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Origin, Physical Properties, Biodegradation and Potential Effects of Microplastics on Aquaculture

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ABSTRACT

This review article effectively highlights the critical issue of microplastics, emphasizing their global prevalence and significant impact on aquatic and terrestrial ecosystems. Categorizing microplastics into primary and secondary particles underscores the urgent need for research and action to address the growing plastic pollution crisis, as it poses severe environmental threats that demand immediate, coordinated efforts from the scientific community and policymakers alike. Micro-plastic pollution is a significant global concern that has far-reaching consequences for the environment and human activities, particularly aquatic ecosystems. Microplastics have become pervasive in all marine environments, from the surface waters to the deep ocean, even in remote regions. Their small size, lightweight nature, and colorful appearance make them highly mobile and easily dispersed by wind and water currents. They enter the ocean through rivers, runoff, and atmospheric deposition. They are easily ingested by various species, from zooplankton to large fish and marine mammals. Consequently, the production of these compound pollutants may also find its way into the food chains of aquatic life and, after an extended period of enrichment, into the human body. Furthermore, cumulative harmful effects of compound pollution on human health and the natural environment are a result. The accumulation of microplastics in their organs can disrupt physiological functions, cause behavioral changes, and impair growth and reproduction. Addressing this problem requires global cooperation and a multifaceted approach to reduce plastic production and better manage plastic waste.

1. INTRODUCTION

Plastic particles with an effective diameter of fewer than 5 millimeters are called microplastics **(Zhang *et al.*, 2018)**.

These are found worldwide, from the continents to the oceans. Two broad groups can be made out of their sources. A particular plastic particle is explicitly made in the micron size range and is referred to as a primary plastic particle.

Examples include industrial abrasives (acrylic acid or polyester beads), plastic beads used in toothpaste and cosmetics, etc. **(Magni *et al.*, 2019).** The other is called secondary plastic particles, which are pieces or particles that have broken off from larger plastics in the environment **(Urbanek *et al.*, 2018).**

According to several recent research studies **(Andrady, 2017; Chae and An, 2017, 2018),** plastic pollution is one of the most pressing concerns of our

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day. Daily, the scientific community reports new evidence of the harmful effects of microplastics, their derivatives, and neoplastic detritus on aquatic and terrestrial ecosystems. Small-sized plastic debris (micro-plastics), which come from various sources, including clothing, fishing, cosmetics, and industrial processes, comprise most of the total litter released in natural environments. Their abundance is expected to grow, a severe concern for people and marine life. Many nations have begun to take action against plastic pollution by launching research projects into the issue, launching public awareness-raising campaigns, and setting up and developing standardized protocols to remove microplastics from the environment **(Miller *et al.,* 2017)**.

The majority of plastic waste is disposed of in the ocean. The seafloor might be considered a hotspot for micro-plastic contamination, with densities of up to 1.9 million particles per square meter. For instance, the Tyrrhenian Sea is propelled by substantial accumulations of seabed sediment by bottom currents called near-bed thermohaline currents **(Kane *et al.,* 2020).**

The outstanding qualities of plastics, such as their lightweight, excellent durability, versatility, and comparatively low production costs, have increased their daily use **(Geyer *et al.,* 2017)**. According to **Kreiger *et al.* (2014),** plastic products are widely used in a variety of industries, including packaging (which accounts for 39.5% of all plastic output), construction (20.1%), automotive parts (8.6%), electrical appliances (5.7%), and agricultural materials (3.4%). The remaining percentages include household appliances, sports equipment, and other items. Plastics have been mass-produced since the 1950s **(Geyer *et al.,* 2017).** Plastic manufacturing was already 300 million tons annually in 2013 and is anticipated to reach 33 billion tons annually by 2050 **(Nasrabadi *et al.*, 2023).** There are several different types of plastics, including low-density polyethylene (LDPE), polymethyl methacrylate (PMMA), polyethylene terephthalate (PET), and polystyrene (PS), polyvinyl chloride (PVC), polypropylene (PP), polyethylene (PE), polyamide (PA), polyethylene terephthalate (PET), and polyethylene terephthalate (PE). According to **Geyer *et al.* (2017),** improperly dumped plastic waste has been infiltrating the aquatic environment and travelling great distances through the hydrodynamic process. This has led to global pollution. According to **Aytan *et al.* (2020),** plastic is about 60 to 80 % of marine trash. China is the world's largest plastics manufacturer, producing 59.08 tons annually. The United States comes in second with 37.83 tons, followed by Germany with 14.48 tons, Brazil with 11.85 tons, Japan with 7.99 tons, Pakistan with 6.41 tons, Nigeria with 5.96 tons, Russia with 5.84 tons, Turkey with 5.6 tons, and Egypt with 5.46 tons. Regarding plastic manufacturing worldwide, India reached number 15 **(Kutralam-Muniasamy *et al.*, 2021)**.

