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Microplastics in Aquatic Ecosystems: Impacts on Fish Health and Potential Risks to Human Health

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Abstract

Marine ecosystems are affected by both micro and macroplastic pollution, which is a major environmental concern. Fish and other marine organisms may suffer physical and metabolic damage if they consume these particles. Microplastics (MPs) can build up in fish and result in digestive obstructions, stunted growth, and altered behaviour. Significantly, exposure to microplastics impairs physiological processes, such as redox or oxidative stress, alters reproductive health, and harms the liver and gills. Through a contaminated food chain, microplastics can find their way into the human food chain; their widespread presence in aquatic food chains underscores their potential to impact biodiversity and human health. Global initiatives are needed to address the problem, including cutting back on plastic production, increasing recycling, and upgrading wastewater treatment systems to lessen the negative effects of microplastic pollution.

Keywords: Microplastics (MPs), Bioaccumulation, Fish Physiology, Environmental Pollution, Human health

Introduction

Plastic has remarkable chemical and physical characteristics, such as its light weight, lean production, and low heat conductivity has led to its widespread use in society and a variety of industries in recent years. Due to their widespread release all over the world, microplastics (MPs) are a major global problem (Alimba and Faggio, 2019). In the 2017-18 timeframe, the world's plastic production rose from 348 to over 359 million tonnes (Plastic Europe, 2019). The Sargasso Sea and coastal waters surrounding England were the sites of the first concerning records about plastic pollution observed in 1970s (Carpenter et al., 1972). MPs with a small diameter, less than 5 milli meters, are among the plastic particles that have drawn attention from all over the world as an emerging pollution in the environment and one of the major world environmental risks, along with climate change, ocean acidification and ozone depletion, that pose a well-being or health risk to humans (Rochman et al., 2013). Human exposure to MPs will undoubtedly result from the excessive utilisation of plastics and the pollution it causes to the environment. Every day, people are susceptible to microparticles throughout their diet, skin contact, and oral inhalation of aerosols containing nano-plastics (Revel et al., 2018). Each person consumes 39,000-52,000 particles annually as a result of exposure from eating contaminated food (Cox et al., 2019). MPs consumption is validated by multiple marine organisms (bivalves, zooplankton, copepods, fish, etc.). Numerous marine organisms, including fish, copepods, bivalves, and zooplankton, have been shown to

consume or ingest MPs. MPs are moved up the food chains, for example, from zooplankton to fish, from mussels to crab and so on (Farrell et al., 2013). The accumulation and allocation of microplastics into marine organisms are species-specific and dependent on particle size, according to several authors. Many nations have set targets for the reduction or elimination of specific products, like disposable items and plastic bags, in an effort to combat the issue of plastic pollution (Sonnemann et al., 2017). Specifically, the European Commission approved a new proposal in May 2018 that prohibits a number of one time use plastic products and places more rigorous restrictions on others (Commissione Europea, 2021). Single-use plastics are currently prohibited in 60 countries (Giacovelli, 2022).

The microplastic

Under the influence of solar radiation, wind, water currents and other environmental factors, large plastic material gradually degrades into smaller particles known as microplastic and nano-plastics (IUCN, 2024). The most commonly accepted definition of microplastics is particles with a maximum length of less than 5 millimetres. The NOAA (National Oceanographic and Atmospheric Administration) of the USA and the MSFD (Marine Strategy Framework Directive) of the EU have both accepted this definition, which takes into account the size below which numerous marine biota species consume (Lusher et al., 2017).

