, more comprehensive studies are required to fully understand the threats of microplastics to food safety and human health.

5. Beware of aquaculture becoming a potential source of microplastics in natural water bodies

Microplastics have emerged as a significant menace to the worldwide aquatic ecosystem, and ongoing endeavors are being made to mitigate plastic and microplastic contamination. The fragmentation and disposal of fishing gear have become an undeniable source of microplastics in the aquaculture environment. Aquaculture water bodies are significant sources of microplastics in natural water bodies. Therefore, it is essential to reduce microplastics before discharging them into rivers and lakes. Fig. 3 demonstrates effective control over the release and migration of microplastics in aquaculture environments. To address the issue of pollution, various technologies and methods are being employed to eliminate microplastics from water bodies. These include membrane bioreactors (Shen et al., 2023b), electrocoagulation (Shen et al., 2022b), traditional sludge methods (Sun et al., 2019), etc. Although these new technologies can effectively mitigate the entry of microplastics into the environment, some studies are still confined to the laboratory stage and cannot be replicated and applied to real-world sites. Accordingly, new processes and solutions need to be established to curb microplastic pollution.

a. Control of microplastic release during aquaculture: development of alternatives to plastic fishing gear

Fishing nets, fishing lines, and fences are significant contributors to the presence of microplastics in aquaculture ecosystems. How to reduce the production and release of microplastics during the breeding process is a challenge we face. In recent years, the use of biodegradable plastics as a substitute for traditional plastics has gained global attention and has started to be promoted (Shen et al., 2020a). Deroine et al. (2019) discovered a new generation monofilament that can be utilized to address the proliferation of plastic fragments. The author suggests that polybutylene succinate can be used as an eco-friendly alternative to traditional polyamides commonly used in fishing gear. Cerbule et al. (2022) demonstrated that replacing nylon or polyester with new materials made of biodegradable plastics can potentially reduce macroscopic and microscopic plastic pollution caused by shedding. Unfortunately, however, the high price of biodegradable fishing gear seriously hinders their successful implementation. Additionally, even biodegradable plastics pose a risk of microplastic pollution. Although biodegradable plastics are an ideal substitute for traditional plastics, biodegradable microplastics become another source because of their inability to show ideal degradation performance. (Zhu and Wang, 2020). Using non-plastic tools and equipment in aquaculture fishing gear may be an environmentally friendly alternative (Mnyoro et al., 2022). The commercial application of these natural materials may be a feasible and sustainable solution to reduce microplastic pollution.

Moreover, when developing environmentally-friendly fishing gear, it is also necessary to enhance the regulation of current plastic products used in aquaculture (Fig. 3). Improper handling and disposal of plastic wastes can become a potential source of microplastics in aquaculture processes. It is necessary to conduct environmental remediation work in breeding areas and regularly clean up garbage in heavily polluted breeding areas. This includes removing discarded fishing nets, ropes, and buoys. A recent study performed by Basurko et al. (2023) has shown that 1643 tons of gear are discarded every year in Spanish ports, which comes from trawling (97.5%), gillnet/trawling (2.3%) and purse seine fishing (0.2%). Liu et al. (2022a) indicated that modified polyamides can be prepared by recycling the upper and middle layers of fishing nets. However, different areas and farming environments (freshwater and mariculture) may also restrict the recycling of used fishing gear. In addition, regular maintenance of facilities is carried out to prevent wear/accidental damage and any unexpected situations. In short, industry practitioners are concerned about controlling microplastic pollution in the aquaculture environment while also benefiting from waste fishing gear.

b. Control of external input of microplastics: limitations on feed and water sources

The regular replacement of water sources is a key component of closed lake aquaculture. However, microplastic pollution is also increasing in natural water bodies. The discharge of influent and surface runoff are both sources of microplastics in water bodies (Shen et al., 2022a). Therefore, when it is necessary to replace the aquaculture water body, pre-treatment can be carried out to reduce the input of microplastics (Fig. 1). Moreover, feed is also considered a pathway for the input of microplastics. Finding alternatives to current aquaculture feed is a crucial approach to effectively reduce microplastic exposure in aquatic products. Recently, Iheanacho et al. (2023) suggested that using plant protein feed is an effective strategy for mitigating microplastic pollution in fish. Algae and bacteria may serve as excellent substitutes. However, it is important to exercise caution when collecting algae from the natural environment due to their tendency to rapidly accumulate microplastics in the surrounding water (Long et al., 2015). Dovidat et al. (2020) reported that microplastics can rapidly aggregate in the root area of the freshwater duckweed *Spirodela polyrhiza*. The adsorption of microplastics onto algae roots may result in their transfer to various herbivorous species within the ecosystem.

