Dean&Francis

ISSN 2959-6157

Microplastic Particle Size Effects in Fish and Shellfish: A Review on Feeding, Digestion, Bioaccumulation, and Seafood Safety Risks

Xifan Zhang

College of art and science, New York University, New York, USA
xz3836@nyu.edu

Abstract:

Microplastics (MPs) have become a pervasive global contaminant, entering marine ecosystems, food webs, and ultimately the human diet. Their environmental and biological effects are strongly size-dependent, influencing ingestion, retention, tissue penetration, and bioaccumulation. Nanoplastics (<1 μm) are of particular concern because they can cross epithelial barriers and accumulate in internal organs, while larger particles are generally confined to the gastrointestinal tract, where they cause physical abrasion and localized tissue injury. Fish and shellfish are critical study targets due to their ecological roles as filter feeders, benthic deposit feeders, and predators, as well as their direct role in transferring MPs from the marine environment to human consumers. Evidence shows that particle size regulates digestive tract damage, distribution in tissues such as gills, liver, and muscle, and trophic transfer efficiency within marine food webs. Nonetheless, significant gaps persist, including inconsistent classification of particle size ranges, limited attention to particles smaller than 10 μm, and inadequate integration of ecotoxicological findings with food safety risk assessments. This review synthesizes current knowledge on the size-dependent effects of MPs in fish and shellfish, with a focus on implications for seafood safety and human health. Advancing standardized methodologies and incorporating size-based risk into monitoring and regulation are urgently needed to guide sustainable fisheries management and protect public health.

Keywords: Microplastics; bioaccumulation; seafood safety; human health.

1. Introduction

Microplastics (MPs) are increasingly recognized as pervasive environmental contaminants that infiltrate aquatic ecosystems, terrestrial food webs, and even the atmosphere [1]. Their persistence, ubiquity, and small size raise pressing concerns for ecological integrity and human health. The COVID-19 pandemic has further accelerated this issue by increasing the use of single-use plastics such as protective equipment, contributing to rising volumes of plastic waste entering natural systems. In marine environments, MPs are now detected in surface waters, sediments, and across trophic levels, underscoring their global reach and long-term persistence [2,3].

Among the various characteristics influencing the ecological and toxicological effects of MPs, particle size plays a particularly critical role. Smaller microplastics, and especially nanoplastics (<1 μm), have the capacity to cross biological barriers and accumulate in internal organs, while larger particles are usually confined to the gastrointestinal tract, where they can cause obstruction and localized injury [1,4]. Experimental studies demonstrate that ingestion probability, retention time, and physiological impacts vary with particle size [5,6]. These findings highlight the need to systematically evaluate how size-specific features govern organism–plastic interactions and subsequent biological outcomes.

Fish and shellfish are highly relevant targets for such assessment. Ecologically, they serve as filter feeders, benthic deposit feeders, and predators, which shape their routes of exposure to MPs. Economically, they form the foundation of global fisheries and aquaculture, supplying essential protein and nutrients to human populations [7]. Their dual significance as ecological indicators and dietary resources makes them pivotal for understanding how MPs transfer through food webs and ultimately reach humans. However, research gaps remain: size classifications of MPs are inconsistent across studies [2], links between organismal effects and seafood safety are rarely established [3,8], and the impacts of particles smaller than 10 μm remain largely unexplored. This review therefore aims to synthesize current knowledge on how particle size influences feeding behavior, digestive damage, bioaccumulation, and retention in fish and shellfish, and to evaluate the implications for seafood safety and human health.

2. Microplastics in the Marine Environment

2.1 Sources

The sources of microplastics are broadly categorized as primary or secondary. Primary microplastics are intentionally produced in microscopic form for commercial or industrial use. These include microbeads in cosmetics and personal care products, micro-sized plastic pellets used as precursors in plastic manufacturing, and synthetic microfibers released during the laundering of textiles. Secondary microplastics, by contrast, originate from the fragmentation of larger plastic debris. Environmental factors such as ultraviolet (UV) radiation, thermal stress, wave action, and microbial degradation progressively break down plastic items into smaller particles. Fishing nets, packaging waste, and bottles represent common precursors, and this continual degradation ensures that marine environments are constantly replenished with particles of diverse sizes and morphologies [2].

