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MICROPLASTICS AND FISH: DISRUPTIONS IN REPRODUCTION, BEHAVIOR, GROWTH, AND IMMUNE FUNCTION, AND THEIR CASCADING EFFECTS ON ECOSYSTEMS AND HUMANS

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Abstract

Years by year the rate of plastic accumulation in oceans is increasing. Microbiological activity, UV radiation, cooling/heating cycles, and freeze/thaw cycles all contribute to the deterioration of plastic. Microplastic, nanoplastic, macroplastic, and mesoplastic are the many types of plastic that decompose. Plastic fragments are present on the surface, in sediments, and the water column, depending on their density. Fish is essential to a diet because of its high protein content. Fish that consume plankton may absorb microplastic that are connected to them or pass them off as food. Fish that consume jellyfish might consume plastic because it resembles the creatures and floats on the surface. Filter feeders also allow fish to drink the water they filter. Both sediments and detritivores fish that consume substrate contain microplastic. The general health of fish is adversely affected by microplastic. Plastic creates digestive problems that result in gastrointestinal blockage, which causes satiation, mortality, and physical deterioration once it enters the body. By changing organismal defense mechanisms, nanoplastics may disrupt innate immune responses in fish populations and function as stressors to fish' innate immune responses. Micro- and nanoplastics may accumulate in fish gonadal tissues, which can be damaging to reproduction. Fatty vacuolation, single-cell necrosis, and loss of glycogen are symptoms of liver stress in fish exposed to virgin treatments and marine plastic.

INTRODUCTION

Because of its high protein content and low cost, fish is an essential part of food all around the Because of its easy accessibility it is mostly consumed and exported within and out of India. That's why Indian seafood stewardship councils make it the world's second-largest fish-producing country (Mohanty et al., 2019). Throughout many Asian countries, such as Bangladesh, Myanmar, South Korea, Vietnam, China, Japan, India, Indonesia, Malaysia, and the Philippines, seafood and fish are inexpensive, essential foods that are commonly eaten as a source of omega-3 fatty acids, vitamins, and animal protein. The livelihoods of people working in the seafood, fishing, and aquaculture industries and Asia's seafood fishery may be threatened by fish species tainted with MP. Furthermore, it might increase the risks to the health of those who consume fish and shellfish (Kibria et al., 2021b; Kibria, 2018).

Haward's (2020) estimation said that approximately (4.8 to 12.8 million tons) of materials related to polymers are flowing away into the world's fundamental water bodies every year. From China 32% of plastic debris flowed in oceans, proceeding that Europe, Asia, the Middle East, East Africa, America, Land America, and Japan contributed to oceans plastic debris respectively15%, 17%, 7%, 19%, 4%, 3% by 2022 as the world's leading producers of plastic. According to research, approximately 14 million tons of polymers (plastic) annually as waste enters waterways. According to Marine Plastic Pollution IUCN (2022), Research showed that about 80% of marine surface and hydel zones are major depositors of marine debris. As stated by Bhuyan et al. (2020), The debris of non-useable plastics in the environment is the core cause of plastic creation, circulation, and deposition in the marine environment.

In approximately 56 spots, 887 kinds of fish have either ingested MPs or become contaminated by their repercussions. 45% of fish worldwide consumed an average of 5.93 MPs particles per fish species (Chelsea et al., 2013). Microplastic can be consumed by lower trophic level species in addition to food particles (Wright et al., 2013). Based on their feeding patterns, animals often swallow plastics of varying sizes (Ozturk et al., 2020). In Antarctica, 0.11% of fish swallowed, and in South America, 17.36% of species swallowed microplastics, in the same way in Europe, Asia, Africa, North America, and Oceania, 17.13%, 44.2%, 5%, 6.5%, 9.7%, respectively, had the most polluted fish species (Chelsea et al., 2013). Compared to 2.5% in the post-monsoon season, 55% of MPs were poisoned during the monsoon season (James et al., 2020). Location-specific microplastic concentrations range from one piece per 100 cubic meters to over a million pieces per cubic meter (Bhusare et al., 2024).

