emergent
Life Sciences Research

Review Article

Effect of microplastics pollution in riverine ecosystem: A review

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Received: 29 May 2024
Accepted: 30 July 2024
Online: 05 August 2024

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Emer Life Sci Res (2024) 10(2): 15-31

E-ISSN: 2395-6658
P-ISSN: 2395-664X

DOI: http://doi.org/10.31783/ELSR.2024.1021531

Abstract

Microplastic contamination in riverine ecosystems includes diverse forms such as threads, fragments, films, foams, and pellets. These tiny particles can be ingested by aquatic organisms and travel long distances, eventually settling in sediments. While many studies have examined microplastics in surface waters and river depths, research on their accumulation and mobilization within riverbeds is limited. Effective mitigation of microplastic contamination requires comprehensive sampling from various locations, including non-point sources and intra-site variations, to better understand their distribution and concentrations. Microplastics degrade from larger plastics through mechanical forces and UV radiation, and they pose significant threats to aquatic life, human health, and ecosystems. This article focuses on the impact of microplastics, including their adsorption of harmful contaminants and their ecotoxicological effects. Additionally, policy interventions are essential for reducing plastic pollution in riverine environments.

Keywords fisheries, microplastic, pollution riverine ecosystem

Introduction

In natural environments, the ongoing degradation of plastic waste into macro, micro, and nano plastics is a consequence of various mechanical forces, including friction, heat degradation resulting from exposure to sunlight, and UV degradation. The prevalence of microplastics is extensive, and they are widely dispersed within river ecosystems, exhibiting the capacity to traverse substantial distances as they flow toward the ocean. Indeed, rivers serve as the principal conduit for microplastic entry into the world's oceans. Due to their ease of transport and diffusion within river and stream networks, microplastics may eventually settle and persist in sedimentary layers. With a population of nearly 1.412 billion people, India is the largest consumer of plastic [1]. Plastic trash degrades in the natural environment as macroplastics, microplastics, and nanoplastics as a result of mechanical, thermal, and UV deterioration, as well biodegradation through photodegradation, and then by mechanical forces such as friction [2]. MPs (microplastics) are synthetic or semi-synthetic polymer plastic particles with an average diameter of 1 to <5 mm [3]. As a result of their proliferation and dispersion in the aquatic environment, plastics have been shown to interfere with marine and freshwater life in a variety of ways, including ingestion and entanglement [4-5]. For more than 50 years, the presence of microplastics in marine environments has been continuously recorded [6] but freshwater microplastics have only recently received consideration [7-9]. The increased frequency of microplastics in soil and water testing has recently brought attention from across the globe to riverine ecosystems. The Yangtze River in China, for example, produces the most plastic waste (0.33 million tonnes per year), followed by the Ganga River in India (0.12 million tonnes per year), which is eventually deposited into marine habitats [10-11]. Plastics cannot be eliminated from seas or rivers with efficient waste management, as proven by aquatic biota ingestion of microplastics. As a result, in the next 30 years, the weight of plastic will exceed that of fish [12]. MPs have been discovered in river water and sediment all around the world [13-14]. Microplastics are permanently deposited in sediments found in freshwater, marine, and terrestrial ecosystems [15-16]. Microplastics in rivers are typically sourced from land, such as anthropogenic sources, industrial activities, and high population density [17]. Numerous studies have shown MPs in edible fish, and MPs enter human systems as a result of biomagnification [18]. The effects of MP on fish species ranged from minimal biological system disruption to major negative consequences, including mortality [19]. Internal body tissue exposed to MPs after transfer within the body, physiological injury caused by MPs buildup in the gastrointestinal system, interruption of organisms' energy flow caused by MPs excreting as pseudo-feces, and all of these consequences are damaging, according to Meng et al., [20]. They can allow trace metals and organic pollutants to enter aquatic environments [21]. MP accumulation and deprivation in key organs such as the gills, intestines, and stomach can impair fish's predatory behavior and create confusion between MPs and actual prey [22-23].

In addition, MPs were found in fish meat and muscle, which are consumed predominantly by humans [24-25]. The accumulation of MPs causes growth retardation, hormone disruption, metabolic disturbance, oxidative stress, immunotoxicity, neurological dysfunction, and genotoxicity-induced behavioral disorders [23, 26]. Only a few studies have looked into the harmful impact of MPs on fish and humans.

Microplastic pollution in the riverine ecosystem

Origins of microplastic pollution

Identifying the origins of MP contamination is an essential first step in regulating their contamination. Depending on where these sources enter the ocean (Figure 1), they might be categorized as marine or terrestrial [27]. The two categories of microplastics are primary MPs, which are manufactured as pellets, microbeads, and fiber, and secondary MPs, which originate from the weathering, fragmentation, or degradation of larger plastic waste [28]. In India, religious institutions were a major source of microplastic contamination. In addition to the ever-changing population, visitors and tourists generate garbage and wish to wash their clothes, bathe, and discard them along the river's banks [29-30]. In the region's pilgrimage centers around the Nethravathi River in Karnataka, the highest concentrations of microplastics were found [31]. Other researchers have demonstrated that human activities have exacerbated MP contamination in pilgrimage sites such as Rameshwaram [32], Thiruchendur [29], and Velankanni [33]. Microplastic pollution in the neighboring aquatic system is primarily caused by densely populated urban areas with important fishing and shipping ports, such as Chennai and Cochin [33]. The presence of marine biota has been documented in these cities, which are important hubs of heavy fishing and intense human activity resulting in unrestricted trash dumping [34]. Compared to other beaches in India, Juhu Beach in Mumbai, which has the highest beach usage and recreation activities, has the highest MP pollution density [35].

However, as indicated above, this could be related to the selection methods employed. Microplastics in effluent were drastically decreased after a further treatment phase [36]. Fibers and plastic flakes were the most prevalent types of microplastics in this study (18.5% and 67.3%, respectively), while microbeads represented just 3% of total particles [37]. Microplastic concentrations in this mixture dropped by 98 percent, from 15.7 particles per liter and 5.23 particles per liter in sewage treatment wastewater to 0.25 particles per liter and 0.04 particles per liter in final effluents [36]. Untreated sewage is dumped into waterways without treatment in numerous nations [38].

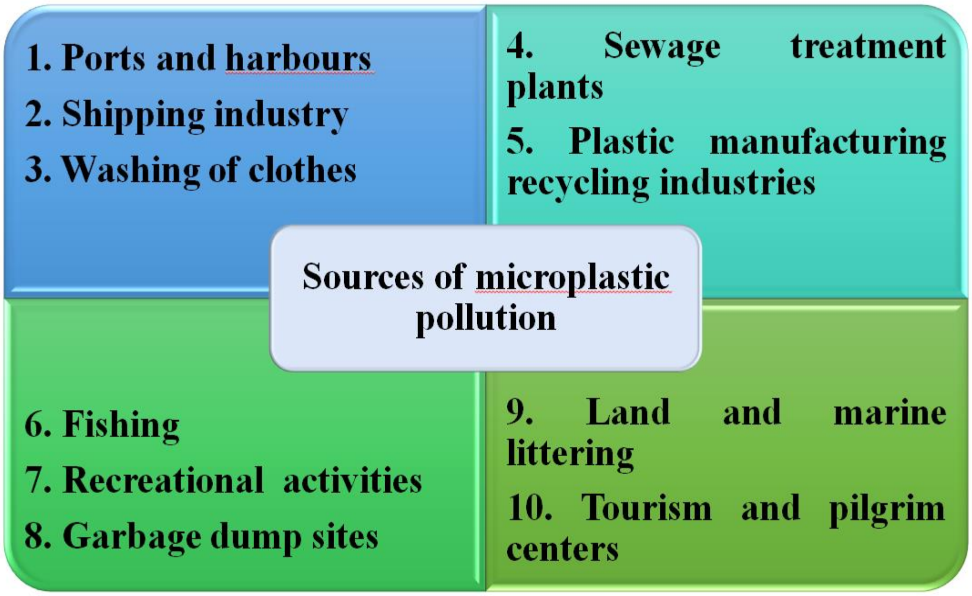

Figure 1. Sources of microplastic pollution

In places lacking the most advanced facilities, these forecasts may differ by up to a factor of 100. Secondary microplastics derived from plastic litter can originate from a variety of sources, such as landfilling and processing, disposal and transportation systems, solid municipal waste, and persons who make litter on intention or by mishap. This comprises both large plastic items and sanitary waste deposited into rivers by combined sewage overflows (CSOs).

