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Original Contribution

MICROPLASTS IN FRESHWATER FISH – PROBLEMS AND CHALLENGES

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ABSTRACT: *The presence of microplastics in the aquatic environment raises concerns about their abundance and potential hazards to aquatic organisms. This review provides insight into the issue that may be of concern to freshwater fish. Plastic pollution is not limited to marine ecosystems; freshwaters also contain plastic particles, as the majority of them enter the oceans via rivers. Microplastics (MPs) can be ingested by fish and accumulate due to their size and poor biodegradability. Furthermore, they have the potential to enter the food chain and cause health problems. Evidence of MP ingestion has been reported in >150 fish species from both freshwater and marine systems. However, the quantification and toxicity of microplastics in freshwater ecosystems are underestimated, ignored and not reported as often as in marine ecosystems. However, their abundance, impact and toxicity in freshwater biota are no less than in marine ecosystems. The interaction of MPs with freshwater fish, as well as the risk of human consumption, remains a mystery. However, our knowledge of the effects of MPs on freshwater fish is still very limited. This study details the state of the toxicity of microplastics (MPs) in freshwater fish. This review will add to our understanding of the ecotoxicology of microplastics on freshwater fish and provide further directions for research.*

KEY WORDS: *Microplastics, Ecotoxicology, Freshwater ecosystem.*

1. Introduction

The ubiquity of microplastics (MPPs) - small plastic particles <5 mm in diameter (Barnes et al., 2009), has recently become a serious environmental problem that causes great public concern, especially since MP is inextricably linked to the use of plastics in everyday life (Rodrigues et al., 2019). Primary MPs are intentionally produced in industry or in various cosmetic products (Godoy et al., 2019; Guerranti et al., 2019), while secondary MPs are formed from the degradation of larger plastics through physical, chemical and biological degradation (Kundungal et al., 2019; Raddadi & Fava, 2019). Microplastics are extremely diverse and vary in size, shape, colour, polymer type and constituent chemicals, which influence how they behave in the environment (e.g. their transport, degradation, adsorption capacity and ultimate fate). However, variants of polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS) and polyvinyl chloride (PVC) account for 90% of all plastic polymers used (Andrady & Neal, 2009) and therefore the majority of MPs.

Although the main focus of research has been on marine species and systems, there is increasing knowledge about how MPs behave and what effects they have on freshwater fish (Li et al., 2018).

2. Related work

Although they cover a relatively small portion of the planet's surface (<0.01%), freshwaters are highly biologically diverse and support a wide range of key ecosystem services (Dodds et al., 2013). They are also already at high risk from multiple anthropogenic stressors, including nutrient pollution, habitat loss, biological invasions and climate change (Reid et al, 2019). MPs therefore potentially pose an additional risk to freshwater bodies. Around 80% of plastic litter in water bodies originates from terrestrial sources (Andrady, 2011) and often reaches the marine environment via freshwater (Galloway et al., 2017). Freshwater fish are extremely diverse in taxonomic composition, spanning a range of TPs, ecological guilds and life forms (Noble et al., 2007). They spend their lives in a limited area, where the presence of anthropogenic barriers can further restrict their range (Grill et al., 2019). Thus, freshwater fish populations and communities can be constantly exposed to a number of factors throughout their lives and must adapt to them and tolerate any changes in their local environment, especially when their movement is restricted. Freshwater fish are therefore a key receptor and bioindicator of MP pollution.