Klein et al. (2018) state that the primary causes of plastic deterioration are oxidation, hydrolysis, drying, thawing, UV light, abrasive pressures, heating, cooling, freezing, thawing, dampness, and biodegradation by microbes, algae, or fungi. Plastic particles are present in both sediment and water columns, but compared to water columns, silt contains over 100 times as many plastic pieces. The number of particles of plastic depends on their depth in the sandstones, their currents in water, and their laying out positions from the banks of water bodies. The density of polymers designs their spots in the columns of water. Microplastics (MPs) particles in the water column separate based on their density. According to Erni-Cassola et al., (2019) density polymers, such as polypropylene and polyethylene, among others are found on the marine surface, but heavier or denser polymers, including acrylic, and polyesters, may be found in the sediment.

1. Types and Sources of Microplastics

MPs are also found in synthetic fabrics; more than 100 fibers per liter are found in wastewater after washing synthetic garments, such as shirts (Yagi et al., 2021). According to Browne et al. (2019), roughly 1900 MP fibers can be released in a single machine wash. Plastic pellets are a basic component used to produce plastic products. Additionally, pellets are used in several industrial operations, including as ingredients for paint spray, abrasives, printing inks, injection molds, and toothpaste (Espinosa et al., 2016). According to particle size, ocean plastic debris decomposes over time into four categories: Macroplastics are larger which is more than 25 mm, mesoplastics range from 5 to 25 mm, microplastics measure from 1 to 5 mm, and nanoplastics are smaller particles and their size range is less than 1 µm (GESAMP, 2015). MPs were classified based on their forms (fragment, fiber, and film,) and colors (blue, white, black, transparent, green, yellow, and others) using the approach implemented in Cheung et al. (2016) and Kobayashi et al. (2021). Pelagic fish (39.1%) exhibited higher MPs and were larger than demersal fish (10.3%). Pelagic and demersal fish confined major MPs such as film and fiber. Research cleared that pelagic and demersal fish containing 70% MPs are white, transparent as well as blue. The rest of the colors were ash, brown, and red, (Yagi et al., 2021).

2. Pathways of Microplastic Entry into Aquatic Ecosystems

Microplastics can enter aquatic environments through a variety of routes, such as runoff from the land, wastewater discharge, and air deposition. Heavy rainfall has a paramount effect on the amount of microplastics in marine habitats (Madiraju et al., 2024). Microplastic concentrations are seen in rivers and seas. Failures in Waste Management: Microplastics flow into aquatic systems consequently, inadequate waste management practices, particularly those brought on by industrial activities (Alqarni, 2024). They contaminate even remote locations and, after being widely spread by ocean currents, inflict physical harm and chemical bioaccumulation in marine organisms (Madiraju et al., 2024).

3. Mechanisms of Microplastic Ingestion in Fishes

According to Kukulka et al., (2012), demersal fish are feeders of the benthic zone, and MP concentration declines as water depth increases. Near the bed surface of oceans, MPs are prevalent, and the fish as mentioned earlier intake them (Suaria et al., 2016; Reisser 227 et al. 2015), Proceeding that microplastics amass in the ocean's hydel zone (Barrett et al., 2020; & Woodall et al., 2014). They might be eaten by detritivores, demersal fish that obtain their food from the sediment (Wootton et al., 2021). The number of microplastics in each type of water source—lakes, estuaries, rivers, bays, seas, and oceans—were ranked from highest to lowest (Bhusare et al., 2024).

