Review

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Current state of knowledge on the effect of microplastics on macroinvertebrate communities in lotic ecosystems

Estado actual del conocimiento sobre el efecto de los microplásticos en comunidades de macroinvertebrados de ecosistemas lóticos

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Abstract

The global production of plastic amounts to 6.3 billion tons, greatly influencing the increasing contamination from plastic products and resulting in a problem that affects ecosystems in various ways, especially freshwater ecosystems. Freshwater ecosystems have recently been identified as the main sinks for plastic particles because they are directly exposed to human settlements and consequently to anthropogenic activities. The incorporation of microplastics at the base of the food web occurs through their ingestion by different macroinvertebrates, such as (i) filter feeders: *Daphnia magna*, (ii) shredders: *Gammarus pulex* and *Hyalella azteca*, (iii) collectors: *Culex pipiens*, *Chironomus riparius*, *Chironomus tepperi*, and (iv) herbivores like the snail *Physella acuta*. Microplastic ingestion can lead to the blockage of the digestive tract, increased mortality, decreased fecundity, inflammatory responses, altered metabolism, disrupted reproduction, behavioral changes, and depleted energy reserves. Consequently, microplastics pose a threat to macroinvertebrate communities with severe ecosystem-level consequences. However, it is necessary to understand the true risks of microplastics in freshwater and other ecosystems, considering the structure, functional characteristics, and behavior of the study organisms to guide public decision-making awareness. This narrative review paper was conducted by consulting national and international databases to compile publications that reflect the current state of knowledge on the effect of microplastics on macroinvertebrate communities in lotic ecosystems.

Keywords: emerging contaminants, microplastics, trophic levels, ecosystem harm, rivers, transfer

Resumen

La producción mundial de plástico asciende a 6300 millones de toneladas, lo cual influye grandemente en la creciente contaminación por productos plásticos, originando un problema que afecta de diferentes maneras los ecosistemas, especialmente los de agua dulce, identificados recientemente como los principales sumideros de partículas plásticas ya que se encuentran directamente expuestos a los asentamientos humanos y por consiguiente a actividades antrópicas. La incorporación de microplásticos en la base de la red alimentaria se realiza a través de su ingestión por parte de macroinvertebrados de diferentes grupos funcionales, como (i) filtradores: *Daphnia magna*, (ii) trituradores: *Gammarus pulex* y *Hyalella azteca*, (iii) recolectores: *Culex*

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pipiens, *Chironomus riparius*, *Chironomus tepperi* y (iv) herbívoros como el caracol *Physella acuta*, lo cual puede conllevar al bloqueo del tracto digestivo, aumentar la mortalidad, disminuir la fecundidad, provocar respuestas inflamatorias, alterar el metabolismo, interrumpir la reproducción, cambiar el comportamiento y diesmar las reservas energéticas. En consecuencia, los microplásticos representan una amenaza para las comunidades de macroinvertebrados con graves consecuencias a nivel ecosistémico. Sin embargo, aún es necesario comprender los verdaderos riesgos de los microplásticos en los sistemas de agua dulce y otros ecosistemas teniendo en cuenta estructura, características funcionales y comportamiento de los organismos de estudio para concienciar la toma de decisiones del público. El presente artículo de revisión narrativa se realizó mediante la consulta de bases de datos nacionales e internacionales para compilar publicaciones que reflejen el estado actual de conocimiento del efecto de los microplásticos sobre las comunidades de macroinvertebrados de ecosistemas lóticos.

Palabras clave: contaminantes emergentes, microplásticos, niveles tróficos, perjuicio ecosistémico, ríos, transferencia

INTRODUCTION

Plastic pollution in global water sources is a widely reported problem; such problems range from visible macroplastics, to smaller plastics including microplastics (MP), which have a dimension of less than five mm and nanoplastics, with a size of less than 1000 nm (Laskar & Kumar, 2019; Yıldız et al., 2022; Zhang et al., 2021). The European Chemicals Agency (ECHA) defines MPs as synthetic polymeric materials, chemically modified biopolymers, solid and/or semi-solid with a spherical morphology, and fibers or sheets (Bollaín-Pastor & Vicente-Agulló, 2019; Vásquez-Molano et al., 2021). Currently, MP polymers are found in all types of ecosystems, including freshwater, estuarine and marine ecosystems (Azevedo-Santos et al., 2019; Rozman & Kalčíková, 2022).

MP research first gained ground in the 1970s when Carpenter and Smith (1972) conducted studies that largely addressed marine environments. In contrast, freshwater MP pollution is a relatively new field of research, with research published only in the last 15 years (Talbot et al., 2022). According to projections by Geyer et al. (2017), global plastic production by 2025 will be 10 billion metric tons, of which 7500 will be discarded as waste, 2500 incinerated, and less than 1000 recycled.

The pandemic produced by the infectious respiratory disease caused by the SARS-CoV-2 severe acute respiratory syndrome coronavirus (COVID-19) has dramatically increased the consumption of single-use plastic; since March 2020, 1.6 million tons/day of plastic waste have been generated worldwide (Orona-Návar et al., 2022). Annually, between four and 12 million tons of plastic have their final destination in the oceans, so much so that in the coming years it is most likely that in the next few years MPs will exceed the number of fish (Barcelo & Pico, 2020). Freshwater ecosystems have recently been identified as the main sinks for MP particles (Gan et al., 2024; Silva et al., 2022a; Wang et al., 2023).

MPs have detrimental effects on aquatic organisms due to a high probability of the leaching of plastic additives that can induce toxic effects evidenced at the molecular, cellular, systemic and organic levels, causing oxidative stress, loss of appetite, inflammatory responses, genetic damage, altered behavior, neurotoxicity and death (Cera et al., 2020; Fu et al., 2022; Vásquez-Molano et al., 2021). On the other hand, the transport, fate and impact of plastics in freshwater systems is a matter of concern because these ecosystems transport plastic material from terrestrial sources, to lakes, lagoons and the marine environment, in addition to acting as temporary or long-term sinks (Kukkola et al., 2021).

