

Occurrence and impacts of microplastics in freshwater fish

Abstract

Plastic production continues to increase as most developed and developing countries continue to adopt the use-and-dispose culture, while some try to implement regulations in the production and recycling of these materials. This high production associated with their durability, unsustainable use, and inappropriate waste management contributes to the introduction and extensive accumulation of plastic debris in natural habitats. Microplastics are of emerging concern, but the amount of research done in freshwater environments is nothing compared to that in marine environments. Following this reality, we seek to investigate the occurrence of these contaminants in freshwater fish and what are the possible impacts to these aquatic species and human beings, since we have a tight relation to this resource.

Keywords: Contamination, Fish, Freshwater, Microplastics, Impacts, Occurrence

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Abbreviations: MP, Microplastic; WWTP, Wastewater Treatment Plant; PCP, Personal Care Product; OPA, Organic Plastic Additives; POP, Persistent Organic Pollutants

Introduction

Plastic production continues to increase as most developed and developing countries continue to adopt the use-and-dispose culture, while some try to implement regulations in the production and recycling of these materials. Annual plastic production increased from 1.5 million tonnes in the 1950s to 322 million tonnes in 2015,¹ bringing many societal benefits, in addition to medical and technological advances.² However, this high production associated with their durability, unsustainable use, and inappropriate waste management contributes to the introduction and extensive accumulation of plastic debris in natural habitats,³ mainly in marine habitats where this problem is vastly documented. Here, macroplastics (> 25 mm) are degraded into mesoplastics (5-25 mm) and then into microplastics (MPs), particles typically smaller than 5 mm in diameter. Besides these degradation products (secondary MPs), MPs can also be produced (primary MPs),⁴ these include microbeads, resin pellets or personal care products (PCPs).

MPs are of special concern since their bioavailability increases with decreasing size, making them easily available to lower trophic organisms.⁵ Many of these organisms capture anything of appropriate size without being able to select between particles.⁶ In addition, MPs contain a variety of organic plastic additives (OPAs)⁷ and have also been shown to adsorb persistent organic pollutants (POPs) from the surrounding seawater (briefly reviewed by Bakir et al.,⁸), potentially affecting all organisms throughout the aquatic food web.⁹

Marine plastic pollution has been of concern since the late 1960's¹⁰ and early 70's,¹¹ when the first reports of MPs ingestion were starting to be published. On the other hand, it has only recently been carried out studies that highlight the contamination of freshwater ecosystems by MPs, as reviewed by Wagner et al.⁴ Nonetheless, information is still scarce and spread regarding freshwater environments and, especially, freshwater fauna.

Fish are an important biological element of the freshwater

ecosystems with significant economic and nutritional value worldwide. About 94% of all freshwater fisheries occur in developing countries,¹² providing food and a livelihood for millions of the world's poorest people, and contributing to the overall economic wellbeing by means of exportation, tourism, and recreation.¹³ Moreover, they generate many ecosystem-services such as: (1) regulating food web dynamics and nutrient balances; (2) regulating carbon flux; (3) regulating sediment processes and (4) are links between ecosystems.¹⁴ Thus, it becomes vital to protect and preserve freshwater fish populations from contaminants of emerging concern like microplastics.

Therefore, our work seeks to investigate the occurrence of these contaminants in freshwater fish around the world and what are the possible impacts to these aquatic species and human beings since we have a tight relation to this resource.

Early works

Occurrence of Microplastics in Freshwater Fish

Despite the greater knowledge on marine microplastics, to date, only five studies have investigated the occurrence of MPs in freshwater fish.

In a 2014 preliminary field report, Sanchez et al.¹⁵ provided the first evidence that freshwater fish ingest MPs. They investigated wild gudgeons (*Gobio gobio*) caught in 11 French streams, characterized by various environmental pressures, and found MPs in the digestive tract of 12% of the fish.

Phillips & Bonner¹⁶ also documented the occurrence of plastic ingested by fishes in freshwater drainages of the Gulf of Mexico with a percent occurrence of MP ingestion of 8%. Later, Peters & Bratton¹⁷ found that 45% of the fish sampled had ingested MPs within the Central Brazos River Basin, Texas. More recently, Jabeen et al.¹⁸ studied micro- and mesoplastic pollution in sea and freshwater fishes from China, finding MPs in 95.7% of freshwater fish. They also reported for the first time the abundance of plastics in the intestines suggesting that the abundance of plastics in the intestines was even higher than in the stomachs in some fish species. In the same issue, Silva-Cavalcanti et al.¹⁹ assessed the ingestion of MPs by *Hoplosternum littorale*, a common freshwater fish consumed daily by

humans, in the Northeast Brazil. Fish were caught in four sampling sites in a city-crossing section of the Pajeú river finding MPs in the digestive system of 83% of the fish, a proportion far above from those reported for another freshwater, estuarine or even marine fish.¹⁹