Benthic fish's trophic ingestion rate is most likely caused by the quantity of marine litter at the sea ground. Additional logic to bring up the topic is the remarkable similarity between the microplastic and the food that these fish enjoy. For example, fish ingest plastic by deceiving their prey since they resemble jellyfish. Another illustration would be when birds eat pellets (Dravid et al., 2005). In addition, fish that eat a lot of plankton and small fish that contain microplastics (Adel Alshawafi et al., 2018). Some Fish and their progeny catch and consume their prey, such as zooplankton, as they see it. Since some zooplankton components might resemble tan, white, or yellow plastic, the fish community may ingest microplastics instead of protein-rich food (zooplankton) (Shaw & Day, 1994). Our findings imply that intentionally following the normal food ingestion cycle some fish intake microplastics patched with their food or the separate matters of plastic within the food. On the other hand, unintentionally during flights MPs enter in their mouth or by incorrectly considering them their food items (fry fish, crustaceans, etc). This type of ingestion is primary in which animals directly eat MPs matter as opposed to trophic transfer (supplementary ingestion) in which a predator ingests MPs intake prey, known as secondary ingestion (Nelms et al., 2018). The study of ATR-FTIR declared the highly common MPs varied in different fish samples. The polyvinyl alcohol (39.76%) concentration was at its peak, polyethylene ranked in second number with a proportion of 16.51% MP, methylcellulose and styrene-related debris was less prevalent which is 12.84% and 9.07% respectively (Mohan et al., 2024).

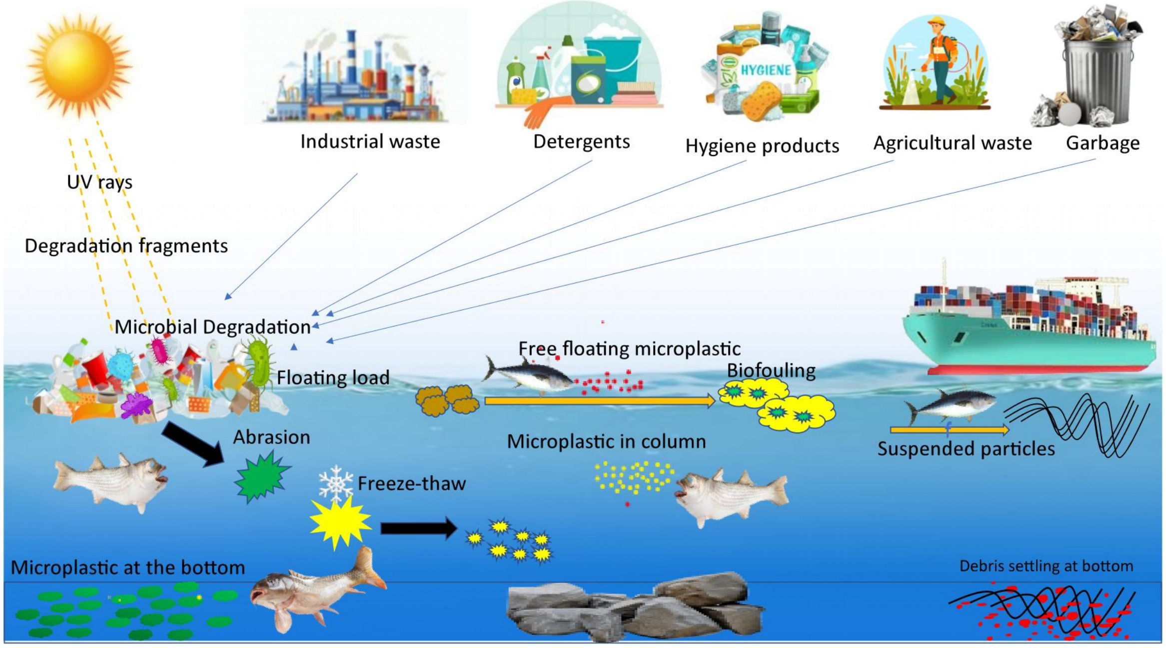

Fig: Sources, transformation, and distribution of microplastics in aquatic environments: Microplastics are produced when large plastic waste from domestic, industrial, and agricultural activities is broken down by UV light, microbes, and physical processes like abrasion and freeze-thaw cycles. These particles contribute to marine pollution and ecosystem disruption by floating, suspending, or settling at the bottom, where they affect aquatic creatures through ingestion and biofouling.

4. Distribution and Absorption of Microplastics in Fish Tissues

After being consumed by seafood animals, MP is stored in the genital tract, abdomen, gastrointestinal tract, tissues, connective tissues, and mantle tissue (Hu et al., 2016; Kolandhasamy et al., 2018). There were accumulating intestinally, functioned MP in the clam's (Scrobicularia plana) hemolymph and digestive system (20 µm) (Ribeiro et al., 2017). Gills take up MP of mussels (Mytilus edulis) and then move to the digestive system.