The presence of MPs represents a significant threat, not only to aquatic ecosystems but also to humanity, due to their negative effects on public health and the environment as pollutants (Usman et al., 2022; Yang et al., 2022). River pollution can often vary spatially and temporally according to land use and degree of urbanization by creating hotspots and critical moments of high pollution

(De Carvalho et al., 2022), becoming an emerging global threat to a wide variety of organisms and species, affecting populations, communities and ecosystems (Chinfak et al., 2021; Li et al., 2022).

The ecosystems most exposed to this phenomenon are streams and rivers, since they are under the action of human settlements and anthropic activities, causing different disturbances to the community and associated environments. This is a growing problem because freshwater environments represent the main transport route for MP from terrestrial to marine and coastal ecosystems (Calderón et al., 2020; De Carvalho et al., 2021; Preciado & Zapata, 2020). In addition, water flow velocity has also been related to MP concentrations, since smooth hydrodynamics could facilitate their accumulation, a reason for the large accumulation of these particles on river banks (Watkins et al., 2019).

When plastic comes into contact with aquatic ecosystems, the interaction of plastic with biodiversity is to be expected, with ingestion by animals being a frequent problem, as these particles can be incorporated into food web (Donoso & Rios-Touma, 2020). Ingestion and translocation of MPs can affect aquatic organisms, including zooplankton, invertebrates, fish and birds (Kumar et al., 2021; Maheswaran et al., 2022; Windsor et al., 2019). Measures such as wastewater treatment offer partial solutions to this problem, as they serve as important delivery pathways for MPs to freshwater environments by retaining less than 80% of the MPs in an effluent, where human population density correlates positively with MP concentration (Ma et al., 2022; Talbot et al., 2022).

A wide range of freshwater biota ingest MPs, including vertebrates such as: *Danio rerio* (Hamilton, 1822), native to South Asia and introduced to different parts of the world as aquarium fish, *Poecilia reticulata* (Peters, 1859), *Oreochromis niloticus* (Linnaeus, 1758), native to South America and Africa, respectively, with global distribution except Antarctica, and *Physalaemus cuvieri* (Fitzinger, 1826), native to South America with a tropical distribution. Invertebrates such as *Daphnia magna* (Straus, 1820), with geographical distribution in North America, South America, Europe, Asia, Africa, Australia and New Zealand; shrimp such as *Paratya australiensis* (Kemp, 1917) native to Australia and clams such as *Corbicula fluminea* (Müller, 1774) distributed in Asia, North America, South America, Europe, Africa and Australia.

Abiotic factors govern biotic interaction. For example, adding stressors such as environmental change, including increased temperature and anthropogenic pollutants such as antibiotics, metals, pesticides and endocrine disruptors, will likely lead to an exacerbation of negative interactions between MPs and freshwater organisms (Castro-Castellon et al., 2022). Due to these interactions, and depending on the physiology of the organism, environmental factors, natural and anthropogenic, may influence the retention of particles and their likelihood to move to other tissues and their transfer within food webs (O'Connor et al., 2022; Yan et al., 2021; Yıldız et al., 2022). The present review article presents the different impacts and consequences of MPs on macroinvertebrate communities of lotic ecosystems.

MATERIALS AND METHODS

A bibliographic search was conducted considering articles published between the years 2019-2023 in the Scopus, web of Science and Google Scholar databases, where different publications were compiled such as scientific articles, books and other academic materials that reflected the current state of the subject of study. After reviewing 105 publications, 56 relevant bibliographic references were selected, where the subtopics of the present article were obtained, with 7% of the references corresponding to national research and 93% to international research from Asia, Europe and North America. In addition, 30% of the information consulted dealt with macroinvertebrates, while 70% mentioned potential sources, ecological risks, spatial-temporal variety and interaction of MPs with the environment.

RESULTS AND DISCUSSION

What are microplastics?

Plastics are synthetic polymer compounds obtained mainly from petroleum chemical derivatives (petrochemicals) and renewable sources. Such compounds have high molecular mass and plasticity, due to the addition of chemical substances or additives, which are what give them the desired properties in terms of texture, strength, malleability, stability, gloss, and other characteristics (Correa, 2020; Laskar & Kumar, 2019). A characteristic of these conventional polymers is their high resistance to degradation, which is the basis of their high levels of contamination; it is currently estimated that the longevity of these elements is hundreds or even thousands of years, depending on their properties and the surrounding environmental conditions (Zhang et al., 2021).

Two types of MPs are found according to Laskar and Kumar (2019): primary MPs, which are particulate emissions released from industrial production. Primary MPs are intentionally manufactured at a microscopic size. Secondary MPs come from the fragmentation of larger synthetic structures due to exposure to external conditions such as solar radiation, oxidation, mechanical action and/or microbial degradation of plastic products (Figure 1). Plastics are composed mainly of six types of petroleum-based polymers: polyethylene (PE), polypropylene (PP) and expanded polystyrene (PS) which are more likely to float, and polyvinyl chloride (PVC), and polyamide (PA), also known as nylon and polyethylene terephthalate (PET), which are more likely to sink in the water column due to differences in their density (Correa, 2020). According to Laskar and Kumar (2019), the sources of MPs are: plastic sand, residues when washing synthetic clothes, cosmetics, toothpaste, abandoned and dilapidated boats, cleaning agents in toiletries, rubbers and car tires.