Furthermore, deep-water aquaculture can also reduce the contact between products and microplastics. Due to limitations in natural conditions, human activities, and technology, aquaculture is primarily concentrated in nearshore bays. The water body is rich in organic matter and plankton, which serve as food for organisms. Accordingly, it is the ideal choice for aquaculture development. However, these regions are also precisely the areas with severe microplastic pollution (Mubin et al., 2023). Deep sea areas have favorable hydrodynamic conditions, high rates of water exchange, and a low abundance of microplastics far from

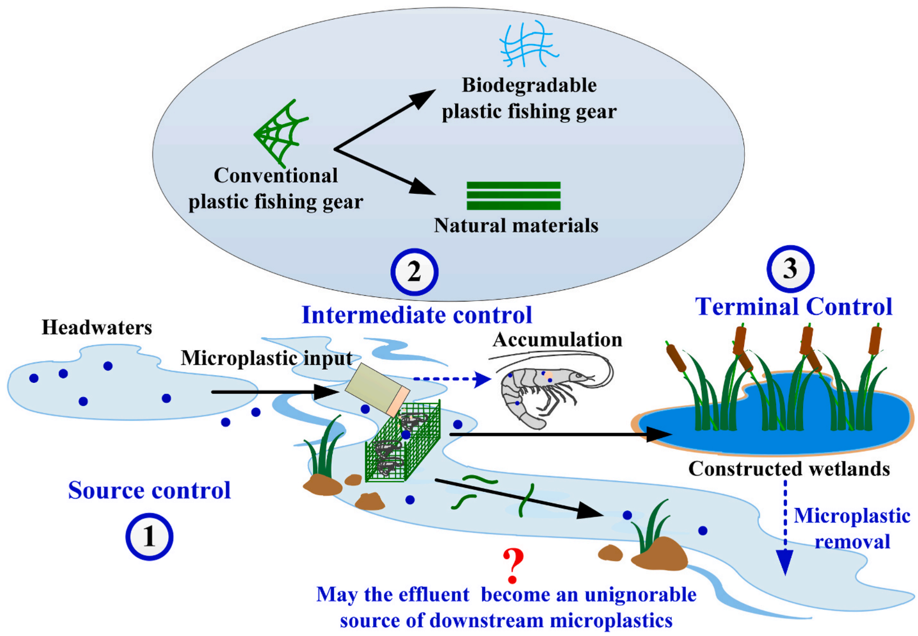

Fig. 3. Control methods for the release and migration of microplastics in aquaculture environments.

land. Actively expanding deep-sea aquaculture may effectively reduce the accumulation of microplastics and other pollutants in aquaculture organisms.

c. Reduction of microplastics in aquaculture system effluent: constructed wetlands

The deterioration of fishing gear and the reduction of water flow during aquaculture can result in the release and movement of microplastics. The discharge of aquaculture water bodies is also a potential source of microplastics in the receiving water. How to prevent the diffusion and transfer of microplastics, and the key issues that need to be addressed at this stage. Constructed wetlands have been proven to effectively remove microplastics from wastewater. Wang et al. (2021a) investigated the removal and interaction of microplastics by *Vallisneria natans*. The findings suggested that the rhizome part of the plant can effectively capture microplastics in water. Wang et al. (2021b) indicated that constructed wetlands can significantly reduce the concentration of microplastics in wastewater, ranging from 6.45 to 0.77 particles/L. Rozman et al. (2023) also recently suggested that constructed wetlands are an effective method for preventing the release of microplastics into the aquatic environment. Additionally, the utilization of natural ecosystems to intercept microplastics in water bodies has also been implemented in practice. Recently, Do and Dang (2022) demonstrated that mangroves can maintain a stable state and mitigate microplastic pollution. Similarly, Duan et al. (2021) also stated that the abundance and proportion of microplastics at the edge of mangroves are significantly higher than those in surrounding areas. Due to the limited distribution of mangroves along the coast, the removal of microplastics from aquaculture waters is still very limited. Therefore, the challenge of removing microplastics from aquaculture water bodies has always been a concern.

6. Upgrading technology

6.1. Continuous monitoring

Now, the methods can only capture the distribution of microplastics in water bodies during a specific time period, whereas it is a long-term and dynamic process. Real-time monitoring and measuring of microplastic distribution in water bodies is of great benefit to improving aquaculture production. As such, it is necessary to continuously investigate the characteristics of microplastic pollution throughout the entire lifecycle of aquaculture. Asamoah et al. (2019) studied a portable prototype optical sensor used for measuring microplastics. The combination of transmission interference detection modes and specular reflection signals can accurately identify the types of microplastics present in a specific volume of water with high confidence. Aguzzi et al. (2019) also reported that video and acoustic imaging have become the primary methods for studying benthic animals and pollutants in a remote, continuous, and long-term manner. The development of in-situ microplastic monitoring technology has broad application prospects in the detection of microplastics. It is required to establish a comprehensive and scientific method for identifying microplastics in order to accurately ensure the comparability of different investigation and experimental results.