MPs distribution and abundance

Several studies have revealed microplastics in urban rivers, major rivers [39], and Estuary Rivers [40]. Surface water concentrations of MP in a highly populated Chicago River range from 730,341 to 6,698,264 pieces per km^2. Ocean and Great Lakes indices are equivalent or perhaps greater than one another [41]. MP concentrations in the mainstream of the Yangtze River in China range from 3,407,700 to 13,617,500/km^2 and from 192,500 to 11,817,500/km^2 in the estuary zones of four river tributaries [42]. MP levels in freshwater environments are influenced by waste management, particle size, number of populations, groundwater flow, and urban and economic growth [43]. The accumulation of MPs in open seas, sediments, and organisms is influenced by several human, environmental, and geographic factors. Along the shore, ocean and wind current location, direction, beach profile, season, and regional geomorphological settings all play a significant effect in the abundance and dispersion of these organisms [44]. Other significant factors include the cumulative effects of longshore drift, the morphodynamic situation of coastlines, and the mixing and depletion of saltwater and freshwater [27]. According to supplementary studies, over 72% of substances are between 0.33 and 1 millimeter in size. Numerous studies of lakes, rivers and oceans have revealed an inverse relationship between the concentration of microplastics and particle size.

Characteristics and chemical composition

A size-splitting study of MPs showed that their sizes vary among aquatic system components. Consequently, a number of researches [28, 30, 45] found that bigger size groups of microplastics predominated in water and sediments, whereas others [46-47] reported that smaller fractions were prevalent. Polyethene, Polystyrene, and Polypropylene are the types of plastic waste most commonly detected on the water surfaces [48]. PE, PS, and PP were the predominant MPs identified in coastal sediments. PP and PE account for 62% of world demand, which coincides closely with global plastic output [2]. In addition, the density of the previously mentioned polymers is less than that of saltwater. Even amongst distinct sample matrices from the same study, there was diversity (sediments and water). A diameter range of 0.3 to 1 mm was prevalent in the soil and sediments of the Nethravathi River, but the range of 1 to 5 mm was more prevalent in water samples [31]. These differences in MP characteristics documented in research may be related to changes in sampling and analytic techniques. The size of MP reflects the effects of the breakdown and fragmentation of plastic trash in aquatic habitats. Determining its impact on bioaccumulation in a variety of aquatic benthic organisms necessitates a thorough investigation [47].

Transport and fate of microplastics in the riverine ecosystem

Plastic pollution has been described as the aquatic environment's difficult moment of industrialization. Microplastics have been found in sediments and water samples from a variety of natural habitats, including coastal zones [49], hills catchments [50], river catchments [51] and others. Degradation from dumping sites, surface runoffs, drainage from agricultural drainage activities, stormwater home activities, sewage effluents, wind and tidal waves, and other pathways all contribute to plastics entering the riverine ecosystem [52]. The main source of microplastic transportation in riverine environments is degradation and fragmentation, besides human-induced activities [53]. In the natural environment, MP goes through various natural processes during transportation, such as degradation, biofouling, egestion, flocculation, and ingestion. Microplastic transport and deposition are heavily influenced by their particle density, size, shape, and surface heterogeneity; hence, particle degradation is essential to their environmental fate [54-55]. Microplastic density, content, and forms decide whether microplastic is neutral, buoyant, or sinks in aquatic habitats [52].

Large microplastics, as indicated by their shapes, seem to be more liable to be deposited in the river bed sediments [51]. Based on this research, the size, shape, and density of microplastic particles have quite a substantial effect on their interactions, illustrating the complexity of microplastic destiny and movement in riverine environments. Biofouling also promotes microplastic settling and density, but the component mass is decreased by breakdown, making microplastic more buoyant, especially in river waters [20]. The flow of microplastics across rivers is assisted by flocculation and aggregation. Due to the ionic strength of saline waters, significant flocculation has been seen in estuarine and marine environments to date. Despite this, more than 90 percent of material transported by rivers is flocculated. Homoaggregation and heteroaggregation describe the microplastic concentration about particle size based on the density and size of the microplastics [55-56]. Additionally, flocculation and aggregation play a significant influence on the migration of microplastics in rivers. By flocculation, the riverine system transports approximately 90% of sediments. Microplastic interactions with the ecological environment are essential for microplastic transport and deposition tracking in river environments. Several studies on microplastic transport in the riverine environment have been published, such as those on the Seine River in Paris [57], some rivers in Switzerland [58], the Ganga River in India [8, 59], the Rhine River in Germany [39] and Danube River [60]. Natural phenomena such as rainfall, surface runoff [61], wind [62], flooding [63], and air currents trigger microplastic movement into rivers [64]. Due to downhill movement, MP is transported in rivers, which is further affected by the longitudinal advection flow of plastic particles in the river [65]. Some scientists employed the transport monitoring apparatus and sample processing technique to examine the transmission of microplastic in big and medium rivers [66].

Source and sink processes influence microplastic movement in a riverine environment [22]. Microplastics from a range of point and nonpoint sources were largely deposited into a river, contributing to pollutant deposition and accumulation in adjacent aquatic bodies [67]. The sedimentation process governs the fate and migration of microplastics in river settings. According to a study, extensive microplastic retention has been recorded in reservoirs and dams in rivers around the globe [10]. The transfer of plastic debris was influenced by river hydrology including water level, river velocity, and total discharge. Scientists demonstrated comparable variables influencing the deposition and transit of plastic waste in river environments [68]. Moreover, river flooding can enhance the aggregation and mobilization of microplastics. The ten nations with the greatest potential for plastic mobilization causing floods are China, Thailand, Egypt, Philippines, Brazil, Turkey, Congo and Vietnam [63]. Microplastic accumulates in a broad river catchment as a result of extensive particulate discharge, water velocity, and surface runoff from a variety of river outlet channels [69]. According to this study, the greater water levels in river streams mobilize plastic waste, which subsequently accumulates on vegetation and in sediments along riverbanks and vegetation. The transport of microplastics downstream of rivers is significantly affected by river morphology and tidal currents. They observed microplastic mobility and abundance in water and sediments [70]. The most common morphologies included fibers, pieces, foils, and spheres. Microplastic concentrations in Elbe River sediments are comparable to Rhine River sediments [71]. Rivers are the important transport mechanism for microplastic and plastic pollution by using geotropic plastic bottles that traveled 2845 kilometers in 94 days down through the Ganga River in India [72].

Gravitational sedimentation is the most prevalent mechanism for microplastics to settle. Sedimentation influences the resuspension of microplastics, followed by their aggregation, interactions with organisms and biofouling. In areas of low energy, such as standing water, fine silt particles gradually settle [73].

Ingestion of microplastic by riverine biota

Due to their extensive presence in ecosystems, microplastics constitute a threat to aquatic ecosystems and, consequently, to aquatic life. Microplastics are consumed by aquatic organisms, disrupt aquatic ecosystems, and thus impact biota [44]. 25 percent of microplastic ingestion studies have been conducted on fish, followed by 15 percent on molluscs, 11 percent on tiny crustaceans, 6 percent on annelid worms, 3 percent on echinoderms and mammals, 2 percent on birds, and 1 percent on cnidarians [74]. Microplastics are small enough for fish to easily consume. According to the findings, more than ten distinct fish species from China's coastal estuary had 20 meters in their guts and gills. 22% to 100% and 22% to 89% of all individuals had microplastics in their intestines and gills, respectively. It contained between 0.3 and 5.3 particles per individual in the intestines and between 0.3 and 2.6 particles per individual in the gills [75]. The incidence of microplastic ingestion in fish was 1.8%, and the average amount of plastic per organism was 0.02 pieces. However, only cod had a higher incidence rate, at 12.3 percent [76]. In addition, microplastics have been detected in the digestive systems of turtles [77] and fish [78] in a variety of rivers. Presence of microplastic in the digestive tracts of 78 wild freshwater gudgeons (*Gobio gobio*) in Flanders, Belgium [79]. The fish were collected from 15 distinct rivers at 17 different locations. The results indicated that 9 percent of gudgeons in all Flemish rivers were contaminated with microplastics. Importantly, it was demonstrated that 9 percent of the fish had consumed at least one microplastic particle, indicating that fish frequently consume microplastic. Scientists investigated the prevalence and properties of microplastic in 25 minor water bodies along the Yangtze River. It was discovered that tadpoles, as well as surface water and sediments, contained microplastics. It was found that microplastic is abundant in small bodies of water and is devoured by native tadpoles [80].