2. ORIGIN OF MICROPLASTICS (MPs)

According to **Henry *et al.* (2019),** as synthetic fiber manufacturing rises globally, there is growing fear that microplastics discharged from these textiles will continue to pollute our environment, according to a recent modeling study by **Hoseini and Al Sulivany (2024),** textile fibers considerably contribute to micro-plastic emissions into freshwater. The primary sources of plastic garbage entering the ocean are frequently cited as littering and improper waste management. Primary microplastics are a growing source of worry nonetheless. Due to the voluntarily added micro-beads in products like cosmetics or from the abrasion of more significant plastic things like fabrics or tires, their release is far less noticeable **(Jones *et al.,* 2021).** The first transport medium for micro-plastic particles might be directly released into the environment, depending on the source. Synthetic fabrics (34%), tire wear (29%), city dust (24%), road markings/dust (7%), marine coatings (4%), micro-beads (2%), and plastic pellets (0.3%) are the primary MP sources noted on a global scale **(Boucher and Friot, 2017).** "City dust" refers to familiar sources found in metropolitan areas, such as MPs produced by abrasion, weathering, and pouring. Examples of sources include MPs from plastic utensils, artificial grass, building coatings, synthetic shoe bottoms, home dust, abrasive blasting, and pouring powders. Generally, primary MPs are defined as those particles that are purposefully produced within the MP size range. In contrast, secondary MPs are created when primary MPs are broken down or fragmented in the environment **(Hoseini and Al Sulivany, 2024).**

3. PHYSICAL PROPERTIES

Microplastics' size, color, density, and shape are some of their most researched physical characteristics, and each contributes differently to the unfavorable outcomes. Physical characteristics alter the morphology and mobility of microplastics in the aquatic environment, which impacts bioavailability by changing their distribution there, giving them a similar appearance to natural substances, and inflicting varying degrees of physical harm on the organism. According to **Setala *et al.* (2016),** Organisms with generalist feeding preferences and prey capture strategies (e.g., predators that can only tell food from other substances based on a few characteristics) are more likely to consume micro-plastics that have characteristics that are similar to their natural prey **(Peters *et al.,* 2017).**

3.1 Size

Microplastics are tiny plastic particles with an undetermined lower limit and a size of less than 5 mm **(Koelmans *et al.,* 2015).** Microplastics comprise 92.4% of ocean plastic contaminants **(Yuan *et al.,* 2020).** It has been demonstrated that the size of the micro-plastic has an exponential relationship with the rate of uptake by Daphnia magna and that the proportion of Daphnia magna with micro-plastics in their guts falls as the average particle size rises. According to research by **Kokalj *et al.* (2018),** *daphnids* prefer food smaller than 100 m, consistent with the most common size of microplastic they swallow. Due to its smaller (50 m) food-feeding preferences compared to *daphnids*, *Artemia franciscana* was shown to consume fewer microplastic particles under the same micro-plastic exposure settings **(Fernández, 2001)**. The most frequent microplastics consumed by *Amber stripescad* and *Decapterus muroadsi* (Carangidae) fish are similar in size to their prey, measuring around 1.3–0.1 mm **(Ory *et al.,* 2017).** After ingestion, particle size determines how easily microplastics can move around inside an organism's body. According to **Browne *et al.* (2008),** smaller micro-plastics (3.0 m) translocate within *Mytilusedulis*more readily and easily than bigger particles (9.6 m). When the particle size was more excellent than 20 m, there was very little transfer of microplastics from the digestive tracts to other tissues in the brown shrimp, *Crangon crangon* (L.) **(Devriese *et al.,* 2015).**