Impacts of Microplastics in Freshwater Fish

Within ecosystems, microplastics can have quite harmful consequences for the local fauna. Ingestion of plastic particles has been reported for over 600 taxa,²¹ being fish among the most affected taxa. Ingestion is the most common form of fish contamination by MPs. It is thought that their ingestion may occur intentionally, as they are mistaken for small food particles suspended in the water column; accidentally, when they ingest it with food or even preferentially, as in the case of *Perca fluviatilis*' larvae.^{17,22,23}

Several studies have demonstrated the negative effects of MPs on fish fauna, from physical to physiological effects.^{3,23,24} The physical risks inherent to its ingestion include the clogging of the alimentary appendages and of the digestive system, and inflammation and laceration of gastrointestinal tissues preventing the correct absorption of nutrients.²⁴⁻²⁷ The physiological interference can also be observed when MPs directly interfere with the immune system of fish through the stimulation of degranulation²⁸ and through behavioural change, reducing the ability of a predator to perceive.²³

Observations and discussion

In view of the above work, MPs were present in 34 different species from all around the world (Table 1). Although the number of examined species is considerably low, it is also expected since some authors chose to select sentinel species based on their: (1) use in ecotoxicology and life cycle traits¹⁵ (2) abundance throughout the study area, sampling accessibility and position within the food chain¹⁷ and (3) demand as a highly consumed fishing resource.¹⁹

All the results obtained in the studies suggested that fish inhabiting freshwater environments near urbanized areas were at a higher risk of exposure to and ingestion of MPs, except Jabeen et al.,¹⁸ whose study focused in the relationship between plastic pollution and the feeding traits and habitats of freshwater fish. Silva-Cavalcanti et al.¹⁹ observed MPs were ingested more frequently in fish collected at stations that were more densely urbanized. Both, Phillips & Bonner¹⁶ and Peters & Bratton¹⁷ showed that several fish species collected in rivers near urbanized areas in Texas showed a significantly higher proportion of ingestion of plastic debris in relation to fish caught in less urbanized areas. Sanchez et al.¹⁵ did not detect MPs in wild gudgeons from low impacted sites located in watersheds' upstream areas, while those collected from urban rivers had MPs in their gut, thus supplementing the hypothesis that wastewater treatment plants (WWTPs), in urbanized areas, are one of the sources of MPs in inland surface waters.²⁰

Table 1 Species of freshwater fish in which microplastics were found

Family	Species	Reference
Callichthyidae	<i>Hoplosternum littorale</i> Hancock, 1828	[19]
Centrarchidae	<i>Lepomis auritus</i> Linnaeus, 1758	[16]
	<i>Lepomis cyanellus</i> Rafinesque, 1819	[16]
	<i>Lepomis humilis</i> Girard, 1858	[16]
	<i>Lepomis macrochirus</i> Rafinesque, 1819	[16,17]
	<i>Lepomis megalotis</i> Rafinesque, 1820	[16,17]
	<i>Lepomis microlophus</i> Günther, 1859	[16]
	<i>Micropterus salmoides</i> Lacepède, 1802	[16]
Characidae	<i>Astyanax mexicanus</i> De Filippi, 1853	[16]
Cichlidae	<i>Herichthys cyanoguttatus</i> Baird & Girard, 1854	[16]
	<i>Oreochromis aureus</i> Steindachner, 1864	[16]
Clupeidae	<i>Dorosoma cepedianum</i> Lesueur, 1818	[16]
	<i>Dorosoma petenense</i> Günther, 1867	[16]
Cyprinidae	<i>Camptostoma anomalum</i> Rafinesque, 1820	[16]
	<i>Carassius auratus</i> Linnaeus, 1758	[18]
	<i>Cyprinella lutrensis</i> Baird & Girard, 1853	[16]
	<i>Cyprinella venusta</i> Girard, 1856	[16]
	<i>Cyprinus carpio</i> Linnaeus, 1758	[18]
	<i>Gobio gobio</i> Linnaeus, 1758	[15]
	<i>Hemiculter bleekeri</i> Warpachowski, 1888	[18]
	<i>Hypophthalmichthys molitrix</i> Valenciennes, 1844	[18]
	<i>Megalobrama amblycephala</i> Yih, 1955	[18]
	<i>Notropis amabilis</i> Girard, 1856	[16]
	<i>Notropis sabiniae</i> Jordan & Gilbert, 1886	[16]
	<i>Notropis stramineus</i> Cope, 1865	[16]
	<i>Notropis volucellus</i> Cope, 1865	[16]
	<i>Pimephales vigilax</i> Baird & Girard, 1853	[16]
	<i>Pseudorasbora parva</i> Temminck and Schlegel, 1846	[18]
Fundulidae	<i>Fundulus notatus</i> Rafinesque, 1820	[16]
Ictaluridae	<i>Ameiurus natalis</i> Lesueur, 1819	[16]
	<i>Ictalurus punctatus</i> Rafinesque, 1818	[16]
	<i>Noturus gyrinus</i> Mitchill, 1817	[16]
Percidae	<i>Etheostoma artesiae</i> Hay, 1881	[16]
Poeciliidae	<i>Gambusia affinis</i> Baird & Girard, 1853	[16]