However, only fibers were identified in the setting of microplastics, and a significance level of 0.05 indicated that there was no detectable difference in microplastic abundance between the fish species that consumed the plastic. Fibers and filaments can clog the digestive tract of fish, inhibiting food absorption [81]. The presence of microplastic particles in the digestive systems of fish caught unintentionally during the swallowing of target species in shrimp fisheries in an estuary [78]. The Attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) method was utilized to identify plastic particles extracted from the fish digestive tract. Based on their size range of 0.38 to 4.16 mm, the scientists categorized microplastic particles as pellets (97.4 percent), sheets (1.3 percent), bits (0.4 percent), and threads (0.9 percent). Polyamide (PA), rayon, and polyethylene were detected in the fish polymers (PE). PA (Nylon) was discovered at the highest concentration, accounting for 97.4% of all microplastics ingested by fish in Amazon estuary samples. A role was performed by yellow particles, nylon pellets, blue thread and translucent sheets.

Effects of microplastic pollution on fish and human health

The effects of MPs on specific physical and biological processes have been investigated. The MP's exposure testing is used to catch fish from a variety of habitats, with the majority coming from the sea. After intake, MPs may cause morphological and functional alterations in the digestive systems (Figure 2), producing nutritional and developmental problems in fish [82].

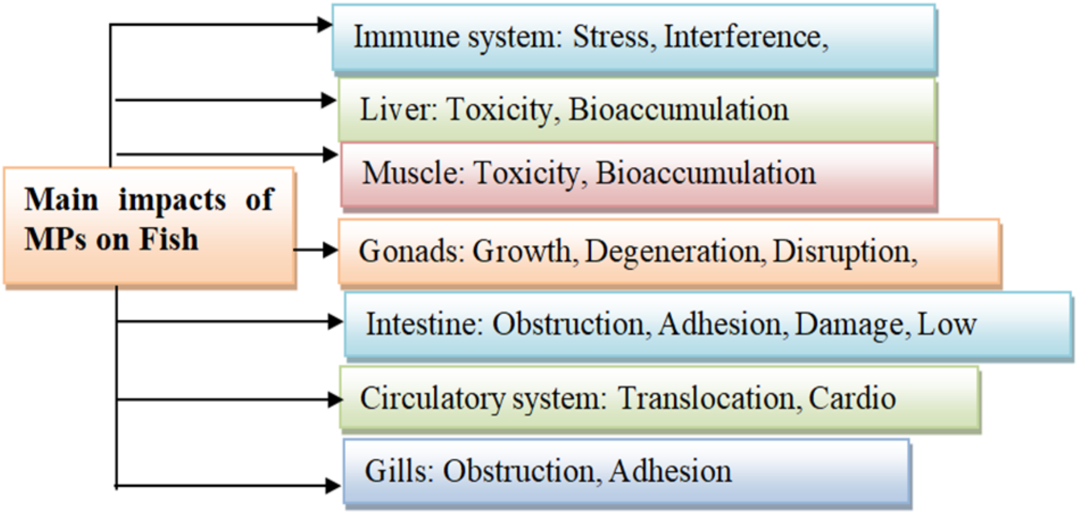

Figure 2. Impacts of MPs on fish

The majority of the study focused on *Danio rerio* including oxidative stress, reduced mobility, gene expression disruption, and reproductive organ damage [83-84]. *Oryzias melastigma* was the second most researched fish that was physically harmed after ingesting MPs [85]. In *Oryzias melastigma*, growth suppression, dysbiosis of the fish gut, weight loss, alteration of the liver's anti-oxidative condition, damage to reproductive organs, and growth retardation are all obvious effects (Table 1) [86-87]. *Sparus aurata* is another often-consumed fish that is harmed by MPs. Stress, oxidative damage; survival, behavioral alterations, and immune system damage were all observed in this fish [88].

Effect of MPs on fish behavior and health

Behavior plays a pivotal role in determining critical parameters such as overall health, growth, reproduction, and survival. Recent research suggests that the olfactory sense of fish larvae may be vulnerable to damage induced by an immunological response triggered by pollutants from microplastics. Microplastics not only impacted essential behaviors such as activity and feeding but also impaired innate responses to olfactory cues signaling danger [92]. This impairment in predator avoidance behavior substantially heightened mortality rates caused by predators targeting larvae.

Table 1. Effect of microplastic in fish species

S.N.	Fish species	Effects	References
1.	*Symphysodon aequifasciatus*	Discus fish (*Symphysodon aequifasciatus*) exhibit neurobehavioral toxicity due to micro- and nanoplastics. Reduction in growth and changes in neurotransmitters in the brain and gut of fish.	82
2.	*Oryzias melastigma*	Secondary PVC microplastics are more harmful to Oryzia smelastigma embryos than main PVC microplastics. Toxic effects are primarily caused by physical impairment in embryos. The particle absorption process in the chorion causes hypoxia.	85
3.	*Oryzias melastigma*	Male marine medaka, polystyrene microplastics enhance the estrogenic effects of 17α-ethynylestradiol (EE2) (*Oryzias melastigma).* Growth, HSI, and GSI indices were inhibited by MPs rather than EE2. In a dose-dependent approach, MPs boosted EE2-induced E2 levels. EE2 with MPs increased oestrogen biomarker gene expression more than EE2 alone. In the EE2 plus MPs group, histopathological harm to the liver and testes was found.	87
4.	*Danio rerio*	Zebrafish (*Danio rerio*) have a preference for bio-based polylactic acid microplastics in their diets, which can cause intestinal injury and microbiota dysbiosis. Bioaccumulation and oxidative stress both increase intestinal damage, and growth retardation is also increased. Lipid metabolism is disrupted, and genes involved in lipid digestion, transmission, and absorption are disrupted.	83
5.	*Ctenopharyngodon idella*	Effects of microplastic exposure at the physiological, biochemical, and transcriptome levels in grass carp (*Ctenopharyngodon idella*). Those fishes ate grass-fed beef lost weight and had histological alterations. MP-1000 therapy causes increased oxidative damage in the liver. Metabolic diseases and oxidative stress are linked, according to pathway enrichment.	89
6.	*Solea senegalensis*	Presence of one or the other affect the toxicity of polyethylene microplastics and modified nanoclays on flatfish (*Solea senegalensis*). MPs boost antioxidant defenses, neurotransmission, and energy expenditure when consumed. Histological changes were generated by PE, MPs alone and in combination with nanoclays. Under joint exposure, energy usage rose.	90
7.	*Dicentrarchus labrax*	Effects of chemical contaminants and polypropylene microplastics on the health and gut microbiota of European sea bass (*Dicentrarchus labrax*). It induces an inflammatory response in the European sea bass gut. The gut microbiota of fish changed significantly after ingesting contaminated MPs.	91

The presence of microplastics poses a significant threat to the survival of fish, profoundly influencing their life cycle dynamics. Fish microplastics primarily build up in the intestine, while they can occasionally also cause major pathogenic alterations in the liver and gills (Figure 2). The gut's damaged epithelium barrier modifies the gut microbiota, increases inflammation and oxidative stress, and impacts gene expression and protein synthesis profiles. In the afflicted fish livers, oxidative stress and evidence of dysregulated lipid and carbohydrate metabolism have also been noted [93].

Effect of microplastics on reproduction of fishes

Microplastic pollution is widespread, with concerns about its enrichment, adsorbability, and toxicity. The study investigated the effects of polystyrene microplastics (PS) and cadmium (Cd) on the gonad development and reproduction of rare minnow (*Gobiocypris rarus*) over 28 days. Decreased condition factors, number of spawning events, number of eggs per spawning, and average hatching rate were observed, likely due to long-term oxidative stress and inflammation affecting gonad development and reproduction function [94]. Polystyrene microplastics (PS-MPs) and 17α-Methyltestosterone (MT) caused varying degrees of reproductive system damage in zebrafish, with increased damage over time. Histological analysis showed a decrease in the ratio of mature oocytes and spermatozoa, and qRT-PCR results indicated significant changes in mRNA expression related to gonad development.