3.2 Color

Another characteristic of microplastics that interferes with foraging by visual predators with different ingestion biases is colour. For instance, in a recent study, 80% of the *Amberstripes cads* (*Decapterusmuroadsi*) consumed mostly blue polyethene fragments, which exhibited a comparable morphology to their blue copepod prey in terms of size and colour **(Ory *et al.,* 2017).** The digestive tracts of flathead grey mullet, Mugilcephalus, were discovered to have mostly dark-coloured microplastics, mainly green micro-plastic fibres that resembled sea plankton **(Cheung *et al.,* 2018).** Due to their resemblance to the fish's food supply, the white, clear, and blue micro-plastics that are comparable in colour to the local plankton were the most frequently consumed hues by planktivorous fish in the North Pacific central gyre **(Boerger *et al.,* 2010)**. Therefore, the colour of microplastics has a considerable impact on the ingesting propensity of visual predators. The hue of micro-plastics was investigated as an intuitive signal reflecting the possible toxicity of micro-plastics in addition to its effect on ingestion preferences. While there was no difference in the enrichment of PAH in micro-plastics made of polyethylene and polypropylene, an expected rise in the PAH content was seen along with a darkening of the hue. Additionally, darker microplastics have higher molecular weight PAH, while lighter microplastics are likelier to have lower molecular weight PAH **(Fisner *et al.,* 2017).**

3.3 Density

The trajectory, sinking velocity, and spatial distribution of microplastics are all influenced by density, which also impacts how widely distributed they are in various biota and habitats. For instance, high-density micro-plastics have repeatedly been found in the digestive tracts of benthic invertebrates **(Naidu *et al.,* 2018),** and low-density micro-plastics that spread to the sediments on the seafloor endanger the deep ocean biota **(Jones *et al.,* 2021).** Low-density polyethylene (LDPE), used in packaging and medical purposes, accounts for 20% of all plastic trash produced worldwide **(Irfan *et al.,* 2022).** Many products that inhibit epidemics (such as garbage bags and bins, shoe bags, and clothing) are made using LDPE. The UN World Health Organization (WHO) predicts that the need for medical personnel will continue to rise as the COVID-19 pandemic spreads **(WHO, 2020).**

3.4 Shape

Albanese *et al.* (2012) state that microplastics can also be categorized as spheres, fibres, pieces, pellets, films, and flakes. By disrupting the distribution and bioavailability, the form modifies the hydrodynamic properties of microplastics, which are related to several biological and toxicological impacts. In contrast to density, shape indirectly influences the dynamics of microplastics. Because of their different forms, microplastics settle at different rates in aquatic settings **(Khatmullina and Isachenko, 2017).** Even though the debris' density and volume are the same, plastic fibres and thin films have higher buoyancy and slower settling velocities than spherical plastic particles **(Zhang, 2017).**

4. OCCURRENCE AND THE FATE OF MPs IN THE AQUATIC ENVIRONMENT

4.1 MPs in Fresh Water Environment

According to some data, wastewater effluent and terrestrial flow are the primary sources of micro-plastic pollution in freshwater sources **(Hamidian *et al.,* 2021).** According to research by **Lebreton *et al.* (2017),** there is a direct association between the amount of plastic trash generated in the upstream watershed and the amount of plastic garbage in the river. According to **Luo *et al.* (2019),** urban areas are one source of plastic emissions. For instance, the Danube River contains much plastic trash, which, according to **Lechner *et al.* (2014),** constitutes around 79% of the industrial raw materials released from urban areas. Urban regions may experience plastic pollution of rivers due to discharge channels like wastewater discharge, wastewater overthrow, rainwater discharge, and littering **(Wagner *et al.,* 2019).**

4.2 MPs in Marine Environment

MPs can be classified as primary or secondary based on their origin. Before entering the environment, primary MPs are transformed into minute particles via direct releases of MP-containing items such as fibres or micro-beads from textiles, pastes, cosmetics, paints, and gels. Large plastic debris broken apart releases secondary MPs into the environment. Thus, a variety of items, including plastic bags, fishing nets, and beverage bottles, are sources of secondary MPs **(Wang *et al.,* 2020).** Most plastic waste in marine environments comes from land, the remainder from shipping and fishing operations **(Khalid *et al.,* 2021).** Due to ocean currents, winds, sea ice, and other factors **(AloSairi *et al.,* 2020),** these plastic particles can travel great distances. Aiming to reduce microplastics in marine ecosystems through improved plastic product design and increased plastic waste recycling rates, the European Strategy for Plastics in a Circular Economy was established in 2018 **(Crippa *et al.,* 2019)**.