The packaging industry produces 39.9% of plastics present on the planet, while other industrial activities such as construction contributes 19.8%, automotive 9.9%, electronics 6.2%, followed by household and leisure use 4.1% and agriculture 3.4% (Lechthaler et al., 2020). Plastic particles are found in various sizes and shapes, as they are exposed to abiotic factors in the environment and interact with other contaminants, changes in their appearance occur, resulting in the breakdown of the macro-scale plastic into secondary pieces. Currently, these polymers are found in all types of ecosystems, including freshwater, estuarine and marine ecosystems (Azevedo-Santos et al., 2019; Rozman & Kalčíková, 2022).

When plastics enter the environment, they can be transported with the wind. Precipitation and surface runoff could be the main routes that transfer plastics from the terrestrial ecosystem to aquatic ecosystems (Yan et al., 2021). MPs can be colonized by microorganisms that form biofilms, increasing their density and reducing buoyancy, being an important mechanism for their settlement at the bottom the water column (Vásquez-Molano et al., 2021). The vertical transport of MPs may be due to biofouling or aggregation with other denser particles. In addition, hyperpycnic flows could play an important role in the vertical transport of plastic particles (Zhang et al., 2021).

Effects of microplastics on macroinvertebrates

At the base of the benthic macroinvertebrate food web, contact with MPs begins (O'Connor et al., 2022). The presence of MPs has been reported in benthic and epibenthic invertebrates collected from natural habitats (Rauchschwalbe et al., 2022; Silva et al., 2021). Macroinvertebrates inhabit the central site of the sediment-water interface, thus playing an important role in sediment decomposition and material exchange between sediments and water bodies (Fu et al., 2022; Silva et al., 2021). Macrobenthic invertebrates provide a critical trophic resource for many fish and bird species (Bertoli et al., 2022). Several studies suggest that MPs encounter, ingestion, and egestion differ among taxa and that counts within the gastrointestinal tract can be predicted from the biological characteristics of the species; higher MP loads are often revealed at higher trophic levels (Parker et al., 2022b; Silva et al., 2022b).

Aquatic macroinvertebrates are potentially exposed to a mixture of MPs, additives, leachates and other degradation products that could affect aquatic ecosystems and thus the food web (Vásquez-Molano et al., 2021). MPs are recognized as a major threat and are emerging global environmental pollutants. MPs can also act as a transport medium for other toxic elements such as dichlorodiphenyltrichloroethane (DDT) and hexachlorobenzene that eventually end up inside the body of the organism that consumes it (Kumar et al., 2021; Laskar & Kumar, 2019).

MPs can adversely affect freshwater organisms through the physical effects of the polymer itself and/or exposure to chemicals added to the plastic during production to achieve the desired characteristics (Ockenden et al., 2022). Several

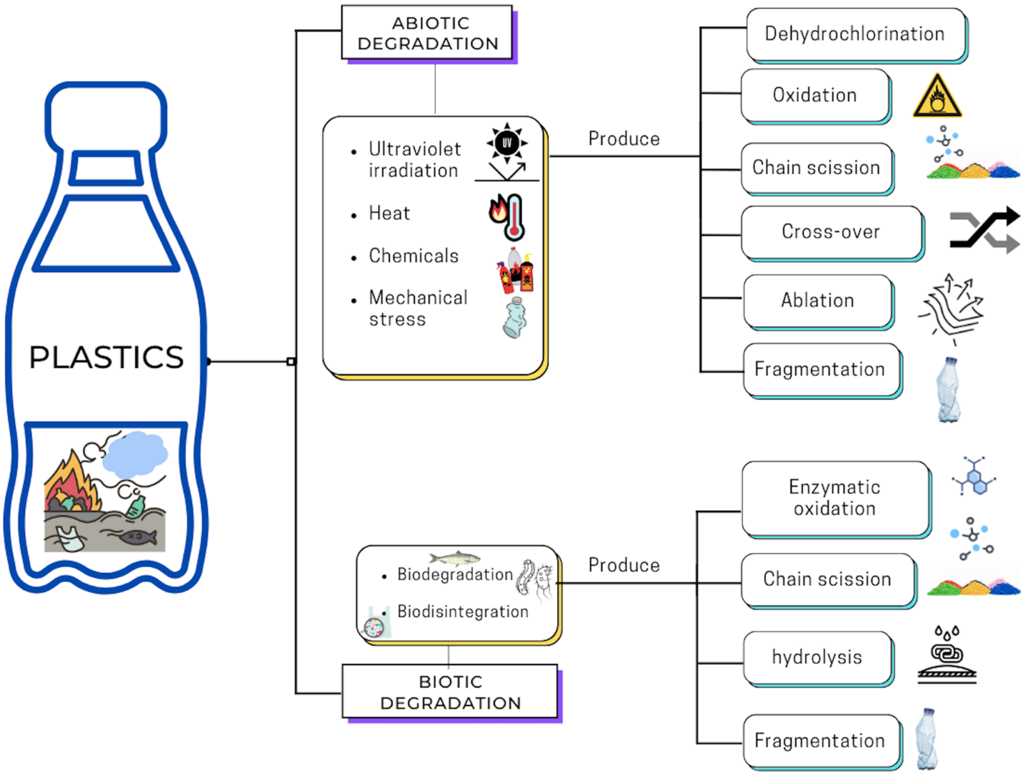

Figure 1. Schematic diagram of the general processes involved in plastic degradation (Source: author). The degradation of plastics can occur due to abiotic factors (light, temperature, air, water and mechanical forces) or biotic factors (organisms that can degrade plastics mechanically or by enzymatic action) (Zhang et al., 2021).

laboratory studies have shown that MPs can be ingested by several freshwater invertebrates belonging to various functional feeding groups, including filter feeders such as *D. magna*, shredders such as *Gammarus pulex* (Linnaeus, 1758) and *Hyalella azteca* (Saussure, 1858), foragers such as *Culex pipiens* (Linnaeus, 1758), *Chironomus riparius* (Meigen, 1804) or *Chironomus tepperi* (Skuse, 1889), and herbivores such as the snail *Physella acuta* (Draparnaud, 1805) (Silva et al., 2021). Therefore, the ingestion of MPs can favor its bioaccumulation, which refers to the progressive increase of MPs in an organism over time as the rate of ingestion exceeds the rate of egestion. In addition, biomagnification can also occur, which refers to higher concentrations of MPs reached at higher trophic levels (Kumar et al., 2021; O'Connor et al., 2022).