Offspring of zebrafish exposed to MT and MT + PS-MPs exhibited delayed incubation, slow development, and increased malformations [95]. Contamination of aquatic creatures with microplastic (MP) is a global danger to human health and aquatic life, as it adversely affects the physiological and physical fitness of different fish species. Virgin MPs and nanoparticles (NPs) compromise the immune, digestive, and reproductive systems, induce intestinal dysbiosis, and may have transgenerational effects. It has been discovered that fish can become harmed by prolonged exposure to low ambient levels of MPs in aquatic habitats [96].

Studies have focused on the combined ecological risks of microplastics and other organic pollutants, such as progestin residues. Exposure of adult zebrafish to polystyrene microplastics (PS) and norethindrone (NET) resulted in gill damage and oxidative stress, with decreased glutathione content and antioxidase activity. Co-exposure to PS and NET led to reduced testosterone and estradiol levels in females, increased androgenic effects, and significant changes in gut microbiota, highlighting the importance of studying their combined toxicity [97].

Most research on microplastics (MPs) has focused on physiological effects, with less attention given to potential behavioral impacts. The study aimed to determine if MPs alone or with the endocrine-disrupting chemical 17-alpha ethinyl estradiol (EE2) alter reproductive behavior and decision-making in fish. While male sexually selected traits were unaffected, non-exposed females showed significant discrimination against males exposed to high concentrations of EE2. The findings suggest MPs may alter social behavior in fish, with more pronounced effects in females, potentially impacting population size and the broader aquatic community [98].

Microplastics impact adult growth, lipid storage, and external coloration in fathead minnows, suggesting a potential food dilution effect. Environmentally sourced microplastics, but not preconsumer ones, had endocrine-disrupting effects on the parental generation and their offspring, leading to delayed egg production, less viable eggs, and higher rates of malformation. Results suggest that environmentally relevant concentrations of microplastics have significant implications for forage fish populations [99].

Effect of microplastics on phytoplankton and zooplankton

Plastic debris has become ubiquitous in marine and freshwater systems, entering the environment via accidental release, mismanaged waste streams, and also through the everyday use of certain personal care products, textiles that shed synthetic fibers into wastewater, and cleaning agents (Figure 3). Fish and invertebrates may consume the tiny particles of plastic waste that are broken down by weathering. As a result of these species being eaten, microplastics may enter the entire food chain and impact people, birds, and marine mammals. Long-term exposure to polystyrene microplastics significantly reduced the growth and chlorophyll concentration of marine microalgae, as well as the survival, nauplii production rate, and lipid concentration of the copepod [100].

Severe threats posed by microplastics (MP), plastic leachates (PL), and associated chemicals on phytoplankton, detailing their impacts at organismal, community, and ecosystem scales, which include decreased photosynthesis and primary productivity, altered microbial community structures, and disrupted nutrient cycling and biogeochemical processes, ultimately affecting ecosystem stability and services [101].

Microplastics are pervasive in the marine environment, posing significant environmental and economic concerns. This review evaluates the ingestion of microplastics by zooplankton, highlighting the negative impacts on biological processes and the potential for microplastics to enter the food web [102].

Microplastic (MP) pollution has been widely reported, with MPs in oceans being ingested by plankton and potentially transferring to other trophic levels via the plankton food web. MPs are often eaten by zooplankton due to their resemblance to prey in size, color, and buoyancy, leading to intestinal damage, reduced ingestion, slow growth, and abnormal gene expression [103]. A study

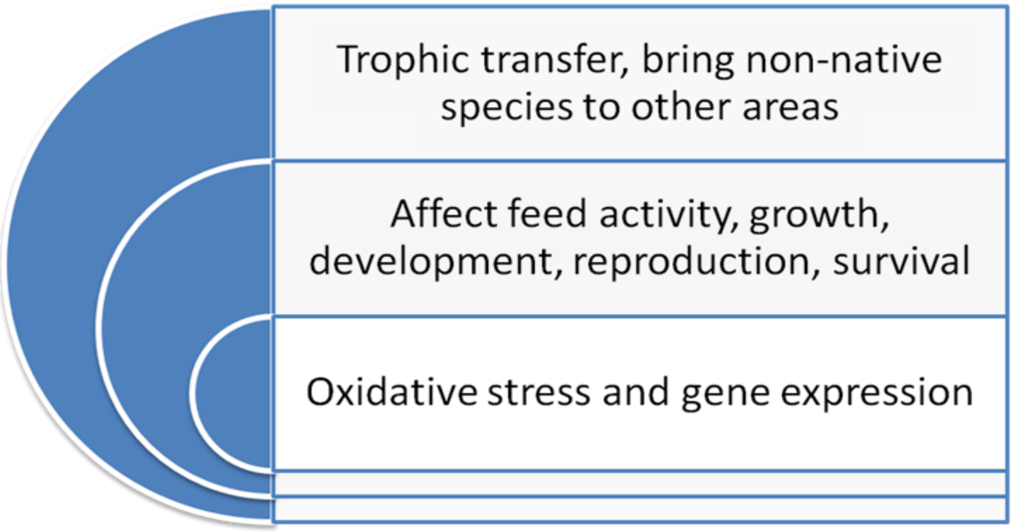

Figure 3. Impact of microplastic pollution on aquatic system

investigates how the shape of microplastics and the presence of algal-derived infochemicals affect ingestion rates in three zooplankton species. Different species showed a preference for certain shapes: *Calanus helgolandicus* for fragments, *Acartia tonsa* for fibers, and *Homarus gammarus* larvae for beads. Additionally, infochemicals increased microplastic ingestion in these species, suggesting that feeding strategies influence susceptibility to microplastic ingestion [104].

When zooplankton consumes microplastics, it can have detrimental effects on their health and ability to operate, such as a decrease in copepod algal eating. Microplastics adhered to the external carapace and appendages of exposed zooplankton. When the copepod Centropages typicus was exposed to naturally occurring algal assemblages with and without microplastics, it was observed that the presence of 7.3 µm microplastics (>4000 mL−1) dramatically reduced algal feeding. Results suggest that marine microplastic pollution may adversely affect zooplankton health and function [105].

Microplastics impact adult growth, lipid storage, and external coloration in fathead minnows, suggesting a potential food dilution effect. Environmentally sourced microplastics, but not preconsumer ones, had endocrine-disrupting effects on the parental generation and their offspring, leading to delayed egg production, less viable eggs, and higher rates of malformation. Results suggest that environmentally relevant concentrations of microplastics have significant implications for forage fish populations [106].

Effect of MPs on Human health

The intake of seafood containing MPs poses a severe threat to human health. It is possible for intestinal MP contamination to spread to other bodily areas. Endocytosis and perception are two of the most common entry points for MPs into the human body. Fish performance may be negatively affected by toxicological consequences for those who eat fish as a main meal, which could have poor effects on fish capture [107]. Additional research is required on these areas, taking into account actual MP and environmental pollution levels [108]. The accumulation of MP and nanoplastics in organs results in inflammation and blockage [109].

The vast surface area of microplastics made them susceptible to becoming vectors when exposed to pathogens and contaminants [110]. MPs might not have much of an effect on exposure to dangerous chemicals as compared to everyday food consumption and dust inhalation [111]. Conversely, a big number of MP exposures could significantly increase their amount. The monomers, additives, and breakdown products carried by MPs could represent significant health concerns to people if they are transmitted. MPs influence the diversity and function of the gut microbiome. Such impacts could have significant repercussions if numerous MPs are consumed by humans.

Microplastic mitigation and policy interventions

Due to their harmful impacts, microplastic cleanup at reliable resources can be an effective method for preventing ecosystem pollution. Environmental restrictions prohibiting plastics for effective waste management have been established internationally, such as the ban on non-biodegradable tableware in France, the prohibition on single-use shopping bags in California, and the ban on plastic-based packaging materials in Massachusetts. The UNEP (United Nations Environment Programme) endorsed the "Beat Plastics Pollution" theme for World Environment Day, 2018 in an effort to inspire local communities, increase public awareness of the effects of plastic pollution on the environment, and persuade people to use fewer single-use plastics. Politicians and governments must devise ways to limit plastic and microplastic manufacturing. The use of plastic water bottles and shopping bags was outlawed in California in 2014. Microplastics have been discovered in bottled water not only in the United States but also in Brazil, India, Thailand, Mexico, Kenya, China and Indonesia (0–10,000 particles). To avoid microplastic contamination, in 2015 the United States banned the use of microbeads made of plastic in personal care items. Currently, there are no specific guidelines for microplastic contamination, nor have any metrics been devised to measure the microplastic limit for drinking purposes.