Secondary sources are considered the dominant contributors to global microplastic pollution because of the vast amount of plastic debris already present in the environment [3]. emphasize that degradation is persistent and long-term, noting that plastic items in the ocean inevitably fragment into microscopic debris over time. Consequently, even if new plastic inputs were reduced, secondary fragmentation would continue to release microplastics into marine ecosystems for decades to come.

2.2 Classifications

Microplastics are generally classified according to their size, morphology, and polymer composition. The most common size-based distinction separates nanoplastics (<1 μm) from microplastics (1–1000 μm). Nanoplastics are of particular concern because they can penetrate biological membranes and accumulate in tissues, thereby exhibiting higher bioavailability and potential toxicity compared with larger particles [1]. By contrast, microplastics, although less able to cross biological barriers, are more frequently documented in field studies due to the relative ease of their detection with existing analytical techniques.

Beyond size, morphology provides another important classification criterion. Microplastics occur in diverse shapes, including fibers, fragments, beads, and films, reflecting their varied anthropogenic sources. Fibers, commonly derived from textiles, often dominate aquatic samples, whereas fragments typically originate from the breakdown of larger plastic items [3]. These morphological features determine transport dynamics in aquatic environments and strongly influence how particles are ingested and retained by organisms at different trophic levels.

Polymer composition constitutes a further layer of classification. Frequently reported polymers include polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET). Differences in density, durabil-

ISSN 2959-6157

ity, and degradation resistance affect their environmental behavior. For example, low-density polymers such as PE and PP tend to float and persist in surface waters, while denser polymers such as PET are prone to sinking and accumulating in sediments [2]. Owing to their resistance to degradation, these polymers make microplastics one of the most persistent forms of anthropogenic contamination in marine ecosystems [3].

2.3 Distribution

The global distribution of microplastics is now well established. They occur in surface waters, where they interact directly with plankton and pelagic fish, as well as in marine sediments, where denser polymers accumulate and expose benthic organisms to high concentrations [2 3]. Surveys have documented microplastics from open-ocean gyres to heavily populated coastal zones, with hotspots often linked to river discharges and urban runoff.

Perhaps most concerning is their incorporation into marine food webs. Microplastics have been identified in zooplankton, bivalves, crustaceans, and fish, demonstrating that no trophic level is exempt from exposure [1,3] highlight that microplastics are not confined to a single compartment but circulate between the water column, sediments, and organisms, increasing the likelihood of trophic transfer and ecosystem-wide consequences.

Finally, microplastic pollution is not restricted to localized regions but is recognized as a global phenomenon. Oceanic currents transport floating particles across basins, and atmospheric deposition delivers plastics to even remote environments. This worldwide distribution underscores the persistence of microplastics as a chronic stressor, and their frequent detection in seafood species establishes a direct link to human food safety.

3. Feeding and Ingestion Pathways

3.1 Influence of Particle Size

The likelihood of microplastic ingestion is closely related to particle size. Laboratory studies on zebrafish have demonstrated that smaller particles (<20 μm) are more easily ingested, while larger ones are often rejected, expelled, or pass through the digestive tract with little retention [5]. The authors reported that exposure to small polystyrene particles caused both behavioral changes and histological alterations in the digestive system, suggesting that finer particles present greater physiological risks. This finding is consistent with the broader understanding that ingestion efficiency increases as particle size approaches the natural size range of an organism's food items.

3.2 Species-Specific Feeding Strategies

3.2.1 Filter Feeders

Filter-feeding bivalves are highly exposed to microplastics because of their continuous filtration of large volumes of water. Experimental research has shown that the blue mussel (Mytilus edulis) readily ingests microplastic fibers, and that exposure significantly reduces filtration rates [9]. Field studies corroborate these findings, with analyses of mussels (Mytilus galloprovincialis) and oysters (Crassostrea gigas) from Apulia fish markets revealing consistent microplastic contamination, and mussels containing higher particle loads than oysters [6]. These results indicate that filter feeders are especially vulnerable to microplastic ingestion, although the extent of uptake is influenced by species-specific traits and environmental conditions.