Recently, remote sensing technology has also provided a reliable method for the dynamic monitoring of microplastics in aquaculture environments (Wu et al., 2023). While monitoring the changes in aquaculture water pollution, it is also able to effectively understand the patterns of microplastic accumulation and migration. Another advantage is that there is minimal release of secondary microplastics during the monitoring process. The application of remote sensing technology in monitoring microplasticity is practical. Space remote sensing technology can also be used to continuously monitor the influx of microplastics (Garaba and Dierssen, 2018). By determining the exact coordinates of the source of microplastic input, adequate preparations can be made in advance to control the spread of microplastics. Additionally, Li et al. (2022d) designed a micro robot based on ion exchange to obtain self-propulsion for monitoring and removing micro/nano plastics in water bodies. The self-driving micro robot is composed of superparamagnetic ferric oxide nanoparticles functionalized with ion exchange resin microspheres. It utilizes the energy exchanged with impurities in the environment to achieve self-driving without the need for additional energy input. At the same time, the long-range electro-osmosis caused by diffusion swimming greatly improves the adsorption range of micro/nanoplastics. Lidar can also indirectly track the migration and potential accumulation of plastic by monitoring wind direction and ocean currents. In conclusion, scientific and technological progress has facilitated the effective monitoring and removal of microplastics in the aquatic environment.

6.2. Reduction strategies

Removing microplastics from aquaculture products before consumption is a pressing issue that needs immediate attention. Packaging has always been a problem that troubles products in their efforts to avoid microplastic pollution (Fig. 1). Kedzierski et al. (2020) have confirmed that microplastic particles in meat primarily originate from packaging, and removing these particles is challenging. Alak et al. (2021) evaluated the impact of packaging techniques on microplastic contamination in rainbow trout fillets. Microplastics were most abundant in the polystyrene board + film group, while they were least abundant in the chitosan film + polystyrene board + film group. The authors also suggested that microplastics in fish fillets greatly increase human daily intake and exposure to microplastics. Therefore, avoiding the use of plastic products in packaging is a crucial way to reduce microplastic contamination.

In addition, microplastic removal can also take place before packaging. The harvested products can be used to remove microplastics from the surface and interior within a specific timeframe. Recently, a report done by Wang et al. (2022a) stated that the technology of combining bacteria and microalgae has the potential to improve fish yield and water quality in closed circulation culture ponds. It is still necessary to consider the removal of microplastics to prevent their re-entry into the aquaculture water environment. Moreover, purification technology can also be used to remove microplastics from products (Solomando et al., 2021). Most of the current research has focused on the influence of aquaculture activities on microplastic concentrations. However, there is still a significant lack of research on methods to remove microplastics from aquatic organism bodies.

6.3. Establishment of standard methods for human health risk assessment

Farmed seafood may be more susceptible to microplastic pollution than wild seafood, posing a potential risk to the food chain and a threat to seafood consumers. The large specific surface area and high hydrophobicity enable microplastics to absorb pollutants and transfer them along the food chain, resulting in bioaccumulation and biomagnification (Parolini et al., 2023). The changes in human cleaning practices and exposure to microplastics have posed a significant challenge in evaluating their effects. Although studies have shown that the accumulation of microplastics has little impact on humans, microplastics and nanoplastics may affect the gut microbiota and the transport of microplastics, particularly in patients with gastrointestinal ulcers (Shen et al., 2019b). Therefore, it is urgent to establish a connection between the intake of microplastics and the assessment of human health risks in a timely manner. With the continuous growth of the global population, the mariculture industry is on the rise. To clarify the ecological and health risks caused by microplastic pollution is essential for ensuring the safety of aquaculture seafood and promoting the healthy and sustainable development of the mariculture industry.

7. Conclusions

Microplastics, an emerging environmental contaminant, pose potentially serious hazards to aquaculture organisms and product safety that should not be underestimated. Internal sources within aquaculture systems, such as plastic fishing gear, are major contributors to microplastic pollution, and microplastic pollution can cause deterioration, which in turn affects the benefits of aquaculture and poses risks to human health. Microplastics may disseminate through hydrodynamic processes, and it is necessary to further explore remote sensing techniques for comprehensive monitoring. Further research is imperative to quantify the relationship between microplastics and aquaculture products and to evaluate the associated health risks. Simultaneously, attention should be paid to legislative provisions and the limit of microplastics to ensure the sustainable development of fisheries and food safety. Efforts should concentrate on investigating the migration patterns of microplastics in diverse aquaculture environments, as well as studying their toxicological effects and conducting ecological risk assessments. By integrating evidence across disciplines, we can achieve a comprehensive understanding of microplastic impacts on aquaculture and formulate management strategies based on scientific findings.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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