Conclusion

Rivers are a major source of microplastics entering the world's oceans. Fragments of plastic are easily transported and disseminated in river streams, where they may settle and become lodged in sediments. Examples of microplastic contamination in riverine ecosystems include threads, fragments, films, foams, and pellets that are ingested by riverine animals and can travel long distances. The most effective strategy for minimizing contamination in riverine ecosystems is testing at non-point sources, such as surface water, downhill flow, and intra-site variations. In addition, there is a significant information gap about the possible origins, transportation, weathering process, identification of polymers, impact, and associated toxins in aquatic systems, which necessitates further research. Monitoring contaminants therefore requires a rapid and critical evaluation of research instruments, particularly comparative evaluation for quantification and identification in watercourse environments.

To evaluate the microplastic contamination in various habitats in order to define the baseline microplastic proportion in riverine ecosystems. It is recommended to perform additional research on the exposure of fish and other riverine creatures to nanoplastics. To further develop cleaning methods, it is vital to examine the relationship between riverine pollution and the presence of microplastics in groundwater and to give recommendations for future research. In terms of its bioecological consequences and trophic exchange, microplastic in freshwater creatures has not yet been thoroughly researched. To have a better understanding of the hazardous contaminants connected to microplastic, additional research is required, and they demand examination. Further research must evaluate the behavior and contamination of microplastics in relation to drainage geometry, changes in flow in the river, and other inputs in order to characterize the distribution and abundance of microplastics in both open-bottom sediments. In addition to the polymers' long-term consequences, nothing is known about their interactions with biota in the case of trophic transfers and riverine settings. Overconsumption, manufacturing, and effective wastewater treatment are the most effective means of addressing pollution issues. As a recommendation, following steps can be prioritized by humans:

- Sampling methodologies

- Obtaining and analyzing samples
- Movement and deposition
- Monitoring the influence on the food chain
- Fluid dynamics analysis
- It is possible to count microplastic concentrations in riverine environments accurately and without bias.

Subsequent studies ought to concentrate on the uptake of microplastics, their interactions with organisms and heavy metals, and their sources, movements, and destinations

References

[1] The Indian express **(2022)**. https://indianexpress.com/article/explained/worlds-population-touches-8-billion-how-india-is-placed-8270044.

[2] A. L. Andrady **(2015)**. Persistence of Plastic Litter in the Oceans. *In*: Bergmann, M., Gutow, L., Klages, M. (eds) Marine Anthropogenic Litter. Springer, Cham. doi: 10.1007/978-3-319-16510-3_3.

[3] S. Sharma and S. Chatterjee **(2017)**. Microplastic pollution, a threat to marine ecosystem and human health: A short review. Environ. Sci. Pollut. Res., **24:** 21530-21547.

[4] W. C. Li, H. F. Tse and L. Fok **(2016)**. Plastic waste in the marine environment: A review of sources, occurrence and effects. Sci. Total Environ., **566-567:** 333-349.

[5] K. R Vanapalli, B. Samal, B. K. Dubey and J. Bhattacharya **(2019)**. Emissions and environmental burdens associated with plastic solid waste management. *In*: Al-Salem SM (ed) Plastics to energy, Applied Science Publisher, pp313-342. doi: 10.1016/B978-0-12-813140-4.00012-1.

[6] E. J. Carpenter and K. L. Smith **(1972)**. Plastics on the sargasso sea surface. Science, **175:** 1240-1241.

[7] N. Singh, A. Mondal, A. Bagri, E. Tiwari, N. Khandelwal, F. A. Monikh and G. K. Darbha **(2021a)**. Characteristics and spatial distribution of microplastics in the lower Ganga river water and sediment. Mar. Pollut. Bull., **163:** 111960. doi: 10.1016/j.marpolbul.2020.111960.

[8] D. J. Sarkar, S. D. Sarkar, B. K. Das, R. K. Manna, B. K. Behera and S. Samanta **(2019)**. Spatial distribution of meso and microplastics in the sediments of river Ganga at eastern India. Sci. Total Environ., **694:** 133712. doi: 10.1016/j.scitotenv.2019.133712.

[9] M. Wagner and S. Lambert **(2018)**. Freshwater microplastics: emerging environmental contaminants? Heidelberg, New York, Dordrecht, London: Springer Nature, doi: 10.1007/978-3-319-61615-5.

[10] D. J. Sarkar, S. D. Sarkar, S. Mukherjee and B. K. Das **(2020)**. Impact and Fate of Microplastics in the Riverine Ecosystem. *In*: Kumar, M., Snow, D., Honda, R., Mukherjee, S. (eds) Contaminants in Drinking and Wastewater Sources. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore. doi: 10.1007/978-981-15-4599-3_4.

[11] R. Singh, R. Kumar and P. Sharma **(2021b)**. Microplastic in subsurface system: extraction and characterization of sediments from River Ganga near Patna, Bihar. *In*: Gupta, P.K., Yadav, B., Himanshu, S. (Eds.), Advances in Remediation Techniques for Polluted Soils and Groundwater. Elsevier. pp191-217. doi: 10.1016/B978-0-12-823830-1.00013-4.

[12] P. Dauvergne **(2018)**. The power of environmental norms: marine plastic pollution and the politics of microbeads. Environ. Polit., **27:** 579-597.

[13] M. Di and J. Wang **(2018)**. Microplastics in surface waters and sediments of the three gorges reservoir China. Sci. Total Environ., **616-617:** 1620-1627.

[14] B. He, B. Wijesiri, G. A. Ayoko, P. Egodawatta, L. Rintoul and A. Goonetilleke **(2020)**. Influential factors on microplastics occurrence in river sediments. Sci. Total Environ., **738:** 139901. doi: 10.1016/j.scitotenv.2020.139901.

[15] C. Guerranti, S. Cannas, C. Scopetani, P. Fastelli, A. Cincinelli and M. Renzi **(2017)**. Plastic litter in aquatic environments of Maremma Regional Park (Tyrrhenian Sea, Italy): Contribution by the Ombrone river and levels in marine sediments. Mar. Pollut. Bull., **117:** 366-370.

[16] M. Rasta, M. Sattari, M. S. Taleshi and J. I. Namin **(2020)**. Identification and distribution of microplastics in the sediments and surface waters of Anzali Wetland in the Southwest Caspian Sea, Northern Iran. Mar. Pollut. Bull., **160:** 111541. doi: 10.1016/j.marpolbul.2020.111541.

[17] A. Bakir, M. Desender, T. Wilkinson, N. V. Hoytema, R. Amos, S. Airahui and J. Graham et al., **(2020)**. Occurrence and abundance of meso and microplastics in sediment, surface waters, and marine biota from the South Pacific region. Mar. Pollut. Bull., 160: 111572. doi: 10.1016/j.marpolbul.2020.111572.

[18] A.Nunez, D. Astorga, L. Caceres-Farías, L. Bastidas, C. S. Villegas, K. Macay and J.H. Christensen (2021). Microplastic pollution in seawater and marine organisms across the tropical eastern Pacific and Galápagos. Sci. Rep., **11:** 6424. doi: 10.1038/s41598-021-85939-3.

[19] A. Mallik, K. M. Xavier, B. C. Naidu and B. B. Nayak **(2021)**. Ecotoxicological and physiological risks of microplastics on fish and their possible mitigation measures. Sci. Total Environ., **779:** 146433. doi: 10.1016/j.scitotenv.2021.146433.

[20] Y. Meng, F. J. Kelly and S. L. Wright **(2020)**. Advances and challenges of microplastic pollution in freshwater ecosystems: A UK perspective. Environ. Pollut., **256:** 113445. doi: 10.1016/j.envpol.2019.113445.