MPs from PP or PET that additionally contain additives or chemicals such as polychlorinated biphenyls (PCBs), (Bisphenol -A) or polycyclic aromatic hydrocarbons, which are carcinogenic or endocrinogenic, tend to present greater toxicity. When organisms ingest these types of compounds they cause stress that can become chronic or lead to a passive or asymptomatic (apparent) bioaccumulation, making the organisms easier prey for predators, which generates a multilevel biomagnification process within the trophic network (Donoso & Rios-Touma, 2020; Fu et al., 2022).

Exposure to MPs can block the digestive tract, increase mortality, decrease fecundity, alter metabolism, decrease energy reserves, elicit inflammatory responses, disrupt reproduction, and change the behavior of species that ingest it directly or indirectly (Wu et al., 2022). Behavior is considered one of the most sensitive indicators of exposure impacts and represents adaptive responses to environmental stimuli. Such changes can be attributed to particle stimulation, positive regulation of estrogen content and oxidative damage to the body (Fu et al., 2022; Silva et al., 2021). The antioxidant defense system has been found to play an essential role in alleviating the pressure of external pollutants, such as MPs, intestinal obstruction and inflammation, because MPs can potentially induce an immune response leading to increased levels of reactive oxygen species (ROS), antioxidant responses, ultimately oxidative stress. In addition, the activation of the immune response and detoxification can also involve energy costs and depletion of energy reserves (Fu et al., 2022; Silva et al., 2021). On the other hand, parasitic infection has also been tentatively linked to MP contamination suggesting that a higher parasite load increases the susceptibility of individuals to have higher MP loads (Parker et al. 2022a).

The structure of the gastrointestinal tract can affect the ability of individuals to expel ingested particles and associated chemicals (e.g., plasticizers such as terephthalates, additives such as butadiene rubber and cross-linked acrylics), causing a range of negative impacts on the feeding and physiology of freshwater biota leading to mortality. In addition, it has been shown that MPs manage to move from the digestive tract to other internal organs and muscle tissue, but the digestive tract remains the main residual site (Parker et al., 2021).

Primarily scavenging and scraping organisms that feed on plants, algae or organic debris, confuse blue-green plastic particles and ingest them, as has been seen in Ephemeroptera larvae or in the Amphipoda *Gammarus duebeni* (Lilljeborg, 1852). It was shown that when amphipods feed directly on relatively high concentrations of polyethylene MPs they have the ability to fragment them. In addition, PVC MP containing dibutyl phthalate affects invertebrate physiology (Mateos-Cárdenas et al., 2022; Ockenden et al., 2022; Parker et al., 2022a).

There appears to be a relationship between microplastic loading within sediment, water and biota (Kukkola et al., 2021). Recent studies have shown that the concentration of MPs decreases with increasing particle size, which is likely to affect ingestion by different organisms. Indeed, smaller MPs are more likely to be ingested by smaller organisms, while larger particles are going to be less accessible for ingestion. Moreover, the negative effects of plastics may increase as particle size decreases (Mateos-Cárdenas et al., 2022; Kooi & Koelmans, 2019). On the other hand, toxicological effects are possible at 540 MP particles per kg sediment. Further, long exposure and high MP concentrations manage to produce biomass loss and death in macroinvertebrates (Lwanga et al., 2023; Vermeiren et al., 2023).

Organic material within freshwater potentially captures and accumulates chemicals. In this sense, a maximum number of 5.04 particles mg^{-1} of tissue was found in *Chironomus* spp. (bay flies) and a maximum number of 0.14 particles mg^{-1} of tissue in the mayfly families Baetidae and Heptageniidae and in the trichoptera family Hydropsychidae. Some reports have suggested the trophic transfer of plastics from producer to consumer species, for example, from marine algae to periwinkles, from microalgae to daphnids and from vascular plants to land snails (Mateos-Cárdenas et al., 2022). In addition, it was shown that MPs can be absorbed on the surface of aquatic plants on which amphipods feed (Figure 2), so that in macroinvertebrates the abundance of ingested MPs increases with trophic position (Garcia et al., 2021). Some taxa reach to actively ingest MPs through the selection of specific particles, while others manage to ingest plastics accidentally during feeding (e.g., sediment ingesting taxa), such as Lumbricidae which are more likely to ingest MPs unnoticed, while filter-feeding taxa select MPs based on their relative dimensions (Windsor et al., 2019). Furthermore, any effects generated by MPs on different functional feeding groups of aquatic macroinvertebrates over multiple generations bring consequences for ecosystem functioning (Marchant et al., 2023).

Regarding the presence of MPs, it has been reported that *Procambarus clarkii* (Girard, 1852) mainly presents fibers, white and transparent <1 mm and *Macrobrachium rosenbergii* (De Man, 1879) possesses PS, PE and PP fibers and MPs of <1 mm (Lv et al., 2019; Liu et al., 2020). On the other hand, when exposed to fluorescent PE particles of 10 to 27 µm, or PE fibers of 20 to 75 µm, *H. azteca* exhibited decreased growth and increased mortality and *C. tepperi* is negatively affected in survival, growth and emergence (Wu et al. 2022) and chironomid development and emergence patterns are affected by these and other MPs (Rauchschwalbe et al., 2022). *Girardia tigrina* (Girard, 1850) individuals exposed to 7-9 µm polyurethane MPs demonstrated behavioral changes by increasing mucus production, decreasing

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gliding and adoption of various body shapes with negative effects on their hunting behavior, scouting competition and their ability to escape from predators. *Dugesia japonica* individuals (Ichikawa & Kawakatsu, 1964) exposed to polyethylene (<10 µm diameter) and polystyrene microspheres (10, 50 and 100 µm), showed delayed atrial regeneration, significant reduction in body and blastema size (Silva et al., 2023).