European Food Safety Authority (EFSA) in 2016 reported, nano plastics are plastic particles that range in size between 0.001 to 0.1 micrometres, whereas microplastics are a diverse range of materials with various shapes (fibres, granules, fragments, pellets, spheroids, splinters, or beads) and dimensions ranging from 0.1 to 5000 micrometres (Efsa, 2016). These MPs are classified into two categories as shown in (Fig. 1): (1) Primary microplastics, which are produced by a small hard plastic material (plastic beads), fibres, powders and granules used in manufactured goods like, drug vectors, sunscreens, cosmetics, detergents and sunscreens (Cole et al., 2015); and (2) Secondary microplastics, which are creating by the gradual chemical and,

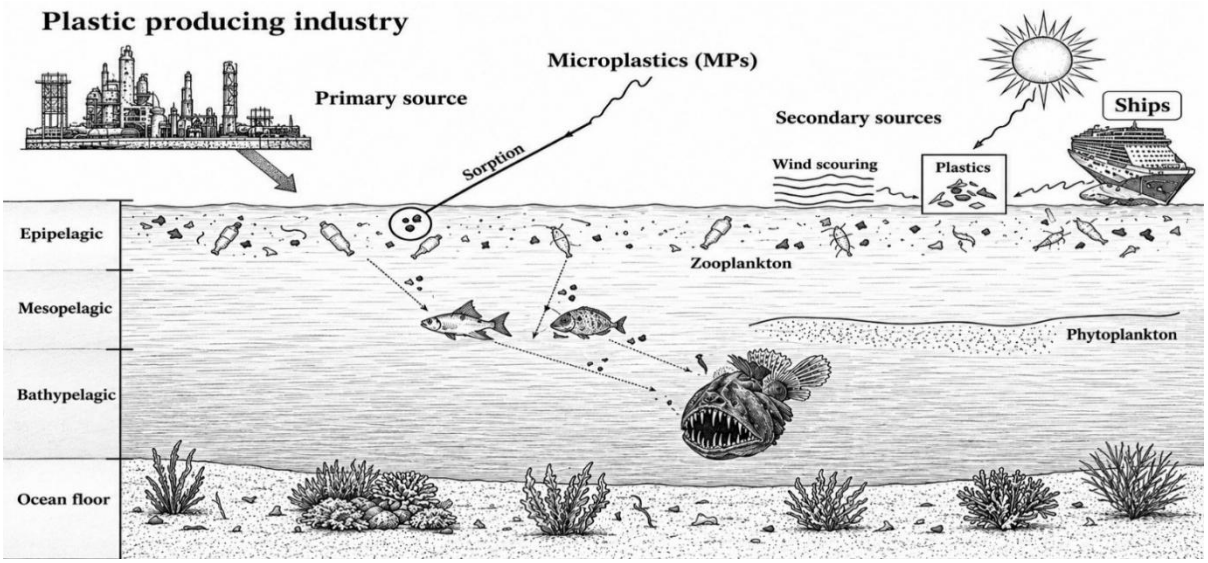


Fig. 1: Potential source and transfer of MPs in fish (Bhuyan, 2022).

biological breakdown of larger pieces of plastic through light degradation, UV radiation, mechanical

abrasion and biological degradation in the environment (Andrady et al., 2011). An estimated 68,500 to 275,000 tons of secondary microplastic released into the marine environment per year (Efsa, 2016).

Impact of microplastic in fish

Plastic is a synthetic polymer primarily derived from fossil fuels such as petroleum and natural gas. Its widespread use has led to global production exceeding 460 million metric tonnes annually (IUCN, 2024). However, improper disposal of plastic waste accumulates in aquatic environment, causing pollution and contributing significantly to biodiversity loss and ecosystem degradation (IUCN, 2024). Exposure to MPs has been investigated in relation to specific biological or physical reactions. Most research studies on MPs' effects on fish had conducted in labs thus far. The majority of the fish involved in the MPs exposure study were from the sea, but they came from a variety of habitats. Following ingestion, MPs may accumulate in fish gastrointestinal tracts, creating blockages throughout the digestive tract and restricting feeding as a result of hunger (Lusher et al., 2013). Fish that consume MPs may also experience dietary and developmental problems due to morphological and functional modification of the gastrointestinal tract (Huang et al., 2022).

Most fish MP experiments had conducted on zebrafish using Polystyrene and Polyethylene particles. The PS particles, which are between 25 and 70 nm in size, pass through the egg membrane, accumulate in the yolk sac, and travel to digestive system. Nanoparticles were detected in the liver, heart, pancreas, intestine and brain of fish and embryo. It has been demonstrated through experimentation that PS nanoparticles are transferred from mother to child. It has been demonstrated that the nanoparticles disrupt fry motility, resulting in either weakness or hyperactivity, raise cortisol levels, lower glucose levels, and accelerate heartbeat, inflammatory responses, and hepatic fatty degeneration (Chen et al., 2017).