Since then, despite growing interest in the problem of microplastics in the marine environment, there is still a lack of knowledge about how these materials may impact ES provisioning and biodiversity as well as the health of marine ecosystems **(Vihervaara *et al.,* 2019).** Given that more than 40 million people worldwide depend on fish for food**,** it is important to have a timely discussion on the presence and concentration of microplastics in fish. **Hoseini and Al Sulivany (2024)** found that the productivity at lower trophic levels and the transfer of energy between trophic levels impact the ecosystem service of fish provisioning, which also depends on the complexity and structure of marine food webs **(Buonocore *et al.,* 2019).** Many researchers have reported on recent studies on microplastics that concentrated on their toxicological effects at the molecular, cellular, and tissue levels of single individuals or certain species **(Reineccius *et al.,* 2020).** However, additional research is required to examine the possible harm that microplastics may cause to ecosystems. Ecosystem-based management strategies, like the ecosystem approach to fisheries, are aware of the close connection between robust and healthy marine ecosystems and human well-being. According to **(Zhang *et al.,* 2020),** the primary sources of MPs entering the sea include coastal land and river input, atmospheric transportation, and offshore operation activities.

4.3 Daily MPs Discharge in The World/Oceans

Asia is the world's most significant producer of plastic, with worldwide production rising 216 times from 1.7 106 tons in 1950 to 3.68 108 tons in 2019. 25 million people who live around the Sea of Marmara dump wastewater from their urban, industrial, and municipal activities into the water **(Gedik *et al.,* 2022).** 6.9 million m^3 of wastewater is dumped into the ocean daily, and pretreatment techniques treat more than half of it **(Oztürk *et al.*, 2021).** Given the volume of wastewater and treatment standards, MP pollution is a significant problem for the Sea of Marmara.

Variable MP Concentrations have reportedly been found in open ocean sediments, including those from the Arctic **(Bergmann *et al.,* 2017),** the subtropical North Atlantic **(Reineccius *et al.,* 2020)**, and the western Pacific Ocean **(Zhang *et al.,* 2020).** While MPs are known to exist on seafloors all around the world, nothing is known about how they are transmitted and concentrated in the deep sea. According to earlier research **(Zhou *et al.,* 2021a),** MPs are transferred to the seabed through the vertical settlement of surface deposits. The primary MPs in the marine environment are thought to be transported and accumulated via land **(Harris, 2020).** Numerous rivers, such as the Ganges, Brahmaputra, and Meghna, are known to empty into the BOB. It is also estimated that the Ganges discharges 1-3 billion MPs into the BOB daily **(Napper *et al.,* 2021).** According to a recent study, Laizhou Bay in the Bohai Sea had the highest MP diversity index, 1.84 ± 0.18. This finding suggests that many rivers entering the area and developing towns that sustain intense human activity may be the causes of the high MP diversity **(Sun *et al.,* 2021).** According to **Gao *et al.* (2022),** the diversity index of MPs in sediments reached 1.93, indicating that frequent shipping and anthropogenic activities may result in many MPs in ports.

4.4 Transfer of MPs in Aquatic Environment

The sources, quantity, degradation, and interactions of MPs with their surface species in aquatic environments have been studied **(Priya *et al.,* 2022).** Many suspended objects are transported to the surfaces of aquatic bodies and even to urban, rural, and remote places via the atmosphere by wind speed and direction, up/down drafts, convection lifts, and turbulence.