Before building up within the lysosomal system, MP passes via the digestive tubules (Von Moos et al., 2012). MP size affects their capacity to move across tissues and organs. Translocation of smaller MPs is simpler than that of bigger MP. (Jeong et al., 2018), Revealed that MP having 50nm (size range) spread throughout several organs, but MPs up to 0.5–6 µm are only found in marine species' digestive systems. The distribution of MP is influenced by the surface charge of aquatic species. The sea species ate MP coated with amine and carboxyl polystyrene. Whole embryos exhibited amine-coated MP, though solely the intestinal tract contained carboxyl-coated MPs (Della Torre et al., 2014).

5. Biological and Physiological Impacts on Fishes

5.1. Impacts on Physiology

Apart from ingestion, adhesion to the body's surface, and breathing, MP may have detrimental effects on aquatic animals across the population, person, connective tissue, organs, cells, amino acids, and genome levels (Thushari, 2020). Furthermore, the bilayer of lipids in the cell membrane is harmed by microplastics (Hollóczki & Gehrke, 2020). Nanoplastics are thought to bind with molecules and enter the cells of organisms (Rujnić-Sokele, 2015). Causing the endocrine system and physiology of the organism to be disturbed. Nanoplastics are more likely to accumulate in tissue or cells as compared to MP (Lusher et al., 2015). Because MP is tiny, marine creatures may ingest them regardless of how they feed. MP takes entry into their blood circulation mechanism and causes deposition in many tissues, according to laboratory studies. (Cruz, 2023).

According to Guggisberg (2024), The fish's endocrine system gets harmed through the ingestion of the aforementioned plastic litter. Studies by Rochman et al. (2024) reflected that these plastic litters are monomers of many polymers like bisphenol, acrylonitrile-butadiene-styrene, rubber, as well as polystyrene-It already mentioned, monomers of polycarbonate may interfere with the functionality of the endocrine system. As stated by Sharifinia et al. (2020) Additionally, it has been demonstrated that plastic additives such as nonylphenol, phthalates, and UV stabilizers have estrogenic as well as antiandrogenic properties. Globally, plastic garbage has also been shown to contain chemicals such as petroleum hydrocarbons, organochlorine, and heavy metals insecticides that have been previously related to detrimental impacts on endocrine system functions (Cruz, 2023).

5.2. Impacts on Behavior

Abnormal behavior may result from the accumulation of 50–170 nm nanoparticles in tissues of fish brains (Karin Mattsson et al., 2017 & Mattsson et al., 2020). Studies by DiBona et al. (2021) Show that vital features including overall health, development, reproduction, and survival are largely determined by behavior. A fish's early development is a critical period of its life cycle. An organism's survival is often determined by its capacity to evade predators. Consequently, possessing an innate ability to identify and react effectively is crucial. (Wootton et al., 2021). Ferrante et al. (2022) Suggested that fish larvae's olfactory receptors could be harmed by microplastic pollution through an immunological response. DiBona et al. (2021) found that microplastics harmed natural responses to olfactory threat cues and critical behaviors like feeding and activity. The reduction of predator evasion behavior considerably increased the rates of larval deaths caused by predators. MPs may significantly affect fish survival since they substantially influence fish life cycles (Cruz, 2023).

5.3. Impacts on Reproduction

Because plastic pollution damages habitats, interferes with reproductive processes, and introduces toxins into the environment, it hurts marine fish spawning. According to Roshmon et al. (2024), These humanely introduced risks folding the stable lifespans of fish and aquatic environments, which may result in a declining fish population. Fish reproductive cycles are disrupted and abnormalities in juvenile development result from plastic pollution, especially microplastics. Research by Ali et al. (2023) shows that fish exposed to these toxins have reproductive limits, which endangers their numbers and raises the possibility that aquatic ecosystems may go extinct. The accumulation of micro and nanoplastics in fish gonadal tissues may be detrimental to reproduction. Studies by Yi et al. (2024) show that microplastic can disrupt the hypothalamic-pituitary gonadal axis, induce oxidative stress, and change the histopathology of the gonadal glands, which could hurt reproduction and possibly endanger future generations.