What will happen in the future?

Freshwater biodiversity in tropical countries is still unknown, so the effects of contaminants on diversity are difficult to measure. However, it is likely that several species have been lost or endangered, so their loss at the ecosystem level can be devastating (Donoso & Rios-Touma, 2020). Field studies should aim to collect representative communities with a significant number of trophic levels and functional groups (Parker et al., 2021). Likewise, food intake rates and gut retention times are important tools to understand the accumulation, translocation and dietary transfer of MP at the population and community level. Thus, it is imperative that further research is conducted to inform bioaccumulation and biomagnification models (O'Connor et al., 2022). Such studies allow for the development and investigation of complexity, including how MP impacts are affected by other stressors, such as warming and nutrient enrichment (Parker et al., 2021). Because of the above, the paucity of data on the occurrence, concentrations, or possible mechanisms of MP effects on freshwater invertebrates generates a limited understanding of ecological risk (Windsor et al., 2019).

Figure 2. Interactions of microplastics with macroinvertebrates of lotic ecosystems (Author's source). The main source of MPs comes from waste products from surrounding urbanizations that are deposited in the lotic ecosystems. Therefore, collecting and scraping macroinvertebrates such as amphipods or ephemeroptera larvae ingest MP particles that are found on the surface of the aquatic plants on which they feed.

The amount of MPs is highly correlated with the concentration of pollutants in the water, mainly with the increase in urbanization. Moreover, issues such as the elimination of riparan forests, loss of vegetation cover and changes in land use are important factors for the runoff of pollutants, such as MPs (Donoso & Rios-Touma, 2020). Given that river food webs are closely related to the terrestrial environment, it is important to gain a better understanding of the potential inputs of MPs associated with these resources, because the extent to which they interact with MPs in riverine ecosystems has not yet been studied and it is recognized that plant resources may represent a pathway for microplastics to enter aquatic food webs (O'Connor et al., 2022). It is likely that MPs share distribution pathways with other pollutants and nutrients that threaten water quality (Talbot et al., 2022). Until such sources or flow pathways are quantified and linked to specific biological effects, it will be difficult to identify optimal strategies for remediating aquatic MP pollution (Windsor et al., 2019).

The decomposition of larger pieces of plastic and garbage can be a critical source of MPs in freshwater bodies, so identifying MP pollution hotspots would help to enhance projects focused on remediation (Talbot et al., 2022). It is urgent that cities located in the upper reaches of watersheds adopt pollution control measures, such as implementing efficient wastewater treatment plants to improve the ecological quality of rivers, especially in urban centers, to stop contributing plastics and other pollutants to aquatic ecosystems; training citizens in the proper management of solid and liquid waste from different anthropogenic activities (agriculture, livestock, industrialization and deforestation); designating ecological control zones with permanent supervision in the urbanized area, as well as frequent cleanups and implementing processes of care, recovery and conservation of the ecosystem through tools such as biomonitoring (Donoso & Rios-Touma, 2020; Zhai et al., 2023).

CONCLUSION

Plastics, composed primarily of synthetic polymers derived from petroleum, are highly resistant to degradation, significantly contributing to environmental pollution. Their durability, variety of shapes and sizes, together with the prevalence of their production, means that they are distributed in all ecosystems, including aquatic ecosystems.

The fragmentation of plastics and their transport capacity through various mechanisms exacerbate their environmental impact, triggering a threat to aquatic ecosystems and freshwater biota. The presence of MPs in benthic and epibenthic macroinvertebrates, which play a crucial role in the exchange of materials between sediments and water, highlights the impact of their contamination on food webs, since exposure to them can cause negative effects such as oxidative stress, alterations in reproduction, and changes in the ecophysiology of organisms.

The effects of MP on freshwater macroinvertebrate biodiversity in tropical countries are evidence of the limited understanding of the ecological risk to the planet. This highlights the need for more detailed studies. It is crucial that policies be developed to reduce MP concentrations in aquatic environments, improve waste management practices and strengthen wastewater treatment capacity. The implementation of control and remediation measures, as well as education and biomonitoring, are essential to protect aquatic ecosystems and mitigate the effects of MP pollution.

AUTHOR CONTRIBUTION

All the authors of this publication made important contributions to the idea and design of the study, data collection, analysis and interpretation of the data, as well as the drafting, critical review of the intellectual content and final approval of the version to be published.

CONFLICT OF INTEREST

There are no competing financial interests or known personal relationships that could have influenced the work presented in this article.

REFERENCES

Azevedo-Santos, V. M., Gonçalves, G. R. L., Manoel, P. S., Andrade, M. C., Lima, F. P. & Pelicice, F. M. (2019). Plastic ingestion by fish: A global assessment. *Environmental Pollution, 255*(1), 112994. https://doi.org/10.1016/J.ENVPOL.2019.112994

Barcelo, D. & Pico, Y. (2020). Case studies of macro- and microplastics pollution in coastal waters and rivers: Is there a solution with new removal technologies and policy actions?. *Case Studies in Chemical and Environmental Engineering, 2,* 100019. https://doi.org/10.1016/J.CSCEE.2020.100019

Bertoli, M., Pastorino, P., Lesa, D., Renzi, M., Anselmi, S., Prearo, M. & Pizzul, E. (2022). Microplastics accumulation in functional feeding guilds and functional habit groups of freshwater macrobenthic invertebrates: Novel insights in a riverine ecosystem. *Science of The Total Environment, 804,* 150207. https://doi.org/10.1016/J.SCITOTENV.2021.150207

Bollaín-Pastor, C. & Vicente-Agulló, D. (2019). Presence of microplastics in water and the potential impact on public health. *Revista Española de Salud Pública, 93.* e201908064. https://www.scielosp.org/article/resp/2019.v93/e201908064

Calderón, H., Martínez, P. & Muñoz, J. (2020). *Caracterización y cuantificación de microplásticos en los sedimentos y la columna de agua del río Magdalena en la ciudad de Neiva, Colombia.* Editorial Instituto Antioqueño de Investigación.