Numerous mechanisms have been observed for microplastics to enter freshwater species. Filter feeding, suspension feeding, direct ingestion, and trophic transfer by consumption of prey exposed to microplastics are only a few of these mechanisms **(Nelms *et al.,* 2018).** Globally, marine systems have been found to include microplastics **(Wang *et al.,* 2018).** In an investigation that sampled the seawater on the coast of South Korea, cities coastal areas had a mean micro-plastic abundance as high as 1051 particles/m3, compared to rural coastal areas, which had 560 particles/m3 **(Song *et al.,* 2018).** Microplastics are also accessible to various aquatic creatures due to their small size and massive surface area, which may harm the entire food chain. Amphipods, copepods, lugworms, barnacles, mussels, decapod crustaceans, seabirds, fish, and turtles are some of the aquatic organisms that have been found to ingest micro-plastics **(Nelms *et al.,* 2018).**

Therefore, the feeding behaviour and the concentration of microplastics in both surface water and sediments impact the uptake of microplastics by freshwater organisms. Animal migration, such as anadromous fish, can also spread microplastics between habitats, ingested by subsequent animal generations. The amount of microplastic contamination in the aquatic ecosystem can also be determined by whether fish or shellfish have microplastics in their digestive tracts. Asian clams (*Corbicula fluminea*), for instance, have been proposed as bio-indicators because they represent internal exposure levels of micro-plastics in benthic organisms, are accessible and widely dispersed throughout the system, and can give an indication of their food sources over a wide geographic area **(Su *et al.,* 2018).**

5. IMPACTS OF MPs ON THE AQUATIC ECOSYSTEM

5.1 MPs As a Vectors

Plastic pollution is a significant global problem that poses a cross-border hazard to the environment and people's health **(MacLeod *et al.,* 2021).** These particles, which can be poisonous or fatal when they approach nano-size (1 m), can be ingested by living things and penetrate immunological barriers. They can then impact the functionality of organs, tissues, and even individual cells **(Rafiee *et al.,* 2018).** Widespread plastic contamination in terrestrial and marine environments has been caused by improper management of plastic trash **(Rakib *et al.,* 2021; Rakib *et al.,* 2022).** As a result, numerous studies have documented the harmful effects of MP, including changes in fish species' metabolism **(Karbalaei *et al.,* 2021; Xu *et al.,* 2019).** Rafting dispersal can encourage the spread of invasive species, especially in light of the enormous amount of litter and the high permanence of plastic items in the waters across the world. In particular, given the possible negative roles played by microplastics on microbial structure and metabolism, interactions of plastic particles with aquatic microbiota at smaller size ranges represent a new research challenge that has to be clarified **(Caruso *et al*., 2018).** The hazard to aquatic biota and aquatic ecosystems has been highlighted by using aquatic invertebrates as prey by predators to explore MP trophic transmission across food webs, resulting in deadly or sub-lethal effects **(Windsor *et al.,* 2019).**

For instance**, Junaid and Wang (2021)** recognized the MPs' ability to absorb contaminants in a recent assessment. The distribution, fate, and interactions of MPs in aquatic environments have been the subject of Ecotoxicological studies. Furthermore, micro-plastics have the potential to act as carriers of a variety of coexisting environmental contaminants, including viruses, persistent organic pollutants, heavy metals, and toxic chemicals. Bring harmful substances to living things **(Moura *et al.,* 2022).** The density, bioavailability, surface charge, and toxicity of plastic particles are all distinct. According to **(Ferreira *et al*., 2022),** this is a "complex, dynamic mixture of polymers and additives to which natural organic matter (NOM), microorganisms, and pollutants can successively bond to form a biofilm or an eco-corona" in the environment. Additionally, various natural materials like glass, cellulose, and wood, as well as planktonic species and even birds, are strongly influenced by microorganisms like Vibrio **(Lenz *et al.,* 2015).**

5.2 MPs As a Carrier of Micro-Organisms (Biofilms)

MPs can survive in freshwater environments for decades due to their low susceptibility to weathering and ageing **(Basheer *et al.,* 2024),** and they can migrate and travel over vast distances under the influence of wind and hydrodynamic forces **(Hurley *et al.,* 2017).** Almost 6300 million metric tons of plastic garbage were produced between 1950 and 2015 due to the enormous rise in plastic consumption, with output reaching 381 million metric tons in 2015 also, most plastics (79%) end up in landfills or other natural habitats, even though the recurrent use of plastic garbage has recently demonstrated a rising tendency **(Geyer *et al.,* 2017).** According to a study, biofilm that forms on substrates like MPs transports toxins from estuaries to the oceans. Heavy metals and drugs, both of which have been linked to antibiotic resistance, can be absorbed by MPs **(Richard *et al.,* 2019).** Thus, in the aquatic environment, MPs might serve as vectors for infections and antibiotic-resistance genes **(Koch *et al.,* 2021).**