5.4. Impacts on Respiratory Metabolism

The results indicate that fish exposed to PE may have a decline in respiratory rate and an imbalance in respiratory metabolism. Nevertheless, earlier studies showed that mussels' gills absorbed microplastics during exposure, boosting their oxygen consumption rate by 40% (Lui et al., 2021). According to Bayo et al. 2019 the primary cause of this was the accumulation of microplastics within organisms, which increased their oxygen requirements. Research by Lui et al. (2021) indicates a deposition of microplastics in fish may be the cause of its lower oxygen consumption rate after exposure, which may also affect the development and growth of the organism.

5.5. Impacts on Development

Yigit et al. (2023) state that fish weight and health condition may be limited by exposure to PE, which may be caused as the result of supplementation of microplastic in the digestive tract, which disrupts the stored food balance and leads to combustion and breathing disorders. The study by Chen et al. confirmed that microplastic exposure may result in zebrafish intestinal muscle layer thinning. Weak connections and muscle cell thinning were the causes of this phenomenon, which further affected the zebrafish's ability to absorb nutrients and ultimately resulted in low energy levels. The study by Kurtela & Antolović (2019) shows, therefore, additional research was conducted to investigate the impact of oxygen consumption rate on fish respiratory metabolism.

5.6. Impacts on immunology

Fish are a potential target for encounters with nanoplastic particles since their cellular innate immune effectors are among their early organ defenses against various pathogens. The activity of granulocytes is crucial for the guest of honor defenses and is also a useful indicator of the health of both human and animal populations (Smith et al., 1986). According to Palic (2005), fish neutropenia can degranulate, migrate through the chemotactic mechanism, unleash the traps of neutrophils, and absorb germs and other microscopic debris. There were hypotheses regarding how MP or nanoplastics interact with macrophages before recent research showed that Acetate and Polyethylene nanoplastics function as a compelling force in fish's genetically interwire defense system (Greven, 2003). That's why, nanoplastic may intercede in the immune functions of fish's body by defeating the defense protocols of fish (Cruz, 2023).

5.7. Impacts on Digestive System

When seafood animals intake microplastic, it generates messages of filled metabolic needs. Consequently, when animals don't ingest food for a longer time then starvation occurs and ultimately animals die. (Jovanović, 2018). Plastics in the water have been reported to cause physical injury to fish by adhering to their gills and fins (Rochman et al., 2013). Most macro, clean, and flexible plastic fragments found in sea turtles' stomachs resembled jellyfish, their main dietary source (Yaghmour et al., 2018). As narrated by Ozturk et al. (2020) consuming plastics that resemble prey, whether on purpose or accidentally, clearly indicates that individuals confuse plastic for prey. However, microplastics in saltwater may promote food intake. According to Baulch & Perry (2014) when debris takes place in the body, it creates digestive hurdles that eventually lead to digestive tract disruption. Resultantly, satiation, death, and physical declines are caused. Decreased reproductive fitness, drowning, a decreased capacity to escape predators, a decreased capacity to feed, the possible spread of toxicants from saltwater, and eventually mortality are all possible outcomes (Gregory, 2009). Plastic-filled stomachs can block and harm digestive tracts, or even cause animals to starve to death, according to studies by Cruz (2023). Fish digestive tracts were found to contain MP polymers polyethylene (PE) along with polypropylene (PP) (Borges-Ramírez et al., 2020). Gills (434) restricts a smaller number of MPs than GIT (441) (Mohan et al., 2024).