[21] M. Gholizadeh and R. Patimar **(2018)**. Ecological risk assessment of heavy metals in surface sediments from the Gorgan Bay, Caspian Sea. Mar. Pollut. Bull., **137:** 662-667.

[22] W. Luo, L. Su, N. J. Craig, F. Du, C. Wu and H. Shi **(2019)**. Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environ. Pollut., **246:** 174-182.

[23] O. Güven, K. Gökdağ, B. Jovanović and A. E. Kideyş **(2017)**. Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environ. Pollut., **223:** 286-294.

[24] L. G. A. Barboza, C. Lopes, P. Oliveira, F. Bessa, V. Otero, B. Henriques and J. Raimundo et al., **(2020)**. Microplastics in wild fish from North East Atlantic Ocean and its potential for causing neurotoxic effects, lipid oxidative damage, and human health risks associated with ingestion exposure. Sci. Total Environ., **717:** 134625. doi: 10.1016/j.scitotenv.2019.134625.

[25] R. Akhbarizadeh, F. Moore and B. Keshavarzi **(2018)**. Investigating a probable relationship between microplastics and potentially toxic elements in fish muscles from northeast of Persian Gulf. Environ. Pollut., **232:** 154-163.

[26] J. S. Choi, Y. J. Jung, N. H. Hong, S. H. Hong and J. W. Park **(2018)**. Toxicological effects of irregularly shaped and spherical microplastics in a marine teleost, the sheepshead minnow (*Cyprinodon variegatus*). Mar. Pollut. Bull., **129:** 231-240.

[27] S. Veerasingam, M. Saha, V. Suneel, P. Vethamony, A. C. Rodrigues, S. Bhattacharyya and B. G. Naik **(2016)**. Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. Chemosphere, **159:** 496-505.

[28] K. Dowarah and S. P. Devipriya **(2019)**. Microplastic prevalence in the beaches of Puducherry, India and its correlation with fishing and tourism/recreational activities. Mar. Pollut. Bull., **148:** 123-133.

[29] K. I. Jeyasanta, N. Sathish, J. Patterson and J. P. Edward **(2020)**. Macro-, meso-and microplastic debris in the beaches of Tuticorin district, Southeast coast of India. Mar. Pollut. Bull., **154:** 111055. doi: 10.1016/j.marpolbul.2020.111055.

[30] R. S. Robin, R. Karthik, R. Purvaja, D. Ganguly, I. Anandavelu, M. Mugilarasan and R. Ramesh **(2020)**. Holistic assessment of microplastics in various coastal environmental matrices, southwest coast of India. Sci. Total Environ., 703: 134947. doi: 10.1016/j.scitotenv.2019.134947.

[31] K. Amrutha and A. K. Warrier **(2020)**. The first report on the source-to-sink characterization of microplastic pollution from a riverine environment in tropical India. Sci. Total Environ., **739:** 140377. doi: 10.1016/j.scitotenv.2020.140377.

[32] A. Vidyasakar, K. Neelavannan, S. Krishnakumar, G. Prabaharan, T. S. A. Priyanka, N. S. Magesh and P. S. Godson et al., **(2018)**. Microplastic distribution in the beaches of Rameswaram Coral Island, Gulf of Mannar, Southeast coast of India: A first report. Mar. Pollut. Bull., **137:** 610-616.

[33] P. K. Karuppasamy, A. Ravi, L. Vasudevan, M. P. Elangovan, P. D. Mary, S. G. T. Vincent and T. Palanisami **(2020)**. Baseline survey of micro and mesoplastics in the gastro-intestinal tract of commercial fish from Southeast coast of the Bay of Bengal. Mar. Pollut. Bull., **153:** 110974. doi: 10.1016/j.marpolbul.2020.110974.

[34] D. B. Daniel, P. M. Ashraf and S. N. Thomas **(2020)**. Abundance, characteristics and seasonal variation of microplastics in Indian white shrimps (*Fenneropenaeus indicus*) from coastal waters off Cochin, Kerala, India. Sci. Total Environ., **737:** 139839. doi: 10.1016/j.scitotenv.2020.139839.

[35] H. B. Jayasiri, C. S. Purushothaman and A. Vennila **(2013)**. Quantitative analysis of plastic debris on recreational beaches in Mumbai, India. Mar Pollut Bull., **77:** 107-112. doi: 10.1016/j.marpolbul.2013.10.024.

[36] F. Murphy, C. Ewins, F. Carbonnier and B. Quinn **(2016)**. Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environ. Sci. Technol., **50:** 5800-5808

[37] A. A. Horton, C. Svendsen, R. J. Williams, D. J. Spurgeon and E. Lahive **(2017)**. Large microplastic particles in sediments of tributaries of the River Thames, UK–Abundance, sources and methods for effective quantification. Mar Pollut Bull., **114:** 218-226.

[38] K. Duis and A. Coors **(2016)**. Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environmental Sciences Europe, **28:** doi: 10.1186/s12302-015-0069-y.

[39] T. Mani, A. Hauk, U. Walter and P. H. Burkhardt **(2015)**. Microplastics profile along the Rhine River. Sci. Rep., **5:** 17988. doi: 10.1038/srep17988.

[40] L. T. Yonkos, E. A. Friedel, A. C. P. Reyes, S. Ghosal and C. D. Arthur **(2014)**. Microplastics in four estuarine rivers in the Chesapeake Bay, USA. Environ. Sci. Technol., **48:** 14195-14202.

[41] A. McCormick, T. J. Hoellein, S. A. Mason, J. Schluep and J. J. Kelly **(2014)**. Microplastic is an abundant and distinct microbial habitat in an urban river. Environ. Sci. Technol., **48:** 11863-11871.

[42] K. Zhang, W. Gong, J. Lv, X. Xiong and C. Wu **(2015)**. Accumulation of floating microplastics behind the Three Gorges Dam. Environ. Pollut., **204:** 117-123.

[43] C. M. Free, O. P. Jensen, S. A. Mason, M. Eriksen, N. J. Williamson and B. Boldgiv **(2014)**. High-levels of microplastic pollution in a large, remote, mountain lake. Mar. Pollut. Bullet., **85:** 156-163.

[44] S. Kumar, M. Rajesh, K. M. Rajesh, N. K. Suyani, A. A. Rasheeq and K. S. Pratiksha **(2020)**. Impact of microplastics on aquatic organisms and human health: A review. Int. J. Environ. Sci. Nat. Resour., **26:** 59-64.

[45] M. N. Sathish, I. Jeyasanta and J. Patterson **(2020)**. Occurrence of microplastics in epipelagic and mesopelagic fishes from Tuticorin, Southeast coast of India. Sci. Total Environ., **720:** 137614. doi: 10.1016/j.scitotenv.2020.137614.

[46] R. Karthik, R. Robin, R. Purvaja, D. Ganguly, I. Anandavelu, R. Raghuraman and G. Hariharan et al., **(2018)**. Microplastics along the beaches of southeast coast of India. Sci. Total Environ., **645:** 1388-1399.

[47] J. Patterson, K. I. Jeyasanta, N. Sathish, A. M. Booth and J. K. P. Edward **(2019)**. Profiling microplastics in the Indian edible oyster, *Magallana bilineata* collected from the Tuticorin coast, Gulf of Mannar, Southeastern India. Sci. Total Environ., **691:** 727-735.

[48] G. Suaria, C. G. Avio, A. Mineo, G. L. Lattin, M. G. Magaldi, G. Belmonte, C. J. Moore **(2016)**. The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. Sci. Rep., **6:** doi: 10.1038/srep37551.

[49] A. Ballent, A. Purser, P. D. J. Mendes, S. Pando and L. Thomsen **(2012)**. Physical transport properties of marine microplastic pollution. Biogeosci. Discuss., **9:** 18755–18798.

[50] S. Allen, D. Allen, V.R. Phoenix, G. Le Roux, P. D. Jimenez, A. Simonneau and S. Binet et al., **(2019)**. Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nature Geosci., **12:** 339-344.

[51] L. Nizzetto, G. Bussi, M. N. Futter, D. Butterfield and P. G. Whitehead **(2016)**. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. Environ. Sci. Processes Impacts, **18:** 1050-1059.

[52] A. A. Horton and S. J. Dixon **(2018)**. Microplastics: An introduction to environmental transport processes. WIREs Water 5, e1268. doi: 10.1002/wat2.1268.