MPs have detrimental effects on the ecological environment and substantial harmful consequences for both humans and marine life. First, harmful plasticizers that hurt the environment are released into the sea. Second, MPs and persistent organic matter can interact to create composite pollutants with more substantial toxicological effects thirdly, interaction with heavy metals may alter the surface structure of MPs, causing them to become charged in saltwater and increase their toxicity. After consuming MPs, marine animals may collect harmful chemicals, which harm marine habitats' biodiversity **(Ahmad *et al.,* 2020).**

It is crucial to compare the microbial communities growing on plastic and natural substrates injected with the same source populations because MP serves as a novel surface for biofilm colonization. However, few studies have examined the formation of biofilms on plastic and non-plastic surfaces **(Ogonowski *et al.,* 2018),** and most recent research has focused on comparing MP-associated and aquatic communities **(Jiang *et al.,* 2018)**. More crucially, compared to assemblages on natural substrates, the particular assemblages colonizing MP may show unique microbial roles with consequential ecological effects.

6. EFFECTS OF MPs ON AQUATIC BIOTA

The health of aquatic biota is currently seriously threatened by plastic-related entanglement, ingestion, and probable toxicity **(Ostle *et al.,* 2019; Owais *et al.,* 2024).** MPs are readily swallowed by aquatic species, accumulate in tissues, and move through food webs due to their small size, broad surface area, and strong hydrophobicity **(Kane *et al.,* 2020).** As one of the most studied behavioral responses of aquatic organisms to MP exposure, the locomotor activity measured by the average speed and moved distance has been used more and more as a sensitive indicator for determining the impact of MPs **(Reineccius *et al*., 2020).**

Recent reports of conflicting effects of MPs on aquatic biota locomotors' activity at environmentally relevant concentrations, such as hyperactive swimming behavior **(Chen *et al.,* 2020)** versus increased static duration **(Bringer *et al.,* 2020),** have been widely reported, and these arguments perplexing both the general public and the community of scientists. In addition, several studies suggested that MPs ingested by aquatic organisms could be retained and accumulated in the gastrointestinal tract, which could lead to several harmful physiological reactions, including a reduction in energy reserves **(Yin *et al.,* 2019)**, a disorder of metabolism **(Zhao *et al.,* 2020)**, symbiosis of the gut microbiota **(Wan *et al.*, 2019)**, and an inflammatory response **(Jin *et al.,* 2018)**. These negative consequences show that MPs may modify aquatic organisms' ability to move by altering their energy supply, physical health, and behavior **(Limonta *et al.,* 2019)**.

6.1 Diseases in Fish Caused by Microplastics

Over 40% of all vertebrates, which vary in size, form, habitat, and biology, are fish **(Maulu *et al.,* 2020)**. In addition to the elements above, fish development, production, reproduction, and illness susceptibility or resistance can all be impacted by infectious diseases and pollutants such as pesticides, micro-plastics, and even nanoparticles **(Zhou *et al.,* 2021b)**.

Oocyte number and diameter, as well as sperm velocity, significantly decreased in MP-exposed oysters when they were allowed to spawn. Compared to control offspring, the yield of D-larvae development in the progeny of MP-exposed parents fell by 41% and 18%, respectively. **Bour *et al.* (2018)** similarly reported an imbalance in energy reserves. A 4-week MP exposure trial with the sediment-dwelling marine clam (PE MPs, three size classes: 4-6, 20-25, and 125-500 m, and three concentrations: 1, 10, and 25 mg/kg of sediment). The lipid content and overall energy reserves of *Ennucula tenuis* decreased with concentration.

In a recent study by **De Sá *et al.* (2018)**, the findings from 130 studies describing the Ecotoxicological effects of MPs on aquatic creatures were compiled. Fish (21%), molluscs (18%), annelid worms (7%), echinoderms (7%), and rotifers (2%), in that order, were the next most often researched groups after crustaceans (45%). These groups occupy various positions in the aquatic food chain, with fish typically acting as intermediate or apex predators that may consume.