6. Ecological Implications

Fish and their habitats may suffer physical and toxicological harm from microplastic, endangering local food security, particularly in regions where protein mostly gets through seafood animals (Bene, 2006; Rochman et al., 2016). Prolonged posture to microplastics and compounds associated with them, may have a detrimental effect on fish health and the stable viability of fisheries (Smith et al., 2018). Since micro-litters of plastics are becoming more and more prevalent in marine habitats worldwide, some concerned consuming seafood that contains microplastic could eventually enter the food chain and be swallowed by humans. In this instance, there is minimal possibility that humans may absorb the microplastic because the fish species being studied are commonly consumed after removing their digestive tracts. (Dawson et al., 2021). Furthermore, it has been demonstrated that microplastic causes physical harm to marine species when it is consumed (Wright et al., 2013), there is also a matter of study that the microscopic particles carry dangerous materials on their surface that are either introduced during production or contaminants that have stuck to the microplastic's surface, including flame retardants, heavy metals, and enduring organic contaminants (Teuten et al., 2009; Bakir et al., 2014). MP pollution might endanger seafood fisheries and the livelihoods of people who work in aquaculture, fishing, and the seafood industry. Additionally, it may jeopardize the health of those who rely on seafood fish for ingestion due to the potential of having hazardous residues penetrated in MPs to be passed down to people following the circulation in the food chain (Gallardo et al., 2023). Many small islands or underdeveloped nations, such as Indonesia, Cambodia, Ghana, Sierra Leone, and Sri Lanka, Bangladesh, consume at least 50% of their animal protein from edible fish (Clements et al., 2018). The nations' economies as mentioned above are directly impacted by the disruption in fish ecosystems through plastic debris, leading to health problems and social catastrophes (Nerland et al., 2014; McKinley & Johnston, 2010; Johnston & Roberts, 2009; FAO, 2016).

Secondary ingestion of microplastics is likely particularly significant for social groups that depend significantly on fish as their primary source of income and protein. In developing countries like Mexico, small-scale fishing is essential to many coastal populations' income, sustenance, and protein intake (Cinner & Pollnac 2004 &de Oliveira et al., 2019). These towns usually endure erratic revenues and year-round economic turbulence (Coronado et al. 2020). The livelihood and health of fishermen in coastal areas, where fish is the basic source of food and a heavily dependent part of the local populace, daily diet may be at risk due to microplastics in fish species (Benitez & Flores-Nava, 2019). Due to their poor income and low average earnings, about 70% of Mexican fishermen experience a lack of food and low living conditions, making them moderately or extremely marginalized (DOF, 2020; Fernandez et al., 2011)

7. Human Health Implications of Consuming Microplastic-Contaminated Fish

Humans are not as contaminated since fish stomachs and intestines have the highest concentration of microplastics, and these parts are usually removed before ingestion. (Browne et al., 2013). Human ingestion of microplastics is increased when shellfish are consumed, particularly in their digestive tract. Because shellfish filter saltwater for consumption. They filter out 40 liters of seawater (equal to 80 liters under fascinating protocols), which implies that their bodies absorb a concentration of MP (UNEP/WHO/IAEA, 1988). Experiments showed that the ingestion of shellfish by the citizens of Europe is equal to the ingestion of 11,000 microplastic residues on average per year (Van Cauwenberghe & Janssen, 2014).

Furthermore, researchers have shown that the presence of microplastic particles in the individual's body sets off several enzymatic activities that lead to oxidative stress. These reactions include Mercury (Hg), other metals, and a mix of the two. Microplastic particles can migrate between trophic levels (Gallardo et al., 2023). Because of this, there is a possibility that these contaminants will be transferred via the trophic levels, which could lead to end consumers becoming unwell. Microplastics can potentially cause undesirable outcomes such as cancer, decreased immune responses, reproductive impairment, and abnormalities in both people and animals (Cruz, 2023).

Furthermore, certain specimens demonstrated that these particles had passed past the intestinal wall and entered the circulatory system (Browne et al., 2008). Microplastic ingestion in seafood animals has numerous concerns. Still, the main one is that they may contain potentially dangerous substances like plastic monomers and additives, or they may absorb environmental pollutants, pathogenic microbes, and algae that could infect humans and cause disease. The food chain is the trophic source of orienting these compounds in the human body. Humans can eventually ingest Microplastics since they are distributed throughout the food chain. (Browne et al., 2013). Sea salt, tinned sardines and sprats, and edible marine tissue (fish, crustaceans, and mollusks) have all been shown to contain microplastics by Toussaint et al. (2019). That's why it's highly predicted that the food chain could be the main pathway of microplastic ingestion in humans (Gallardo et al., 2023).

