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Review

Interconnected impacts of water resource management and climate change on microplastic pollution and riverine biocoenosis: A review by freshwater ecologists

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ABSTRACT

The relationship between river hydrology and microplastic (MP) pollution is complex: increased discharge does not always mobilize more MPs, but floods can effectively flush out MPs from river catchments. Climate change and water resource management further influence MP pollution and its fate by altering river hydro-sedimentary regimes. This review investigates the interconnected impacts of these factors from a comprehensive perspective, focusing on how they affect MP concentration in freshwater ecosystems, particularly in regulated rivers and associated reservoirs. Our review reveals a scarcity of studies that jointly analyze the interrelated issues of MP pollution, water resource management, and climate change. Key findings indicate that variations in river discharge significantly influence MP mobilization, mainly depending on catchment land use, channel morphology, position within the catchment, and MP characteristics. Reservoirs function as both sinks and sources of MPs, underscoring their complex role in MP dynamics and the need for sustainable sediment management strategies. The increasing frequency of extreme weather events, driven by climate change, along with prolonged droughts intensified by water management practices, exacerbates MP pollution. These changes contribute to the local concentration of MPs, posing direct physical threats to aquatic organisms, particularly benthic species, through pollution and habitat alterations. Current policies on plastic pollution, water resources and climate change are underdeveloped, as these topics have been treated separately so far. In conclusion, this review provides perspectives on future research and policy directions to address challenges posed by MPs and to preserve rivers against multiple stressors.

1. Introduction

Freshwater ecosystems and their biodiversity are increasingly threatened by anthropogenic activities, particularly by water diversion and microplastic (MP, i.e., plastics with a dimention below 5 mm) pollution, which disrupt natural hydrological processes and introduce harmful contaminants into aquatic environments (Dudgeon, 2019).

Rivers play a pivotal role in the dynamics of plastic pollution, being the primary pathways for the 70–80% of the plastics found in marine ecosystems (Meijer et al., 2021; Wang et al., 2021). Lebreton et al. (2017) estimated that between 1.15 and 2.41 million tons of plastic waste enter the ocean from rivers each year. This estimate accounts for factors such as population density, rates of mismanaged plastic waste production per inhabitant, monthly catchment runoff, and presence of artificial barriers like dams and weirs. Despite this warning data, the impacts of MP pollution on riverine ecosystems remain understudied if compared to marine ecosystems (Bellasi et al., 2020; Cera et al., 2020). MPs in rivers mainly derive from sewage treatment plants, agricultural pollution, industrial wastewater, and personal care products (Galafassi et al., 2019; Windsor et al., 2019). The transport of MPs is significantly influenced by hydrological characteristics, storm events, and hydraulic conditions, in addition to their physical properties (Eo et al., 2019; Nizzetto et al., 2016). Moreover, reservoirs are prone to serve as either key vectors for MP transport or long-term MP storage, intercepting 65% of plastic waste before it reaches the ocean (Lebreton et al., 2017).

Humans have altered river hydro-sedimentary regimes and

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connectivity through the construction of dams, reservoirs, and water-diversion schemes, leading to only 23% of the world's 12 million kilometers of rivers longer than 1,000 km remaining free-flowing (Belletti et al., 2020; Lehner et al., 2011). Densely populated areas like Europe are significantly impacted by dams and reservoirs (Grill et al., 2019). Most of the 58,000 large dams (higher than 15 m) have been built in the last 60 years, storing one-sixth of the annual river flow into the ocean (ICOLD, 2023; Mulligan et al., 2020). Additionally, over 16 million smaller impoundments have increased the Earth's freshwater surface by more than 7% (Lehner et al., 2011). Demand for food and energy is estimated to rise by 56% by 2040 and by 70% by 2050 and to address this, more dams will be necessary, particularly in low-income countries (Crist et al., 2017; Zarfl et al., 2015). This water overexploitation will further impact freshwater ecosystems and biodiversity (Grill et al., 2019).

MP pollution has garnered considerable attention in recent years due to its pervasive presence in freshwater ecosystems. Previous reviews have tackled this issue from different perspectives: Alfonso et al. (2021) discussed the role of hydrological processes in the transport and accumulation of MPs; other reviews have emphasized the interaction between MP pollution and climate change, outlining how increasing temperatures and altered precipitation patterns exacerbate plastic transport and accumulation in aquatic environments (Haque and Fan, 2023). However, most existing reviews did not comprehensively address the integrated roles of water management practices and climate changes in determining MP dynamics in freshwater ecosystems. While previous studies have focused on isolated aspects such as runoff or artificial barriers (Lebreton et al., 2017), there remains a significant gap in understanding how reservoirs—often overlooked—serve as either sinks or sources of MPs. Furthermore, little has been done to examine the potential harmful effects of MP pollution on organisms living in rivers and reservoirs (i.e., biocoenosis) in the context of changing hydro-sedimentary regimes.