Carpenter, E. & Smith, K. (1972). Plastics on the Sargasso Sea surface. *Science, 175*(4027), 1240-1241. DOI: 10.1126/science.175.4027.1240

Castro-Castellon, A., Horton, A., Hughes, J., Rampley, C., Jeffers, E., Bussi, G. & Whitehead, P. (2022). Ecotoxicity of microplastics to freshwater biota: Considering exposure and hazard across trophic levels. *Science of The Total Environment, 816*, 151638. https://doi.org/10.1016/J.SCITOTENV.2021.151638

Cera, A., Cesarini, G. & Scalici, M. (2020). Microplastics in freshwater: what is the news from the world?. *Diversity, 12*(7), 276. https://doi.org/10.3390/d12070276

Chinfak, N., Sompongchaiyakul, P., Charoenpong, C., Shi, H., Yeemin, T. & Zhang, J. (2021). Abundance, composition, and fate of microplastics in water, sediment, and shellfish in the Tapi-Phumduang River system and Bandon Bay, Thailand. *Science of The Total Environment, 781*, 146700. https://doi.org/10.1016/J.SCITOTENV.2021.146700

Correa, J. (2020). *Revisión de la problemática de la contaminación por microplásticos en el recurso hídrico* [Tesis de especialización, Universidad de Antioquia]. Repositorio Institucional de la Universidad de Antioquia. https://bibliotecadigital.udea.edu.co/handle/10495/15453

De Carvalho, A. R., Garcia, F., Riem-Galliano, L., Tudesque, L., Albignac, M., Ter Halle, A. & Cucherousset, J. (2021). Urbanization and hydrological conditions drive the spatial and temporal variability of microplastic pollution in the Garonne River. *Science of The Total Environment, 769*, 144479. https://doi.org/10.1016/J.SCITOTENV.2020.144479

De Carvalho, A. R., Riem-Galliano, L., Ter Halle, A. & Cucherousset, J. (2022). Interactive effect of urbanization and flood in modulating microplastic pollution in rivers. *Environmental Pollution, 309*, 119760. https://doi.org/10.1016/J.ENVPOL.2022.119760

Donoso, J. M. & Rios-Touma, B. (2020). Microplastics in tropical Andean rivers: A perspective from a highly populated Ecuadorian basin without wastewater treatment. *Heliyon, 6*(7), e04302. https://doi.org/10.1016/J.HELIYON.2020.E04302

Fu, L., Xi, M., Nicholaus, R., Wang, Z., Wang, X., Kong, F. & Yu, Z. (2022). Behaviors and biochemical responses of macroinvertebrate *Corbicula fluminea* to polystyrene microplastics. *Science of The Total Environment, 813*, 152617. https://doi.org/10.1016/J.SCITOTENV.2021.152617

Gan, M., Zhang, Y., Shi, P., Cui, L., Zhang, C. & Guo, J. (2024). Occurrence, potential sources, and ecological risk assessment of microplastics in the inland river basins in Northern China. *Marine Pollution Bulletin, 205*, 116656. https://doi.org/10.1016/j.marpolbul.2024.116656

Garcia, F., De Carvalho, A. R., Riem-Galliano, L., Tudesque, L., Albignac, M., Halle, A. & Cucherousset, J. (2021). Stable isotope insights into microplastic contamination within freshwater food webs. *Environmental Science & Technology, 55*(2), 1024–1035. https://doi.org/10.1021/acs.est.0c06221

Geyer, R., Jambeck, J. R. & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), 275-280. https://doi.org/10.1126/sciadv.1700782

Kooi, M. & Koelmans, A. (2019). Simplifying Microplastic microplastic via continuous probability distributions for size, shape, and density. *Environmental Science & Technology Letters, 6*(9), 551–557. https://doi.org/10.1021/acs.estlett.9b00379

Kukkola, A., Krause, S., Lynch, I., Sambrook Smith, G. H. & Nel, H. (2021). Nano and microplastic interactions with freshwater biota – Current knowledge, challenges and future solutions. *Environment International, 152*, 106504. https://doi.org/10.1016/J.ENVINT.2021.106504

Kumar, R., Sharma, P., Manna, C. & Jain, M. (2021). Abundance, interaction, ingestion, ecological concerns, and mitigation policies of microplastic pollution in riverine ecosystem: A review. *Science of The Total Environment, 782*, 146695. https://doi.org/10.1016/J.SCITOTENV.2021.146695

Laskar, N. & Kumar, U. (2019). Plastics and microplastics: A threat to the environment. *Environmental Technology & Innovation, 14*, 100352. https://doi.org/10.1016/J.ETI.2019.100352

Lechthaler, S., Waldschläger, K., Stauch, G. & Schüttrumpf, H. (2020). The Way of Macroplastic through the

Environment. *Environments, 7*(10), 73. https://doi.org/10.3390/environments7100073

Li, H. X., Shi, M., Tian, F., Lin, L., Liu, S., Hou, R., Peng, J. P. & Xu, X. R. (2022). Microplastics contamination in bivalves from the Daya Bay: Species variability and spatio-temporal distribution and human health risks. *Science of The Total Environment, 841*, 156749. https://doi.org/10.1016/J.SCITOTENV.2022.156749