From all the plastic morphotypes studied, fibres were the most predominant in every work. Compared to larger plastic particles,

microfibrils are more flexible and smaller being more likely to be ingested accidentally throughout the trophic chain or mixed with

sediments.¹⁹ For instance, microfibrils have been observed in the guts of several gudgeons from French rivers,¹⁵ in fish species from Texas rivers¹⁶ and in *Hoplosternum littorale*.¹⁹ Also, 96% of all plastic particles ingested by Centrarchidae fish from the Brazos river in the Texas were microfibrils,¹⁷ and in some fish species found in China microfibrils represented 26.3 – 88.2 % of all the plastic ingested.¹⁸

Jabeen et al.¹⁸ found demersal species showed significantly higher abundance of plastics than pelagic fishes ($p < 0.05$), saying, afterwards, that freshwater fish feeding habits and habitats play an important role in the ingestion of plastic debris. Silva-Cavalcanti et al.¹⁹ corroborated this interaction by relating the feeding trait of *H. littorale*, a microphagous scavenger, with the accidental ingestion of plastic debris mixed with sediment when foraging on the bottom for food. Furthermore, Sanchez et al.¹⁵ related the higher ingestion of plastic debris, by *Gobio gobio*, with its bottom feeding behaviour.

Microplastics have several properties, and believed to have effect on organisms directly or indirectly, working as a vehicle of chemical substances. These chemical impacts of the MPs structure are complex and works at different levels. Because polymers are molecules of high dimensions, they are biochemically stable. However, the polymerization reaction is rarely complete, evidencing the presence of residual monomers which varies up to 4%.²⁹ These monomers can be leached from the polymer matrix and many of them can be considered toxic to the environment, evidenced by the ranking of Lithner et al.³⁰ In addition to the effects of its structural matrix, the toxic effects can be caused by the chemical additives inserted during its manufacturing process, such as solvents and catalysts, as well as plasticizers and antimicrobial agents, which are part of the structure of the final composition of the plastic. As these components have low molecular weight, they can easily migrate or diffuse into the environment causing adverse effects on the ecosystem.³¹

The affinity of the organic contaminants to the plastic matrix leads to its accumulation and absorption^{32,33} acting in a similar way to the chemical additives. However, studies that substantiate these impacts to the fish fauna are limited. Study conducted by Lönnstedt & Eklöv,²³ which shows that the exposure of larvae of *Perca fluviatilis* to plastic polymers does not respond to threat stimulate by inducing the predator mortality rate. However, such a study does not clearly demonstrate whether the effects are on exposure responses of chemical or physical contaminants from MPs. Differently from the study conducted by Browne et al.³⁴ that exposes *Arenicola marina* sand contaminated with MPs demonstrating a tissue accumulation of 250% of the contaminants. Thus, there is a great limitation of information regarding the exposure of chemical contaminants by parts of the MPs associated with fish fauna, being of major importance further studies to determine the impacts of chemical and organic pollutants from plastic polymers in the aquatic ecosystem of water candy.

Gaps in research

Most rivers with a high rate of plastic debris are located close to large urban centres, presenting a great risk to fish biodiversity and especially to general fish^{17,35} and are related to the consumer market. In this way, the presence of MPs in fish consumption has raised a great problem in the potential of transference to humans,³⁶ since MPs are vectors of dispersion of several types of contaminants, increasing their proportion of thousands of times along the trophic chain through biomagnification.^{37,38}

Although many studies involving the MP related to marine environments, in recent years there have been many studies regarding

freshwater environments that aim to relate their presence with possible impacts to local fauna. However, there is a limitation of studies that evidence the impacts of MPs on the long trophic chain being humans the final receivers. Thus, if the severity of adverse effects on the ecosystem is severe enough to favour population decline, food security will be compromised.

Conclusion

From our review, we can conclude that freshwater fish are extremely vulnerable to microplastics pollution and that urbanized areas appear to be a major factor contributing to the pollution of freshwater environments with MPs. Nevertheless, there only exists a handful number of articles reporting these situations. Moreover, the lack of standard protocols makes it difficult to replicate the data and, consequently, validate it. Also, more information on the transportation of MPs throughout the food chain and subsequently the possible impacts in each population are importantly in demand.

The investigation of MPs in aquatic environments is a highly dynamic and interdisciplinary area of research that, in recent years, as advanced our understanding of the environmental impact of this emerging concern.⁴ However, nowadays research is still focused almost on marine MP with a lot of scarce data on freshwater ecosystems as we showed in our review. We hope that in the future the knowledge gaps that still exist regarding MPs in freshwaters are mitigated with the help of environmental and financial incentive provided by environmental agencies.

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Conflicts of interest

None.

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