This review aims to shed light on these themes, focusing on the interrelated roles played by the current water management practices and climate changes on MP pollution in rivers and their biocoenoses. Understanding MP dynamics in freshwater ecosystems is essential for managing this pollution along with water resources and climate change.

2. Methodology

Bibliographic analysis was conducted from May 2023 to July 2024 by searching the Web of Science (WoS) core database without temporal limitation. For each chapter the keywords listed in Table 1 were used.

From the pool of retrieved articles, those deemed most representative and pertinent for each topic were considered. Moreover, relevant literature that is within the authors' existing knowledge base has been incorporated in this review. We critically analyzed all the selected papers to evaluate and discuss the topic of each chapter.

Table 1
List of keywords used for the bibliographic analysis in each chapter (from 3 to 7), and the amount of papers found and critically analyzed.

Chapter number	Keywords	Paper amount
3	"microplastics" AND ("river hydrology" OR "river flow" OR "river discharge")	63
4	"microplastics" AND "river" AND "reservoir"	136
5	"microplastics" AND "river" AND ("climate change" OR "extreme event") OR ("microplastics" AND "river" AND "water management")	27
6	"microplastics" AND "impact" AND ("river" OR "reservoir") AND ("biota" OR "organism")	44
7	"policy" AND "plastic" AND "water" AND "climate change"	32

3. Relationship between microplastic pollution and river hydrology

The transport of plastics released in freshwater environments depends on several factors such as weather conditions and river hydrology. However, the expected positive relationship between precipitations, discharges, and plastic concentrations is not consistently observed. As reviewed in van Emmerik and Schwarz (2020), available studies on plastic transport mechanisms show contradictory results. Increased discharge may not always mobilize additional plastics, as seen in areas with aquatic vegetation. In other cases, higher discharge raises water level and flow velocity, which can either i) remobilize settled or accumulated plastics on riverbanks and hydraulic infrastructure, increasing plastic concentration, or ii) dilute plastic concentration in a specific location due to the increased water volume (van Emmerik et al., 2019). The complexity of the relationship between MP pollution and river hydrology is further illustrated in Table 2, where study results show negative, positive, or no correlation depending on factors such as the geographical context, catchment land use and other factors discussed below.

3.1. Catchment land use

The significance of floods for plastic transport is highlighted by Hurley et al. (2018), who observed a 70% decrease in MPs in river sediments across the United Kingdom after heavy floods, concluding that MP contamination is effectively flushed from river catchments during flooding events. Accordingly, de Carvalho et al. (2021) reported that, regardless of the global flux of MPs, the level of MP pollution on the water surface decreases under high discharge conditions. By sampling 14 sites across the Garonne River catchment (France), they found higher MP concentrations and smaller particle size during warm seasons with low discharge.

On the contrary, in the Ofanto River (Italy), MP concentrations were higher during wet periods and were positively correlated to water level and flow velocity. This indicates a land-based source, likely linked to waste from the surrounding agricultural areas (Campanale et al., 2020). Similarly, in rivers draining in the Los Angeles urban area (USA), micro and macroplastic densities were highest in samples collected in the wet season, in the middle of the channels and near the surface rather than in samples from the dry season and taken in the middle of the water column, near the river bottom or the riverbank (Moore et al., 2011). Likewise, Faure et al. (2015) showed that rain events lead to an increase in plastic concentration from five (Venoge River, Switzerland) up to 150 times (Vuachère River, Switzerland), with this latter being mainly fed by street runoff water. A common factor to all these studies is the presence of anthropized areas which act as plastic source during rainy events, making positive the relationship between river flow and plastic concentration (Cesarini et al., 2023a, Fig. 1). Numerous studies found positive correlations between MP abundance and the size of industrial, residential and/or traffic areas in river catchments, and negative correlation with natural areas (Dendievel et al., 2023; He et al., 2020; Kunz et al., 2023). However, in certain cases, also non-point sources (i.e., agricultural areas or forested areas affected by atmospheric MP transport) can substantially influence MP concentration in freshwater systems, especially if combined with point sources (Kabir et al., 2021).

3.2. Plastic features

To fully understand how MP pollution is linked to hydrology, it is important to consider MP characteristics (such as shape, size, and polymer composition), as their behavior under different hydrological conditions strictly depends on these factors (Fig. 1).

Baldwin et al. (2016) found in Great Lakes tributaries greater concentrations of litter-related plastics (fragments, films, foams) and pellets/beads during runoff events while no association between fibers and

Table 2

Examples of studies in which the relationship between plastic concentration and river discharge was investigated. Details on the characteristics of the studied river system and the connection with the four main factors affecting the relationship (see Fig. 1) are reported. Plastic type: PE = polyethylene, PP = polypropylene, PS = polystyrene, PO = polyolefin, PET = polyethylene terephthalate, PVC = poly vinyl chloride, TDI-PUR = toluene diisocyanate - polyurethane, PAN = polyacrylonitrile, PA = polyamide, SIL = silicone; NA = not assessed.