Liu, X., Shao, Z., Cheng, G., Lu, S., Gu, Z., Zhu, H., Shen, H., Wang, J. & Chen, X. (2020). Ecological engineering in pond aquaculture: a review from the whole-process perspective in China. *Reviews in Aquaculture, 13*(2), 1060-1076. https://doi.org/10.1111/raq.12512

Lv, W., Zhou, W., Lu, S., Huang, W., Yuan, Q., Tian, M., Lv, W. & He, D. (2019). Microplastic pollution in rice-fish co-culture system: A report of three farmland stations in Shanghai, China. *Science of The Total Environment, 652*, 1209–1218. https://doi.org/10.1016/J.SCITOTENV.2018.10.321

Lwanga, E., Roshum, I., Munhoz, D., Meng, K., Rezaei, M., Goossens, D., Bijsterbosch, J., Alexandre, N., Oosterwijk, J., Krol, M., Peters, P., Geissen, V. & Ritsema, C. (2023). Microplastic appraisal of soil, water, ditch sediment and airborne dust: The case of agricultural systems. *Environmental Pollution, 316*. https://doi.org/10.1016/j.envpol.2022.120513

Ma, M., Liu, S., Su, M., Wang, C., Ying, Z., Huo, M., Lin, Y. & Yang, W. (2022). Spatial distribution and potential sources of microplastics in the Songhua River flowing through urban centers in Northeast China. *Environmental Pollution, 292*, 118384. https://doi.org/10.1016/J.ENVPOL.2021.118384

Maheswaran, B., Karmegam, N., Al-Ansari, M., Subbaiya, R., Al-Humaid, L., Sebastin Raj, J. & Govarthanan, M. (2022). Assessment, characterization, and quantification of microplastics from river sediments. *Chemosphere, 298*, 134268. https://doi.org/10.1016/J.CHEMOSPHERE.2022.134268

Marchant, D., Rodríguez, A., Francelle, P., Jones, J. & Kratina, P. (2023). Contrasting the effects of microplastic types, concentrations and nutrient enrichment on freshwater communities and ecosystem functioning. *Ecotoxicology and Environmental Safety, 255*, 114834. https://doi.org/10.1016/j.ecoenv.2023.114834

Mateos-Cárdenas, A., Moroney, A. von der G., Van Pelt, F., O'Halloran, J. & Jansen, M. A. (2022). Trophic transfer of microplastics in a model freshwater microcosm; lack of a consumer avoidance response. *Food Webs, 31*, e00228. https://doi.org/10.1016/J.FOOWEB.2022.E00228

Ockenden, A., Northcott, G. L., Tremblay, L. A. & Simon, K. S. (2022). Disentangling the influence of microplastics and their chemical additives on a model detritivore system. *Environmental Pollution, 307*, 119558. https://doi.org/10.1016/J.ENVPOL.2022.119558

O'Connor, J. D., Lally, H. T., Koelmans, A. A., Mahon, A. M., O'Connor, I., Nash, R., O'Sullivan, J. J., Bruen, M., Heerey, L. & Murphy, S. (2022). Modelling the transfer and accumulation of microplastics in a riverine freshwater food web. *Environmental Advances, 8*, 100192. https://doi.org/10.1016/J.ENVADV.2022.100192

Orona-Návar, C., García-Morales, R., Loge, F. J., Mahlknecht, J., Aguilar-Hernández, I. & Ornelas-Soto, N. (2022). Microplastics in Latin America and the Caribbean: A review on current status and perspectives. *Journal of Environmental Management, 309*, 114698. https://doi.org/10.1016/J.JENVMAN.2022.114698

Parker, B., Andreou, D., Green, I. D. & Britton, J. (2021). Microplastics in freshwater fishes: Occurrence, impacts and future perspectives. *Fish and Fisheries, 22*(3), 467–488. https://doi.org/10.1111/faf.12528

Parker, B., Andreou, D., Pabortsava, K., Barrow, M., Green, I. D. & Britton, J. R. (2022a). Microplastic loads within riverine fishes and macroinvertebrates are not predictable from ecological or morphological characteristics. *Science of The Total Environment, 839*. https://doi.org/10.1016/J.SCITOTENV.2022.156321

Parker, B., Britton, J. R., Pabortsava, K., Barrow, M., Green, I. D., Dominguez Almela, V. & Andreou, D. (2022b). Distinct microplastic patterns in the sediment and biota of an urban stream. *Science of The Total Environment, 838*, 156477. https://doi.org/10.1016/J.SCITOTENV.2022.156477

Preciado, D. K. & Zapata A. P. (2020). *Contaminación por basura marina y microplástico en puntos priorizados de suelos de manglar del municipio de San Andrés de Tumaco – Nariño* [Tesis de pregrado, Corporación Universitaria Autónoma del Cauca]. Repositorio Uniautónoma del Cauca. https://repositorio.uniautonoma.edu.co/handle/123456789/336?show=full

Rauchschwalbe, M. T., Höss, S., Haegerbaeumer, A. & Traunspurger, W. (2022). Long-term exposure of a free-living freshwater micro- and meiobenthos community to microplastic mixtures in microcosms. *Science of The Total Environment, 827*, 154207. https://doi.org/10.1016/J.SCITOTENV.2022.154207

Rozman, U. & Kalčíková, G. (2022). Seeking for a perfect (non-spherical) microplastic particle – The most comprehensive review on microplastic laboratory research. *Journal of Hazardous Materials, 424*, 127529. https://doi.org/10.1016/j.jhazmat.2021.127529