3.2.2 Deposit Feeders

Benthic deposit-feeding fish and invertebrates ingest microplastics primarily through their close interaction with sediments, which serve as long-term sinks for plastic particles. Evidence from the Mediterranean Sea indicates that benthic organisms exhibit significantly higher ingestion rates than pelagic species, a pattern consistent with their sediment-based feeding strategies [10]. Such chronic exposure increases the likelihood of particle accumulation in digestive systems and tissues, with potential consequences for organismal health and broader benthic food web dynamics.

3.2.3 Predators

Predatory species are exposed to microplastics primarily through trophic transfer. [11] documented ingestion in several marine fish species, noting that MPs can be mistaken for prey items or acquired indirectly through consumption of contaminated prey. This predator-prey pathway highlights how particle size determines not only direct ingestion but also the efficiency of transfer through food webs. The authors emphasized that predatory ingestion is often "species-specific," depending on feeding ecology and habitat. Such trophic interactions facilitate the movement of microplastics from lower to higher trophic levels, ultimately reaching species consumed by humans.

3.3 Evidence from Laboratory and Field Studies

Both laboratory experiments and field surveys provide strong evidence for particle size–dependent ingestion. Laboratory studies allow for controlled exposures and have consistently demonstrated that smaller microplastics are retained more effectively and cause more severe histological effects [5]. Field studies complement this by documenting ingestion across diverse habitats and taxa. For instance [6], found widespread ingestion in bivalves sampled from European coasts, while [10] reported high rates of microplastic ingestion among benthic fish in the Mediterranean. Together, these studies confirm that microplastic ingestion is not uniform but instead reflects the interaction between particle size, feeding ecology, and environmental conditions.

4. Digestive Tract Impacts

4.1 Physical Damage

Microplastics can induce direct mechanical injury within the gastrointestinal tract. Laboratory and field studies have reported abrasion of tissues, fragmentation of intestinal villi, and excess mucus secretion in organisms exposed to high concentrations of particles [11-13]. Such changes compromise normal digestive function by disrupting nutrient absorption and impairing gut integrity. These alterations resemble responses typically observed under exposure to other irritant stressors, suggesting that microplastics act as persistent mechanical abrasives within the gut.

4.2 Histopathological Changes

In addition to causing physical injury, microplastics are linked to marked histological alterations in aquatic organisms. Documented effects include inflammation, thinning of epithelial layers, vacuolization of enterocytes, and, in severe cases, fibrosis of the intestinal wall. Experimental studies on marine fish exposed to polypropylene microplastics have reported inflammatory cell infiltration and epithelial degeneration in gut tissues [14], while other investigations highlight that prolonged exposure disrupts tissue architecture and triggers chronic inflammatory responses, ultimately impairing digestion and overall physiological health [8].

4.3 Size-Specific Effects

The severity of digestive tract impacts often depends on the size of ingested particles. Small particles (<5–20 μm) are able to cross epithelial barriers and translocate to other tissues, including the liver and circulatory system [4]. This process exposes internal organs to microplastic-associated stress and toxicants, magnifying systemic risks beyond the gut. Evidence from multiple fish species confirms this pattern, showing that nanoscale plastics are particularly concerning due to their ability to reach sensitive tissues such as the brain.

By contrast, larger particles (>200 μm) are generally too big to cross epithelial linings and instead remain confined to the digestive tract, where they may accumulate and cause localized obstruction [5]. observed that zebrafish exposed to larger polystyrene microplastics showed retention in the gut lumen and reduced feeding activity. These size-dependent outcomes underscore the importance of considering microplastic dimensions in toxicological studies, as particle size determines whether effects are localized or systemic.

5. Bioaccumulation and Retention

5.1 Mechanisms of Translocation

Once ingested, microplastics may either remain confined to the gastrointestinal tract or cross into surrounding tissues depending on their size and physicochemical properties. Smaller particles have the ability to translocate through the intestinal epithelium and enter circulation [4] reported that ingested microplastics in fish were “taken up by enterocytes and transported into systemic tissues,” including the liver and gills. This movement across epithelial barriers provides the main mechanism by which microplastics extend their effects beyond local digestive damage to systemic impacts.