[53] A. L. Andrady **(2011)**. Microplastics in the marine environment. Mar. Pollut. Bullet., **62:** 1596-1605.

[54] A. L. Andrady **(2017)**. The plastic in microplastics: A review. Mar. Pollut. Bullet., **119:** 12-22.

[55] Z.Wang, Y. Zhang, S. Kang, L. Yang, H. Shi, L. Tripathee and T. Gao **(2021)**. Research progresses of microplastic pollution in freshwater systems. Sci. Total Environ., **795:** 148888. doi: 10.1016/j.scitotenv.2021.148888.

[56] M. Kooi, S. Primpke, S. M. Mintenig, C. Lorenz, G. G. Gunnar and A. A. Koelmans **(2021)**. Characterizing the multidimensionality of microplastics across environmental compartments. Water Res., **202:** 117429. doi: 10.1016/j.watres.2021.117429.

[57] R. Dris, J. Gasperi, V. Rocher and B. Tassin **(2018)**. Synthetic and non-synthetic anthropogenic fibers in a river under the impact of Paris Megacity: Sampling methodological aspects and flux estimations. Sci. Total Environ., **618:** 157-164.

[58] F. Faure, C. Demars, O. Wieser, M. Kunz and L. F. D. Alencastro **(2015)**. Plastic pollution in Swiss surface waters: nature and concentrations, interaction with pollutants. Environ. Chem., 12: 582-591.

[59] R. Singh, R. Kumar and P. Sharma **(2021b)**. Microplastic in subsurface system: extraction and characterization of sediments from River Ganga near Patna, Bihar. *In*: Gupta, P.K., Yadav, B., Himanshu, S. (Eds.), Advances in Remediation Techniques for Polluted Soils and Groundwater. Elsevier. doi: 10.1016/B978-0-12-823830-1.00013-4.

[60] A. Lechner, H. Keckeis, F. L. Lumesberger, B. Zens, R. Krusch, M. Tritthart and M. Glas et al., **(2014)**. The Danube so colourful: a potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. Environ. Pollut., **188:** 177-181.

[61] J. Castro-Jiménez, D. González-Fernández, M. Fornier, N. Schmidt and R. Sempéré **(2019)**. Macro-litter in surface waters from the Rhone River: Plastic pollution and loading to the NW Mediterranean Sea. Mar. Pollut. Bull., **146:** 60-66.

[62] A. Bruge and M. Dhamelincourt **(2018)**. Sampling microplastics in turbulent rivers using a stationary net from a bridge: what should be the sampling duration? how many samples are needed to reduce bias?. *In*: MICRO 2018. Fate and Impact of Microplastics: Knowledge, Actions and Solutions, pp68. MSFS-RBLZ.

[63] J. Roebroek, S. Harrigan and T. V. Emmerik **(2020)**. Forecasting plastic mobilization during extreme hydrological events. EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-22384, doi: 10.5194/egusphere-egu2020-22384.

[64] L. Cai, J. Wang, J. Peng, Z. Tan, Z. Zhan, X. Tan and Q. Chen **(2017)**. Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. Environ. Sci. Pollut. Res., **24:** 24928-24935.

[65] S. Cook, H. Chan, S. Abolfathi, G. D. Bending, H. Schäfer and J. M. Pearson **(2020)**. Longitudinal dispersion of microplastics in aquatic flows using fluorometric techniques. Water Res., **170:** 115337

[66] M. Liedermann, P. Gmeiner, S. Pessenlehner, M. Haimann, P. Hohenblum and H. Habersack **(2018)**. A methodology for measuring microplastic transport in large or medium rivers. Water, **10:** 414. doi: 10.3390/w10040414.

[67] Z. Ouyang, R. Mao, E. Hu, C. Xiao, C. Yang and X. Guo **(2022)**. The indoor exposure of microplastics in different environments. Gondwana Res., **108:** 193-199.

[68] T. Emmerik and A. Schwarz **(2020)**. Plastic debris in rivers. WIREs Water. **7:** e1398. doi: 10.1002/wat2.1398.

[69] M. Dagg, R. Benner, S. Lohrenz and D. Lawrence **(2004)**. Transformation of dissolved and particulate materials on continental shelves influenced by large rivers: plume processes. Cont. Shelf Res., **24:** 833-858.

[70] C. Scherer, A. Weber, F. Stock, S. Vurusic, H. Egerci, C. Kochleus and N. Arendt **(2020)**. Comparative assessment of microplastics in water and sediment of a large European river. Sci. Total Environ., **738:** 139866. doi: 10.1016/j.scitotenv.2020.139866.

[71] S. Klein, E. Worch and T. P. Knepper **(2015)**. Occurrence and spatial distribution of microplastics in river shore sediments of the Rhine-Main area in Germany. Environ. Sci. Technol., **49:** 6070-6076.

[72] E. M. Duncan, A. Davies, A. Brooks, G. W. Chowdhury, B. J. Godley, J. Jambeck and T. Maddalene et al., **(2020)**. Message in a bottle: Open source technology to track the movement of plastic pollution. PLoS One, **15:** e0242459.

[73] T. J. Hoellein, A. J. Shogren, J. L. Tank, P. Risteca and J. J. Kelly (2019). Microplastic deposition velocity in streams follows patterns for naturally occurring allochthonous particles. Sci. Rep., **9:** 3740. doi: 10.1038/s41598-019-40126-3.

[74] L. C. De Sá, L. G. Luís and L. Guilhermino **(2015)**. Effects of microplastics on juveniles of the common goby (*Pomatoschistus microps*): confusion with prey, reduction of the predatory performance and efficiency, and possible influence of developmental conditions. Environ. Pollut., **196:** 359-362.

[75] L. Su, H. Deng, B. Li, Q. Chen, V. Pettigrove, C. Wu and H. Shi **(2019)**. The occurrence of microplastic in specific organs in commercially caught fishes from coast and estuary area of east China. J. Hazard. Mater., **365:** 716-724.

[76] S. Kühn, J. A. van Franeker, A. M. O'donoghue, A. Swiers, M. Starkenburg, B. van Werven, E. Foekema et al., **(2020)**. Details of plastic ingestion and fibre contamination in North Sea fishes. Environ. Pollut., **257:** 113569

[77] S. Rezania, J. Park, M. F. M. Din, S. M. Taib, A. Talaiekhozani, K. K. Yadav and H. Kamyab **(2018)**. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Marine Pollut. Bull., **133:** 191-208.

[78] T. Pegado, L. Brabo, K. Schmid, F. Sarti, T.T. Gava, J. Nunes and D. Chelazzi et al., **(2021)**. Ingestion of microplastics by *hypanus guttatus* stingrays in the Western Atlantic Ocean (Brazilian Amazon Coast). Mar. Pollut. Bull., **162:** 111799.

[79] B. Slootmaekers, C. C. Carteny, C. Belpaire, S. Saverwyns, W. Fremout, R. Blust and L. Bervoets **(2019)**. Microplastic contamination in gudgeons (Gobio gobio) from Flemish rivers (Belgium). Environ. Pollut., **244:** 675-684.

[80] D. Hu, Y. Zhang and M. Shen **(2020)**. Investigation on microplastic pollution of Dongting Lake and its affiliated rivers. Mar. Pollut. Bull., **160:** 111555. doi: 10.1016/j.marpolbul.2020.111555.

[81] S. L. Wright, R. C. Thompson and T. S. Galloway **(2013)**. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut., **178:** 483-492.

[82] J. N. Huang, B. Wen, L. Xu, H. C. Ma, X. X. Li,J. Z. Gao andZ. Z. Chen **(2022)**. Micro/nano-plastics cause neurobehavioral toxicity in discus fish (*Symphysodon aequifasciatus*): Insight from brain-gut-microbiota axis. J. Hazard. Mater., **421:** 126830. doi: 10.1016/j.jhazmat.2021.126830.

[83] Y. Zhang, X. Zhang, Q. Yan, C. Xu, Q. Liu, Y. Shen and P. Zhao **(2022)**. Melatonin attenuates polystyrene microplastics induced motor neurodevelopmental defect in zebrafish (Danio rerio) by activating nrf2-isl2a Axis. Ecotox. Environ. Saf., **241:** 113754. doi: 10.1016/j.ecoenv.2022.113754.