Silva, C. J. M., Machado, A. L., Campos, D., Rodrigues, A. C. M., Patrício Silva, A. L., Soares, A. M. V. M. & Pestana, J. L. T. (2022a). Microplastics in freshwater sediments: Effects on benthic invertebrate communities and ecosystem functioning assessed in artificial streams. *Science of The Total Environment, 804*, 150118. https://

doi.org/10.1016/J.SCITOTENV.2021.150118

Silva, C. J. M., Machado, A. L., Campos, D., Soares, A. & Pestana, J. L. T. (2022b). Combined effects of polyethylene microplastics and natural stressors on *Chironomus riparius* life-history traits. *Environmental Research, 213*, 113641. https://doi.org/10.1016/J.ENVRES.2022.113641

Silva, C. J., Patrício Silva, A. L., Campos, D., Soares, A. M., Pestana, J. L. & Gravato, C. (2021). *Lumbriculus variegatus* (oligochaeta) exposed to polyethylene microplastics: biochemical, physiological and reproductive responses. *Ecotoxicology and Environmental Safety, 207*, 111375. https://doi.org/10.1016/J.ECOENV.2020.111375

Silva, S., Prata, J., Pereira, P., Rodrigues, A., Soares, A., Sarmento, R., Santos, T., Gravato, C. & Silva, A. (2023). Microplastics altered cellular responses, physiology, behaviour, and regeneration of planarians feeding on contaminated prey. *Science of The Total Environment, 875*, 162556. https://doi.org/10.1016/j.scitotenv.2023.162556

Talbot, R., Granek, E., Chang, H., Wood, R. & Brander, S. (2022). Spatial and temporal variations of microplastic concentrations in Portland's freshwater ecosystems. *Science of The Total Environment, 833*, 155143. https://doi.org/10.1016/J.SCITOTENV.2022.155143

Usman, S., Abdull Razis, A. F., Shaari, K., Azmai, M. N. A., Saad, M. Z., Mat Isa, N. & Nazarudin, M. F. (2022). The burden of microplastics pollution and contending policies and regulations. *International Journal of Environmental Research and Public Health, 19*(11), 6773. https://doi.org/10.3390/ijerph19116773

Vásquez-Molano, D., Molina, A. & Duque, G. (2021). Distribución espacial y aumento a través del tiempo de microplásticos en sedimentos de la Bahía de Buenaventura, Pacífico colombiano. *Boletín de Investigaciones Marinas y Costeras, 50*(1), 27-42. http://www.scielo.org.co/pdf/mar/v50n1/es_0122-9761-mar-50-01-27.pdf

Vermeiren, P., Ikejima, K., Uchida, Y. & Cynthia C. (2023). Microplastic distribution among estuarine sedimentary habitats utilized by intertidal crabs. *Science of The Total Environment, 866*, https://doi.org/10.1016/j.scitotenv.2023.161400

Watkins, L., Sullivan, P. J. & Walter, M. T. (2019). A case study investigating temporal factors that influence microplastic concentration in streams under different treatment regimes. *Environmental Science and Pollution Research, 26*(21), 21797–21807. https://doi.org/10.1007/s11356-019-04663-8

Wang, B., Lan, X., Zhang, H. & Hu, Y. (2023). Benthic biofilms in riverine systems: A sink for microplastics and the underlying influences. *Environmental Pollution, 337*, 122607. https://doi.org/10.1016/j.envpol.2023.122607

Windsor, F. M., Tilley, R. M., Tyler, C. R. & Ormerod, S. J. (2019). Microplastic ingestion by riverine macroinvertebrates. *Science of The Total Environment, 646*, 68–74. https://doi.org/10.1016/J.SCITOTENV.2018.07.271

Wu, C., Xiong, X., Hamidian, A. H., Zhang, Y. & Xu, X. (2022). A review on source, occurrence, and impacts of microplastics in freshwater aquaculture systems in China. *Water Biology and Security, 1*(3), 100040. https://doi.org/10.1016/J.WATBS.2022.100040

Yan, Z., Chen, Y., Bao, X., Zhang, X., Ling, X., Lu, G., Liu, J. & Nie, Y. (2021). Microplastic pollution in an urbanized river affected by water diversion: Combining with active biomonitoring. *Journal of Hazardous Materials, 417*, 126058. https://doi.org/10.1016/J.JHAZMAT.2021.126058

Yang, X., Man, Y. B., Wong, M. H., Owen, R. B. & Chow, K. L. (2022). Environmental health impacts of microplastics exposure on structural organization levels in the human body. *Science of The Total Environment, 825*, 154025. https://doi.org/10.1016/J.SCITOTENV.2022.154025

Yıldız, D., Yalçın, G., Jovanović, B., Boukal, D. S., Vebrová, L., Riha, D., Stanković, J., Savić-Zdraković, D., Metin, M., Akyürek, Y. N., Balkanlı, D., Filiz, N., Milošević, D., Feuchtmayr, H., Richardson, J. A. & Beklioğlu, M. (2022). Effects of a microplastic mixture differ across trophic levels and taxa in a freshwater food web: In situ mesocosm experiment. *Science of The Total Environment, 836*, 155407. https://doi.org/10.1016/J.SCITOTENV.2022.155407

Zhai, T., Chang, M., Ma, Y., Huang, L. & Li, L. (2023). Exploring the changes and driving mechanisms in the production-transport-consumption process of ecosystem services flow in the Yellow River Basin under the background of policy changes. *Ecological Indicators, 151*, 110316. https://doi.org/10.1016/j.ecolind.2023.110316

Zhang, K., Hamidian, A. H., Tubić, A., Zhang, Y., Fang, J., Wu, C. & Lam, P. (2021). Understanding plastic degradation and microplastic formation in the environment: A review. *Environmental Pollution, 274*, 116554. https://doi.org/10.1016/J.ENVPOL.2021.1165