8. Countries and regions with high, medium, and low levels of MP consumption by fish

Microplastics are the most prevalent kind of litter in the marine ecosystem, accounting for 60 to 80% of all waste in the world's seas (Kurtela et al., 2019). Consumption of MPs in fish varies with nation and location. Fish MP intake was categorized as high, medium, and low.

i. MPs are consumed by 100% of fish in Poland, Bangladesh, Portugal, Brazil Ghana, South Africa, the Atlantic Ocean, Iran, Tunisia, the Arctic Ocean, Italy, Argentina, Turkey, North Pacific Gyre, Slovenia, Indonesia, South Korea, China, and the United States.

ii. Intake of medium MPs: 40 and 60% of fish in Ethiopia, Norway, Tanzania, and Tahiti consume MPs.

iii. iii. Low MP ingestion: Between 1% and 10% of fish consume MPs in the Antarctic Ocean, Belgium, Ecuador, and Peru.

Fish in areas and nations with higher ingestion (100%) may be more likely to swallow MPs due to inadequate food supplies and high MP availability and building (e.g., Indonesia, North Pacific Gyre, China) (Boerger et al., 2010). Cannon et al. (2016) suggested that conversely, areas like the Antarctic Ocean with low MP abundance have less microplastic intakes no more than 1 to 10%.

Battaglia et al. (2016) and Romeo et al. (2015) assert that the quantity of microplastic in the surrounding ecosystem is proportional to the number of microplastic consumed by fish. Additionally, fish serve as bioindicators of the conditions under which MPs are consumed (Bray et al., 2019)

One ton of plastic will be present in the oceans for every three tons of fish by 2025, or roughly 250 million tons; by 2050, there will be more plastic than fish (Kurtela et al., 2019).

9. Mitigation Strategies and Policy Recommendations

Plant and seaweed-derived polymers should be used to make green plastics, also known as biodegradable plastics. Microbeads and plastic bags should also be prohibited (Oyena et al., 2021). In the digestive system of some microorganisms especially, in algae, bacteria, and fungi, microplastics are being broken down by the protocols of enzymatic activities. Scientists must do much research to exacerbate the current MPs (Othman et al., 2021). Small lifestyle adjustments including reuse, reduction, and recycling of plastics can improve our quality of life (Mohan et al., 2024).

Given our study's massive volumes of fibers, primarily from fishing nets and clothes, MPs should be reduced using bioplastics rather than plastics. Synthetic clothing can be swapped for organic apparel (Shruti & Kutralam-Muniasamy et al., 2019). Using plastic straws, headphones, cutlery, balloon holders, and drink-mixing tools will be forbidden. Microplastics can be removed by producing these things by employing environment-friendly practices.

For the sake of justice with seafood animals, developed continents (Europe) must shift their focus from plastic-related items, drink cups, and containers to eco-friendly manufactured items by 2025. Furthermore, they must ensure the implementation of a returns scheme to recover 90% of abandoned plastic bottles. (Kurtela et al., 2019).

Finally, we conclude that pelagic fish contained a mounted amount of microplastics which was 39.1% and demersal fish ingested 10.3% MPs. Results revealed that demersal animals are the least impacted, the literature advises TAs to try eating sea bass, grouper, sole, hake, and catfish (Cruz, 2023).

Conclusion:

Human health and aquatic ecosystems are seriously threatened by microplastic pollution. This study addresses how fishes frequently consume microplastics and how this harms their physiology and behavior, leading to stress, toxicity, and irregular feeding habits. Human health hazards, such as chemical exposure and toxicity from eating seafood, are increased by the bioaccumulation of microplastics in fish and their movement through the food chain.

Despite an increase in studies, there are still unanswered questions about the long-term effects of microplastics on human health and marine biodiversity. Reducing plastic trash and protecting ecosystems will require a coordinated strategy that includes public awareness campaigns, regulatory changes, and research. Immediate action is necessary to reduce the hazards that microplastic contamination poses to the environment and human health.

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