[84] T. Zhao, Y. M. Lozano and M. C. Rillig **(2021)**. Microplastics increase soil pH and decrease microbial activities as a function of microplastic shape, polymer type, and exposure time. Front. Environ. Sci., **9:** 675803. doi: 10.3389/fenvs.2021.675803.

[85] B. Xia, Q. Sui, Y. Du, L. Wang, J. Jing, L. Zhu and X. Zhao et al., **(2022)**. Secondary PVC microplastics are more toxic than primary PVC microplastics to *Oryzias melastigma* embryos. J. Hazard. Mater., **424:** 127421. doi: 10.1016/j.jhazmat.2021.127421.

[86] C. Li, Y. Gan, C. Zhang, H. He, J. Fang, L. Wang and J. Liu **(2021)**. "Microplastic communities" in different environments: differences, links, and role of diversity index in source analysis. Water Res., 188: 116574. doi: 10.1016/j.watres.2020.116574.

[87] J. Wang, X. Li, M. Gao, X. Li, L. Zhao and S. Ru **(2022)**. Polystyrene microplastics increase estrogenic effects of 17α-ethynylestradiol on male marine medaka (*Oryzias melastigma*). Chemosphere, **287:** 132312. doi: 10.1016/j.chemosphere.2021.132312.

[88] H. Jacob,M.Besson, F.Oberhaensli, A.Taylor, B.Gillet, S. Hughes and S. D. Melvin **(2021)**. A multifaceted assessment of the effects of polyethylene microplastics on juvenile gilthead seabreams (*Sparus aurata*). Aquat. Toxicol., **241:** 106004. doi: 10.1016/j.aquatox.2021.106004.

[89] Y. Liu, X. Jia, H. Zhu, Q. Zhang, Y. He, Y. Shen, X. Xu and J. Li **(2022)**. The effects of exposure to microplastics on grass carp (*Ctenopharyngodon idella*) at the physiological, biochemical, and transcriptomic levels. Chemosphere, **286:** 131831. doi: 10.1016/j.chemosphere.2021.131831.

[90] L. M. Santana, A. C. Rodrigues, D. Campos, O. Kaczerewska, J. Figueiredo, S. Silva and I. Sousa et al., **(2022)**. Can the toxicity of polyethylene microplastics and engineered nanoclays on flatfish (*Solea senegalensis*) be influenced by the presence of each other? Sci. Total Environ., **804:** 150188. doi: 10.1016/j.scitotenv.2021.150188.

[91] D. Montero, S. Rimoldi, S. Torrecillas, J. Rapp, F. Moroni, A. Herrera and M. Gomez et al., **(2022)**. Impact of polypropylene microplastics and chemical pollutants on European sea bass (*Dicentrarchus labrax*) gut microbiota and health, Sci. Total Environ., **805:** 150402. doi: 10.1016/j.scitotenv.2021.150402.

[92] O. M. Lonnstedt and P. Eklov **(2016)**. Environmentally relevant concentrations of microplastic particles influence larval fish ecology. Science, **352:** 1213-1316. doi: 10.1126/science.aad8828.

[93] N. Zolotova, A. Kosyreva, D. Dzhalilova, N. Fokichev and O. Makarova **(2022)**. Harmful effects of the microplastic pollution on animal health: a literature review PeerJ., **10:** e13503. doi: 10.7717/peerj.13503.

[94] M. Hou, X. Zou, L. Su, C. Xu, Z. Xia, Q. Wang and X. Zhao et al., **(2024)**. Effects of environmentally relevant polystyrene microplastics and cadmium on the development and reproduction of rare minnow (*Gobiocypris rarus*), J. Environ. Chem. Eng., **12:** 111886. doi: 10.1016/j.jece.2024.111886.

[95] W. Rong, Y. Chen, Z. Xiong, H. Zhao, T. Li, Q. Liu and J. Song et al., **(2024)**. Effects of combined exposure to polystyrene microplastics and 17α-Methyltestosterone on the reproductive system of zebrafish, Theriogenology, **215:** 158-169.

[96] R. A. H. Bhat, M. J. Sidiq and I. Altinok **(2024)**. Impact of microplastics and nanoplastics on fish health and reproduction, Aquaculture, **590:** 741037. doi: 10.1016/j.aquaculture.2024.741037.

[97] S. Zhou, H. Lin, Z. Liu, X. Lian, C.G. Pan, Z. Dong and Z. Lin et al., **(2024)**. The impact of co-exposure to polystyrene microplastics and norethindrone on gill histology, antioxidant capacity, reproductive system, and gut microbiota in zebrafish (*Danio rerio*), Aquat. Toxicol., **273:** 107018. doi: 10.1016/j.aquatox.2024.107018.

[98] G. Carter and J. Ward **(2024)**. Independent and synergistic effects of microplastics and endocrine-disrupting chemicals on the reproductive social behavior of fathead minnows (*Pimephales promelas*). Ecol. Evol., **14:** e10846. doi: 10.1002/ece3.10846.

[99] K. Bucci, M. Bayoumi, K. Stevack, T. W. Leung, C. M. Rochman **(2024)**. Microplastics may induce food dilution and endocrine disrupting effects in fathead minnows (*Pimephales promelas*), and decrease offspring quality, Environ. Pollut., **345:** 123551. doi: 10.1016/j.envpol.2024.123551.

[100] P. Raju, P. Santhanam, S. S. Pandian, M. Divya, A. Arunkrishnan, K. N. Devi, S. Ananth **(2022)**. Impact of polystyrene microplastics on major marine primary (phytoplankton) and secondary producers (copepod). Arch. Microbiol., **204:** 84. doi: 10.1007/s00203-021-02697-6.

[101] C. Amaneesh, S. A. Balan, P. S. Silpa, J. W. Kim, K. Greeshma, A. A. Mohan and A. R. Antony et al., **(2023)**. Gross negligence: impacts of microplastics and plastic leachates on phytoplankton community and ecosystem dynamics. Environ. Sci. Technol., **57:** 5-24.

[102] Botterell, L.R. Zara, N. Beaumont, T. Dorrington, M. Steinke, R. C. Thompson, P. K. Lindeque **(2019)**. Bioavailability and effects of microplastics on marine zooplankton: A review. Environ. Pollut., **245:** 98-110.

[103] H. Meiting, Y. Muting , X. Chen, W. Xukun, H. Gong, W. Wenjing and J. Wang **(2022)**. Bioavailability and toxicity of microplastics to zooplankton. Gondwana Res., **108:** 120-126.

[104] Z. L. R. Botterell, N. Beaumont, M. Cole, F. E. Hopkins, M. Steinke, R. C. Thompson and P. K. Lindeque **(2020)**. Bioavailability of microplastics to marine zooplankton: effect of shape and infochemicals. Environ. Sci. Technol., **54:** 12024-12033.

[105] M. Cole, P. Lindeque, E. Fileman, C. Halsband, R. Goodhead, J. Moger and T. S. Galloway **(2013)**. Microplastic Ingestion by Zooplankton. Environ. Sci. Technol., **47:** 6646-6655.

[106] K. Kor andA.Mehdinia **(2020)**. Neustonic microplastic pollution in the Persian Gulf. Mar. Pollut. Bull., **150:** 110665. doi: 10.1016/j.marpolbul.2019.110665.

[107] D. Neves, P. Sobral, J. L. Ferreira and T. Pereira **(2015)**. Ingestion of microplastics by commercial fish off the Portuguese coast. Mar. Pollut. Bull., **101:** 119-126.

[108] J. C. Prata **(2018)**. Airborne microplastics: Consequences to human health? Environ. Pollut., **234:** 115-126.

[109] A. Bakir, S. J. Rowland and R. C. Thompson **(2014)**. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. Environ. Pollut., **185:** 16-23.

[110] S. M. Rodrigues, C. M. R. Almeida, D. Silva, J. Cunha, C. Antunes, V. Freitas and S. Ramos **(2019)**. Microplastic contamination in an urban estuary: abundance and distribution of microplastics and fish larvae in the Douro estuary. Sci. Total Environ., **659:** 1071-1081.

[111] N. L. Fahrenfeld, G. A. Keil, N. N. Beni and S. L. B. Hunt **(2019)**. Source tracking microplastics in the freshwater environment. TrAC Trends Anal. Chem., **112:** 248-254.