Frequency of occurrence of MP in freshwater fish

Fish activity and feeding rate are inextricably linked to environmental temperature, but also vary with the size, sex, and metabolic activity of individuals, as well as the abundance, nutritional quality, and processing time of their prey (Jobling, 1981). These same factors may therefore determine the extent to which fish encounter and ingest MPs. Although it is assumed that fish encounter MPs primarily during active feeding, there is increasing evidence that MPs are found in the gills and/or epidermis of wild freshwater fish (Hurt et al., 2020; Park et al., 2020). Experimental studies have also shown accumulation of MPs in the gills (Roch et al., 2020). Thus, passive uptake of MPs is an additional source of MPs, following exposure to the environment during swimming and respiration. In a study by Collard et al. (2017) quantified the uptake of anthropogenic particles in several marine fish and found that uptake was highest in species with the most efficient filtration. In a similar manner, fish characteristics such as gill area, gill structure, habitat, etc. may correlate with the number of MPs on the gills, which suggests passive accumulation. The feeding habitats of freshwater fish should also influence MP, given that the distribution and accumulation of MP differ, with generally higher amounts in sediments compared to the overlying waters (Bondelind et al., 2020). Therefore, within a given location, pelagic species should encounter less floating MP (e.g., less dense fibers) than benthic fish, while the latter may encounter higher concentrations of sunken and sessile MP (e.g., denser), provided that there is also a relatively higher concentration of MP. Accordingly, the trophic level of the fish and the food chain can also influence the levels of exposure to MPs, with piscivores only encountering MPs passively or indirectly through ingested prey, while species from other food chains are more likely to encounter MPs directly (Hoang & Felix-Kim, 2020).

MP uptake by freshwater fish

Ingestion patterns of MPs in freshwater fish may vary depending on the constituents encountered and whether the particle is externally identifiable (Markic et al., 2020). Mouth size limits the size of prey and MPs that fish can ingest, with larger fish generally ingesting larger plastic particles (Pegado et al., 2018; Ryan et al., 2019), although there are exceptions (Slootmaekers et al., 2019). According to Jâms (2020), the ratio of the maximum size of plastic ingested by an animal to its body size is approximately 1:20. As body size increases, MPs potentially accumulate in the gastrointestinal tract (GIT) of top predators, as demonstrated in populations of large perch (Micropterus salmoides, Centrarchidae) (Hurt et al., 2020), which had higher MP levels in the GIT compared to other fish in the same system. However, pike have also been found to have lower MP compared to other fish (Roch et al., 2019), suggesting some complexities in the transport of MPs within food chains and limitations of current "point-of-care" methods for MP screening. Experiments also suggest that the likelihood of ingestion is increased when microplastics have similar characteristics such as color, odor, and/or taste (Roch et al., 2020). Ingestion of red microplastic fibers by fish that feed by sight may occur, possibly due to their similarity to chironomid larvae, while binding or leakage of informational chemicals, such as dimethyl sulfide, may trigger ingestion by fish that feed by taste (Procter et al., 2019). Increased levels of ingestion of MPs when associated with a feeding cue are supported by experimental data that many fish will reject MPs unless presented in combination with nutrients (Kim et al., 2019). This could also explain why older MPs with altered structures and chemistry may be more likely to be consumed than newly ingested MPs, given that older MPs typically degrade, develop biofilms, or bind other chemicals over time (Song, Hou et al., 2020). Adsorption and uptake of MPs by aquatic plants is another understudied concentrating mechanism that has the potential to increase the probability of ingestion of bound MPs by herbivorous fish (Kalčíková, 2020). Many questions remain unanswered, such as whether fish are able to distinguish MPs when hunting and assess the suitability of MPs as a food source before ingestion, whether fish can avoid or ingest MPs, whether ingestion is intentional, and under what conditions does MP ingestion increase (Huuskonen et al., 2020; Li, Su et al., 2019).

After ingestion, the morphology of the digestive tract (GIT) and ingested MPs can influence their passage through the fish (Jabeen et al., 2017) and whether they will temporarily or permanently be retained on GIT structures, such as coils or protrusions.