5.2 Micro vs. Nanoplastics

The distinction between microplastics and nanoplastics is critical for understanding retention patterns. Nanoplastics, defined as particles <1 μm, are especially concerning because their small size allows them to enter the bloodstream and accumulate in organs [1] emphasized that “nanoplastics can cross biological membranes, accumulate in tissues, and exert toxic effects,” highlighting their elevated potential for bioaccumulation compared to larger fragments. In contrast, microplastics larger than a few micrometers are more likely to be retained in the gastrointestinal tract, where they can cause localized inflammation and obstruction rather than systemic effects.

5.3 Patterns in Fish and Shellfish

Empirical evidence demonstrates that microplastics accumulate in multiple tissues in fish and shellfish [15] analyzed commercial fish from the southern Baltic Sea and found particles not only in the digestive tract but also in the liver, gills, and muscle. The authors concluded that “the presence of microplastics in edible tissues may pose a potential risk to seafood consumers.” These findings confirm that particle translocation is not limited to experimental conditions but occurs under natural exposure levels in

ISSN 2959-6157

commercially important species. Because the muscle is the main edible portion of fish, the detection of microplastics in this tissue directly links environmental contamination to human dietary exposure.

5.4 Trophic Transfer and Human Exposure

Microplastics also move through ecosystems via trophic transfer. Organisms that ingest contaminated prey accumulate microplastics indirectly, facilitating their upward transfer in food webs. [8] reviewed this process and noted that "microplastics can be transferred along trophic levels, ultimately reaching humans through seafood consumption." This trophic pathway underscores the importance of fish and shellfish as both ecological receptors of contamination and vectors of human exposure. The persistence of microplastics in tissues, coupled with their ability to adsorb toxic chemicals such as heavy metals and persistent organic pollutants, amplifies the potential health risks for seafood consumers.

6. Implications for Seafood Safety

6.1 Evidence in Seafood Species

A growing body of evidence confirms that commercial seafood species consistently contain microplastic contamination [15] analyzed fish from the southern Baltic Sea and reported that microplastics were detected not only in the digestive tract but also in edible tissues such as the liver, gills, and muscle. The authors highlighted that "the presence of microplastics in edible tissues may pose a potential risk to seafood consumers," drawing attention to the direct dietary exposure pathway. These findings reinforce observations from other field studies showing that both fish and shellfish destined for human consumption frequently contain ingested particles. The widespread detection of microplastics in seafood underscores the importance of considering size-specific accumulation patterns when evaluating food safety risks.

6.2 Risks for Human Health

The risks posed to human consumers stem from both the physical presence of plastic particles and their role as carriers of toxic chemicals. Microplastics can adsorb heavy metals, persistent organic pollutants (POPs), and other environmental contaminants, which may desorb during digestion and increase toxicological burden [1] emphasized that "microplastics are more than inert particles; they can act as vectors for a wide range of harmful chemicals," including endocrine-disrupting compounds and hydrophobic organic contaminants. Once consumed through seafood, these particles–toxin complexes have the potential to accumulate in human tissues, posing risks to metabolic, reproductive, and neurological health. Vulnerable populations, such as pregnant women and infants, may be at particular risk, as suggested by parallels with studies of transplacental transfer of POPs like DDT.

6.3 Regulatory Gaps

Despite these risks, current monitoring and regulatory frameworks for seafood safety remain inadequate. There are currently no size-specific thresholds for microplastic contamination in seafood, meaning that nanoplastics—which present the highest potential for tissue penetration—are not specifically regulated. Detection challenges exacerbate this issue, as analytical methods for identifying particles below 10 μm remain inconsistent [3] highlighted this problem, noting that "the absence of standardized methodologies hampers comparison of data and the assessment of risks to human health." This lack of harmonization across studies not only complicates scientific assessments but also prevents policymakers from establishing clear guidelines for permissible levels of microplastic contamination in food.