The freshwater sediment-dwelling *Diptera Chironomus tepperi* experienced adverse consequences for its growth and emergence due to environmental concentrations of PE MPs. Particle size significantly impacted these effects, with particles with a size range of 10–27 m producing more pronounced reactions **(Ziajahromi *et al.,* 2018)**. Despite consistent body accumulation at 24 h exposure, which largely depended on dose and life stage (i.e., juveniles ingested more MPs than adults), chronic exposure of the amphipod *Gammarus pulex* exposed to PET fragments (10–150 m size range) did not affect survival, development (molting), metabolism (glycogen, lipid storage), or feeding activity **(Weber *et al.,* 2018)**.

The neurotoxic effects of microplastic exposure were validated in a lab setting by assessing acetylcholinesterase (AChE) activity in fish, among other consequences **(Barboza *et al.,* 2018)**. Microplastics can impact antioxidant defence responses, which in turn cause lipid peroxidation (LPO) of cellular membranes, enhancing cellular oxidative stress and neurotoxicity **(Alomar *et al.,* 2017)**.

These results are concerning because the activity of the enzymes cholinesterase (ChE), some of which are crucial for cholinergic neurotransmission in neuromuscular junctions and cholinergic brain synapses **(Massoulié *et al.,* 1993)**, and lipid peroxidation (LPO), which is recognized as an essential molecular mechanism involved in the oxidative damage to cell structures and in the toxicity process that results in cell death. Furthermore, due to the potential consequences of transferring these tiny plastic items and/or associated pollutants to edible fish tissues, microplastics detected in the stomachs of several commercially significant fish species constitute a potential concern to human health **(Fossi *et al.,* 2018)**.

Fish exposed to micro-plastic exhibit changes in feeding, swimming, predatory performance, foraging, and ventilation patterns **(Liang *et al.,* 2023)**. Immunity, growth, reproduction, survival, metabolism, and other toxicological reactions (such as oxidative stress) are all impacted by micro-plastic intake in fish. Microplastics can also harm organs and trigger apoptosis and inflammatory reactions. Small fish and bivalves have large concentrations of microplastics in their digestive tracts **(Adineh *et al.,* 2024)**. Microplastics reach the human diet when such fish are consumed **(Smith *et al.,* 2018)**.

Barboza *et al.* (2020) investigated the presence of microplastic contamination in three economically significant fish species: European seabass *(Dicentrarchusl abrax)*, Atlantic horse mackerel (*Trachurus trachurus*), and Atlantic chub mackerel (*Scombercolias*). According to **(Fang *et al.,* 2021)**, crucian carp livers suffered oxidative damage from acrylic micro-plastics exposure. The levels of antioxidant enzymes (CAT and SOD) were found to be declining, while ROS and LPO levels were rising. According to **(Li *et al.,* 2022),** polypropylene microplastic exposure elevated oxidative stress in the intestines of grass carp by causing inflammation and immunological activation. Due to their buildup in seafood like fish, microplastics and pesticides impact human health **(Adineh *et al.,* 2024).** Microplastics and pesticides are ingested and retained by aquatic species in some organs, resulting in oxidative stress and a consequent decrease in the growth and quality of sea life **(Pagano *et al.,* 2020; Stara *et al.,* 2020).**

7. METHODS FOR DETECTION OF MPs IN AQUATIC ENVIRONMENT

After the purification and separation procedure, MPs must be distinguished from the leftover plastics to conduct the analysis. Notably, although large plastics can be sorted quickly, minute MPs require further monitoring with an optical microscope. The MPs may be recognized visually thanks to their consistent color, brightness, and lack of cellular characteristics. Visual sorting is carried out; however, it is not necessarily reliable. Only a few studies (**Sathish *et al.,* 2019; Jeyasanta *et al.,* 2020)** have combined visual sorting with hot needle tests to demonstrate the existence of MP.