The second most used fish that experienced morphological impairment as a result of ingesting MPs was *Oryzias melastigma* (Xia et al., 2022). *Oryzias melastigma* experience growth inhibition, loss of body mass, harm to reproductive organs, dysbiosis of the fish gut (Wang et al., 2022).

Microplastics (PVC 40–200 μm; PE 40–100 μm or PS 0.025–15 μm) accumulated in the gills, brain, liver and intestine of various fish including minnow, common carp, tilapia, crucian carp, perch and catfish, according to similar experiments. Fry growth retardation, altered feeding and behaviour and reduction in swimming performance which were all brought on by the exposure (Fig. 2). Elevated oxygen uptake and nitrogen waste excretion, altered liver enzyme activity, oxidative stress, morphological or histological abnormalities to the muscles, gills, skin, liver, and Inhibition of brain acetylcholinesterase activity, and modified expression of reproductive axis genes were all signs of a severe metabolic disturbance in tissues (Yong et al., 2020).

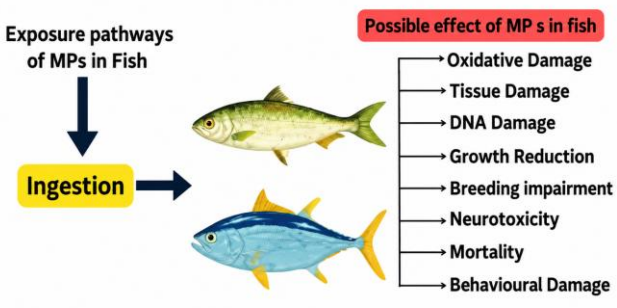


Fig. 2: Possible consequences of MPs in fish after consumption (Padhi et al., 2025).

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Impact of Microplastics in humans

Human health is seriously threatened by the presence of microplastics in seafood. Because seafood is a vital component of the human diet, microplastic contamination can cause immune system disruption, metabolic changes, neurotoxicity, carcinogenicity (Fig. 3) and reproductive toxicity (Padhi et al., 2025).

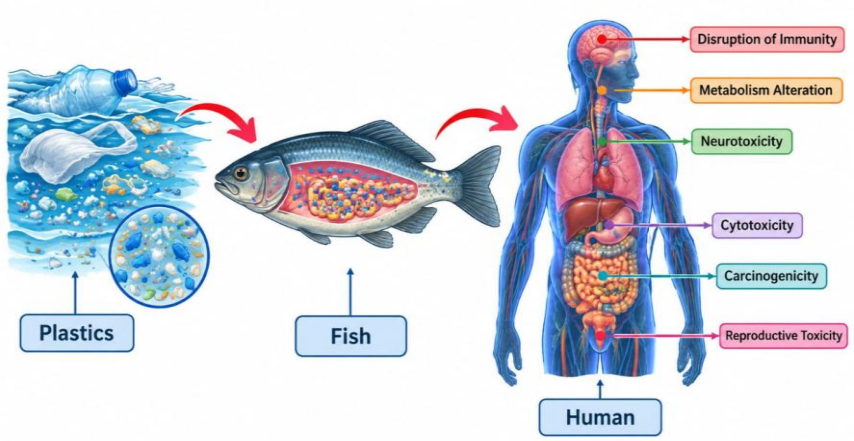


Fig. 3: Microplastic contamination and its impact on human health

Microplastics enters in human body through various ways including ingestion, inhalation, and skin contact as shown in (Fig. 4). Among these, human exposure to microplastics occurs most frequently through ingestion. Contaminated seafood, drinking water, food packaging, and plastic utensils can all contain microplastics. Microplastics may build up in the gastrointestinal tract and other organs tissues after consumption (Mamun et al., 2023).