7. Knowledge Gaps and Research Directions

7.1 Small Particle Studies (<10 μm, Nanoplastics)

One of the most critical research gaps concerns the impacts of small microplastics and nanoplastics. While many studies have focused on particles larger than 100 μm in fish and shellfish [5,6,9], far fewer have examined particles below 10 μm, despite their higher potential to cross epithelial barriers and translocate into internal tissues such as the liver, gills, and muscle [4]. Nanoplastics, in particular, are capable of penetrating biological membranes, accumulating in tissues, and exerting toxic effects, highlighting their elevated bioavailability [1]. Nevertheless, the long-term toxicological consequences of particles <10 μm remain poorly understood, and no systematic investigations have yet addressed chronic exposure in either aquatic organisms or humans. Without such data, it remains difficult to define thresholds directly relevant to seafood safety.

7.2 Standardization of Methods

Another major limitation lies in the lack of standardized methodologies for sampling, classifying, and quantifying microplastics [2] noted over a decade ago that inconsistent definitions hindered comparisons across studies, and this remains true today [3] further highlighted that "the absence of standardized methodologies hampers comparison of data and the assessment of risks to human health." Detection methods for small particles remain especially problematic, as most routine approaches fail to reliably identify plastics <10 μm. As a result, existing datasets may underestimate exposure levels, particularly in seafood species where small particle accumulation has been documented [15]. Harmonized international protocols for size classification, polymer identification, and reporting are urgently needed.

7.3 Linking Ecotoxicology to Human Exposure

Current research remains disproportionately focused on ecological impacts in aquatic organisms, while human health implications are comparatively underexplored. Studies have clearly shown that fish and shellfish accumulate microplastics in their digestive tracts, livers, and even muscles [15]. However, few studies integrate this ecotoxicological evidence with food safety assessments to evaluate actual dietary exposure [16] reviewed animal models and concluded that while adverse health effects are evident across taxa, "data directly linking microplastic ingestion to human health outcomes remain scarce." This gap is particularly striking given the economic and nutritional importance of seafood [7] and the demonstrated ability of other persistent pollutants, such as POPs, to transfer through the food chain to humans.

7.4 Interdisciplinary Approaches

Bridging these knowledge gaps requires an explicitly interdisciplinary approach. [8] argued that understanding microplastic risks demands integration of marine ecology, toxicology, and public health perspectives. Laboratory toxicology provides critical insights into mechanistic effects, while field ecology identifies real-world exposure scenarios [11, 12]. At the same time, food safety science and risk assessment frameworks are necessary to translate these findings into dietary guidelines and regulations. Predictive models, including trophic transfer simulations and chronic exposure scenarios, could further help connect ecological outcomes with human health implications. Only by combining these disciplines can researchers move beyond descriptive studies toward actionable evidence for sustainable fisheries and seafood safety policy.

8. Conclusion

The evidence reviewed in this paper demonstrates that particle size is a decisive factor shaping the biological impacts of microplastics in fish and shellfish. Smaller particles, particularly those below 10–20 μm, are capable of crossing intestinal barriers and translocating into internal tissues such as the liver, gills, and muscle, resulting in systemic accumulation. By contrast, larger particles are generally confined to the gastrointestinal tract, where they may cause physical obstruction, abrasion, and reduced feeding efficiency. These size-dependent pathways explain the diversity of histopathological outcomes observed in aquatic organisms, ranging from epithelial inflammation to fibrosis, and highlight the necessity of evaluating microplastic effects through a particle-size perspective rather than treating them as a uniform category.

The presence of microplastics in commercially important fish and shellfish has significant implications for seafood safety and human health. Because these organisms act simultaneously as ecological indicators and dietary staples, their contamination not only reflects environmental pollution but also constitutes a direct exposure pathway for consumers. Microplastics have been detected in edible tissues such as fish muscle, raising concerns that seafood consumption may be a major source of human intake. Beyond their physical presence, microplastics can adsorb and transport hazardous chemicals including heavy metals and persistent organic pollutants, thereby compounding toxicological risks. Populations with high seafood consumption, along with vulnerable groups such as pregnant women and infants, may therefore face heightened health concerns.