The surface morphology and elemental analysis of NPls can be characterized using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) **(Mariano *et al.*, 2021).** It must be dried before the sample is placed on a surface for viewing **(Fu *et al.,* 2020).** Since plastics do not conduct well, surface-charging effects are minimized by coating the sample with a thin, conductive layer of metal or graphite **(Mariano *et al.,* 2021).** The sample must also be electrically grounded to avoid any electrostatic charge accumulation. As a result, one of SEM's significant limitations is sample preparation. Other drawbacks include high expenses and sample destruction **(Doan *et al.,* 2023).**

By gathering fluorescence emissions emitted by the excitation of fluorophores, fluorescent microscopy creates an image of the sample **(Mariano *et al.,* 2021).** Because polymers naturally emit fluorescence, fluorescence microscopy is excellent for illustrating plastics. Due to its selectivity for plastic particles, Nile Red, a fluorescent dye, can quickly detect and quantify NPls **(Li *et al.,* 2022).** However, pre-purification is necessary for environmental samples since Nile red also stains NOM. Furthermore, chemical pollutants and additives can affect and obstruct the fluorescence signals **(Al Sinjari, *et al.*, 2019; Fu *et al.*, 2020).**

When the dipole moments of the molecule change due to the absorption of infrared radiation, infrared (IR) spectroscopy is used to quantify the transitions between molecular vibrational energy levels **(Lee and Chae, 2021)** based on the sample's adsorption or emissions, FTIR generates a spectrum that corresponds to particular chemical bonds. The properties of the sample can subsequently be determined for plastics by comparing the resulting IR spectrum of the unknown sample with the spectra of well-known plastic polymers **(Mariano *et al.,* 2021).**

8. MICROPLASTIC DEGRADATION

Microplastics (MPs) significantly impact aquaculture and the aquatic environment, with various tools and equipment used in fish farming made from or containing plastic materials. These include fishing nets, buckets, breeding and hatching devices, and more. The extensive use of plastic in fishing gear and aquaculture equipment has led to a considerable amount of plastic waste being discharged into water bodies. This pollution is particularly problematic in oceans and can result from lost or discarded fishing gear. For example, the accumulated lost/discarded fishing gear (trawls, purse seines, Danish seines, gillnets, long lines, and traps/pots) was less than 500 tons in 2007. However, it was over 4000 tons 2016 in the oceans along the Norwegian commercial fishing alone **(Deshpande *et al.,* 2020).**

Microplastics in aquaculture systems have diverse sources, including fishing gear, plastic products used in fish farming, equipment in breeding facilities, feeds (both natural and synthetic), animal health products, atmospheric precipitation, and recreational fishing activities. Microplastics can be absorbed by aquatic animals and plants and attached to aquatic microorganisms. This means that MPs can enter the aquatic food chain, eventually making their way into the human food supply when people consume seafood **(Wang *et al.,* 2020).**

9. CONCLUSIONS AND FUTURE PERSPECTIVE

Plastics and microplastics have become an intricate part of aquaculture, but their pollution and the complex interactions between microplastics and aquatic environments pose serious challenges to the industry. This issue necessitates further research, environmental management, and sustainable practices to mitigate plastic pollution's impact on aquaculture and the marine ecosystem. Many organisms are being exposed to these particles, which could have various negative effects and endanger various species, the ecosystems in which they exist, and, ultimately, humans. Microplastics have significant, often indirect, financial effects on tourism, resulting in costs that producers and polluters rarely bear. Microplastics degrade an ecosystem's recreational value, aesthetics and historical value, and it appears that these contaminants will continue to grow in number, as it is impossible to eliminate their presence. On the other hand, microplastics' adverse effects cannot be mitigated without involving the public, socio-economic sectors, tourists, government policy and regulation, and waste management companies.

- Reducing Plastic Use: Encouraging the reduction of single-use plastics and the development of more environmentally friendly materials.
- Enhanced Waste Management: Improving waste collection and recycling systems to prevent plastics from entering the environment.
- Regulations and Bans: Implementing regulations to ban microbeads in personal care products and limit plastic waste.
- Research and Monitoring: Researching to understand better the extent of the problem and its ecological impacts.
- Education and Awareness: Raising public awareness about the consequences of microplastic pollution and the importance of responsible plastic disposal.

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There is no conflict of interest regarding the publication of this manuscript.

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