By using in vivo, in vitro and silico studies, the prospective health hazards which are related to the microplastics are investigated which shows that there is a great potential impact of microplastics on human health. Damage of intestinal wall causing inflammation, oxidative stress and alteration in gut microbiota are the harmful impacts caused due to ingestion of microplastics (Osman et al., 2023). The above points would ultimately cause unwanted adverse effects such as autoimmune disorder, cancer and neurodegenerative diseases etc.

Other than ingestion, even if the microplastics is just inhaled, it results in respiratory irritation and damages which can cause chronic-obstructive pulmonary disease (COPD) and asthma which are harmful respiratory illnesses (Amato-Lourenco et al., 2020). Endocrine disruption and reproductive toxicity are also seen when microplastic is exposed to the dermal layer of skin which causes skin irritation and inflammation (Campanale et al., 2020).

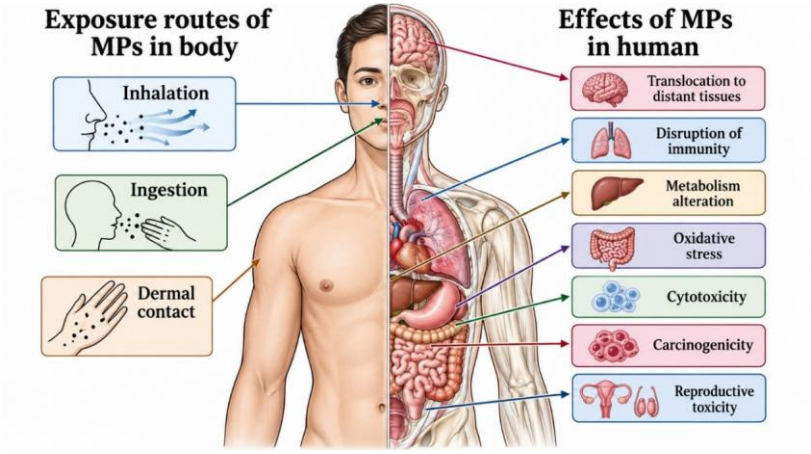


Fig. 4: Possible consequences of microplastic exposure in the human body

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Mitigation method

Effective mitigation of microplastic pollution requires an integrated approach encompassing the regulation of environmentally harmful plastic production and consumption, increasing the use of recycled plastics through incentives and taxes or sanctions on virgin plastic production, strengthening waste collection systems through door-to-door collection and deposit-refund schemes to prevent plastic leakage, and improving e-waste recyclability with proper collection and treatment to reduce plastic contamination of the environment (Prata et al., 2019). With continuing industrialisation, urbanisation, and other anthropogenic activities contributing to marine pollution, targeted pollution-control measures such as improved waste management and stricter environmental regulations are increasingly necessary to minimise environmental damage and protect aquatic ecosystems (Padhi et al., 2025).

Conclusion

Microplastic pollution has emerged as a serious environmental concern with significant implications for aquatic ecosystems, fish health, and potentially human health. The available evidence discussed in this article indicates that fish can ingest and accumulate microplastics, leading to digestive disturbances, growth retardation, behavioural changes, oxidative stress, tissue damage, and impaired reproductive and physiological functions. The transfer of microplastics through aquatic food chains also raises concerns regarding their entry into seafood and, consequently, the human food chain. Human exposure may occur through ingestion, inhalation, and dermal contact, with potential risks including inflammation, oxidative stress, disruption of gut microbiota, respiratory effects, endocrine disturbances, and reproductive toxicity.

The persistence and widespread distribution of microplastics make their complete removal from aquatic environments difficult. Therefore, effective management requires an integrated and preventive approach, including reduction in unnecessary plastic production and consumption, promotion of recycling and biodegradable alternatives, improved solid-waste collection and disposal, and enhanced wastewater treatment. Greater public awareness, environmental monitoring, and further research are also essential to understand the long-term ecological and health consequences of microplastic exposure. Coordinated efforts among researchers, policymakers, industries, fishers, and the public are necessary to reduce plastic leakage into aquatic ecosystems, protect fish biodiversity and ecosystem health, and minimise potential risks to human health..

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