Addressing these risks requires both scientific and policy advances. Future research must systematically investigate the long-term effects of sub-10 μm particles and nanoplastics, which remain poorly understood despite their high potential for tissue penetration and chronic toxicity. At the same time, the adoption of standardized methodologies for microplastic detection, classification, and reporting is essential to ensure comparability across studies. Interdisciplinary collaboration between ecologists, toxicologists, food safety scientists, and public health experts will be vital for translating ecological evidence into human risk assessments. On the policy side, regulators should establish monitoring thresholds that incorporate particle size and develop seafood safety guidelines that better protect consumers. Integrating these scientific and regulatory efforts will be critical to advancing sustainable fisheries and safeguarding both environmental and human health in the face of pervasive microplastic pollution.

References

[1] Ziani K, Ioniță-Mîndrican C B, Mititelu M, et al. Microplastics: A real global threat for environment and food

ISSN 2959-6157

safety—A state of the art review. Nutrients, 2023, 15(3): 617.
[2] Andrady A L. Microplastics in the marine environment. Science of the Total Environment, 2011, 409(24): 2177-2190.
[3] Shim W J, Thompson R C. Microplastics in the ocean. Archives of Environmental Contamination and Toxicology, 2015, 69(3): 265-268.
[4] Guerrera M C, Aragona M, Porcino C, et al. Micro and Nano Plastics Distribution in Fish as Model Organisms: Histopathology, Blood Response and Bioaccumulation in Different Organs. Applied Sciences, 2021, 11(13): 5768.
[5] De Sales-Ribeiro C, Brito-Casillas Y, Fernandez A, et al. An end to the controversy over the microscopic detection and effects of pristine microplastics in fish organs. Scientific Reports, 2020, 10: 69062.
[6] Ding J, Sun C, He C, Li J, Ju P, Li F. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. Science of the Total Environment, 2021, 782: 146830.
[7] Azra M N, Okomoda V T, Tabatabaei M, et al. The contributions of shellfish aquaculture to global food security: Assessing its characteristics from a future-food perspective. Frontiers in Marine Science, 2021, 8: 654897.
[8] Bhuyan M S, Venkatramanan S, Selvam S. Effects of Microplastics on Fish and in Human Health. Frontiers in Environmental Science, 2022, 10: 827289.
[9] Woods M N, Stack M E, Fields D M, et al. Microplastic fiber uptake, ingestion, and egestion rates in the blue mussel (Mytilus edulis). Marine Pollution Bulletin, 2018, 137: 638-645.
[10] Rios-Fuster B, Alomar C, Deudero S. Assessing microplastic ingestion and occurrence of bisphenols and phthalates in bivalves, fish and holothurians from a Mediterranean marine protected area. Environmental Research, 2022, 214(B): 114034.
[11] Savoca ML, Wohlfeil R, Kostka JE, et al. Plastic ingestion by marine fish is widespread and increasing. Global Change Biology, 2021; 27(16): 4135–4146.
[12] Rashid E, Hussain S M, Ali S, et al. Microplastics accumulation in gut and revealing their impacts on nutritional quality and health of freshwater carp, Catla catla. Aquaculture Reports, 2024, 38(12): 102299.
[13] Sofield C E, Anderton R S, Gorecki A M. Mind over microplastics: Exploring microplastic-induced gut disruption and gut–brain–axis consequences. Current Issues in Molecular Biology, 2024, 46(5): 4186-4202.
[14] Tian R, Guan M, Chen L, Wan Y, He L, Zhao Z, Gao T, Zong L, Chang J, Zhang J. Mechanism insights into the histopathological changes of polypropylene microplastics induced gut and liver in zebrafish. Ecotoxicology and Environmental Safety, 2024, 280: 116537.
[15] Piskuła P, Astel A M. Microplastics in commercial fishes and by-catch from selected FAO major fishing areas of the southern Baltic Sea. Animals, 2023, 13(3): 458.
[16] Jeong E, Lee J Y, Redwan M. Animal exposure to microplastics and health effects: A review. Environmental Conservation, 2024: 100369.