Internal environments within fish will vary in temperature and pH, which can modify the GIT and promote the release of certain harmful chemicals associated with MPs (Wu et al., 2020). These in vitro studies suggest that a variety of chemical and physiological signals in different types and regions of the GIT may alter the absorption profile of MPs. Chemicals in MPs often include additives such as flame retardants and bisphenols, which are added to plastics to achieve certain properties (Sun, Nan et al., 2019), while exogenously bound chemicals may include a variety of pharmaceuticals, fertilizers, pesticides, and heavy metals encountered and bound in freshwater environments (Atugoda et al., 2020). MPs can therefore vector or extract a variety of different chemicals into fish and other organisms, which then produce effects depending on factors such as the type of chemical, concentration, where the chemical is released in the GIT, and whether the chemicals are absorbed across the intestinal barrier (Gunaalan et al., 2020). The size and shape of microplastics are also important characteristics influencing the processing of ingested MPs, especially since small particles, typically <10 μm, can pass through the intestinal barrier, reaching the blood and ultimately the rest of the body (Ribeiro et al., 2019). However, the range of particles that can cross the intestinal barrier varies depending on the species, and only particles with a specific shape, size, and chemistry can pass through (Ribeiro et al., 2019). MPs ingested by fish may already be able to pass through; however, MPs can also be modified and degraded internally in the GIT. MPs present in fish at the time of capture should be considered transient, representing those that are currently ingested as well as those that are about to be excreted or translocated. Laboratory experiments have shown that goldfish (Carassius auratus, Cyprinidae) can clear 50% of MP within 10 hours and 90% within 33 hours after ingestion (Grigorakis et al., 2017), although rates of excretion vary within and between species, depending on MP and GIT structure, food availability, and stomach fullness (Gouin, 2020; Hoang & Felix-Kim, 2020). For example, fiber tends to accumulate at higher levels than fragments and pellets because they are more difficult to expel (Qiao et al., 2019). Intestinal pellets can act as a concentrated source of MP and organic material that can be utilized by a range of pelagic or benthic organisms as they sink and settle, transferring MP and material between biota (Hoang & Felix-Kim, 2020).

Biological consequences

Behavioral changes resulting from MP exposure often occur when MPs and/or related chemicals affect cells in the brain or central nervous system, which can negatively impact swimming activity and/or survival of freshwater fish (Qiang & Cheng, 2019; Yang et al., 2020). Impairments in swimming behavior may be temporary; however, some studies also suggest more detrimental effects if MP exposure affects early development (Pannetier et al., 2020). Fish eggs may also bind to MPs externally and/or take up smaller NPs, which can alter gas exchange and delay hatching time (Duan et al., 2020). Since the uptake of MPs by fish is predominantly through feeding (Gouin, 2020), the association of parasites with MPs could potentially benefit trophically transmitted parasites by increasing the likelihood of their transmission to fish hosts. MPs can also indirectly increase transmission rates and parasite virulence by suppressing the immune response and/or general condition of the affected individual (Limonta et al., 2019). For example, infection of the three-spined stickleback (Gasterosteus aculeatus, Gasterosteidae) by the cestode Schistocephalus solidus, (Schistocephalidae) results in infected fish seeking smaller prey (Barber & Huntingford, 1995) and altering habitat use to increase encounters with prey and subsequent transmission of parasites to the final avian host (Barber et al., 2004). These parasite-induced behavioral manipulations can lead to trophic differences between infected and uninfected fish in populations (Britton & Andreou, 2016), potentially also altering their exposure to MPs. However, the consequences of MPs for the relationship between freshwater fish and parasites remain unclear.

3. Conclusion

Aquatic foods are increasingly preferred due to their important role in food security and nutrition, which highlights the urgent need to manage and protect this natural resource from pollution.

Global plastic production has increased dramatically over the past few decades, reaching 350 million tonnes in 2017.

Plastics are widely used worldwide due to their ease of processing, water resistance and reliability. It can be said that we live in a world of plastics. Water pollution by microplastics is a worrying signal due to their widespread distribution and potential threat to underwater life.

Freshwater systems are equivalent to or perhaps worse in terms of microplastic pollution than the marine environment. However, the quantification and toxicity of microplastics in freshwater ecosystems have been underestimated. The current status of microplastic pollution in freshwater ecosystems is summarized in this review article. Potential environmental impacts, such as ingestion and toxicity to freshwater fish, are discussed. As a result, future studies on the distribution and ecotoxicology of microplastics on freshwater fish are needed to fully understand the problem. Progress on this issue requires a strong systematic basis, as well as appropriate legislation at global and national levels.

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