River	River morphology/ Order	Anthropization/Land use	Basin area (km^2)	Plastic size (µm)	Plastic Type	Plastic concentration (C_P) (p/m^3)	Discharge (Q) (m^3/s)	Relationship C_P-Q	Reference
Garonne River and tributaries (France)	Largely canalised and regulated; sixth to eighth order river according to the section	From moderate to high	53,536	700–5000	PE, PP, PS, and others	0–3.4	0.5–480	Negative	de Carvalho et al. (2021)
Saigon (Vietnam)	Largely canalised and regulated	Very high (agriculture, urban and industrial areas)	4,717	mainly >5000	PS, PO, PET, and others	0–90	30–1450	Negative	van Emmerik et al. (2018)
Ofanto (Italy)	Meandering (lower part)	Moderate (50% agricultural, 8% natural and 3% urban areas)	2,790	<500-5000	PE (76%), PS (12%), PP (10%), PVC (0.7%) and TDI-PUR (0.35%)	0.9 ± 0.4 to 13 ± 5	0.5–11	Positive	Campanale et al. (2020)
Venoge (Switzerland)	Meandering	Low (forested area) to moderate (rural-agricultural area)	236	>5000	Mostly fragments and foams	0.034 ± 0.06 (dry season); 2.1 ± 2.9 (wet season)	NA	Positive (indirect: wet season/dry season)	Faure et al. (2015)
Venoge (Switzerland)	Meandering	Low (forested area) to moderate (rural-agricultural area)	237	<5000	Mostly fragments and foams	6.5 ± 5.3 (dry season); 12 ± 0.92 (wet season)	NA	Positive (indirect: wet season/dry season)	Faure et al. (2015)
Ems (Germany)	Largely canalised and fragmented/regulated	Moderate (rural-agricultural area)	17,934	<5000	Flakes, fibres, and films (flakes & films were PET)	0–5.28	NA	Positive (indirect: lower discharge due to weirs and impoundments)	Eibes and Gabel (2022)
Snake and lower Columbia (USA)	Both braided and meandering	From low (national park) to high (agricultural and industrial areas)	240,765	100–5000	Fibers (45–60%), Fragments (20–25%), films (5–25%), beads (5–10%)	0–13.7	(<0.2–0.735 m/s)	Negative (flow velocity)	Kapp and Yeatman (2018)
Weser (Germany)	Largely canalised	From moderate (mainly agriculture and forestry) to high (industrial and urban areas)	49,000	300–5000	94% fibres (PET 61%, PAN 17%, PP 11%, PA 10%) and 6% fragments	0–2.05	70–900	No significant relationship	Moses et al. (2023)
Weser (Germany)	Largely canalised	From moderate (mainly agriculture and forestry) to high (industrial and urban areas)	49,000	10–500	98.2% fragments (PP 68%, PE 13%, PS 5%, PVC 4%, SIL 3%, and PET 3%), 1.2% fibres, and 0.6% spheres	57-14,536	70–900	Positive	Moses et al. (2023)
Aare (Switzerland)	Largely canalised and fragmented/regulated	High (urban and industrial areas)	17,779	300–5000	Variable but dominated by fragments (both hard and foam) predominantly constituted by PET followed by PP for hard fragments and PS for foams	0.17–0.81	138–430	No significant relationship	Mani and Burkhardt-Holm (2020)
Limmat (Switzerland)	Largely canalised and fragmented	High (urban and industrial areas)	2,416	300–5000	Variable but dominated by fragments (both hard and foam) predominantly constituted by PET followed by PP for hard fragments and PS for foams	0.07–0.56	57–70	No significant relationship	Mani and Burkhardt-Holm (2020)
Lower Rhine (Rees, Germany/The Netherlands border)	Numerous straightening and canalisations	High (urban, industrial and navigation areas)	190,000	300–5000	Variable but dominated by hard fragments followed by foams and opaque spherules predominantly constituted by PET followed by PP for hard fragments and PS for foams and opaque spherules	292–543	1343–2733	No significant relationship	Mani and Burkhardt-Holm (2020)
Parthe River (Rural subcatchment; Germany)	Numerous straightening and canalisations; first order	Moderate (rural-agricultural area)	245	>500	Finest particles a mixture of PS, PET, and PP whilst coarse dominated by PS	66,000 ± 41,000	0.20–0.83	No significant relationship	Wagner et al. (2019)
Parthe River (Urban subcatchment; Germany)	Numerous straightening and canalisations; first order	High (54% urban area)	150	>500	Finest particles a mixture of PS, PET, and PP whilst coarse dominated by PS	74,000 ± 67,000	0.47–1.92	Positive	Wagner et al. (2019)
Gallatin River and tributaries (USA)	Mainstream and tributaries	Low (forested and natural areas) to moderate (rural and urban areas)	28,489	100–9600	Microfibers (80%), fragments (19.7%), microbeads (0.3%); fibres were 30% semi-synthetic cellulose, 20% PS, 13% PET and other	0-67,500	10–118	Negative	Barrows et al. (2018)

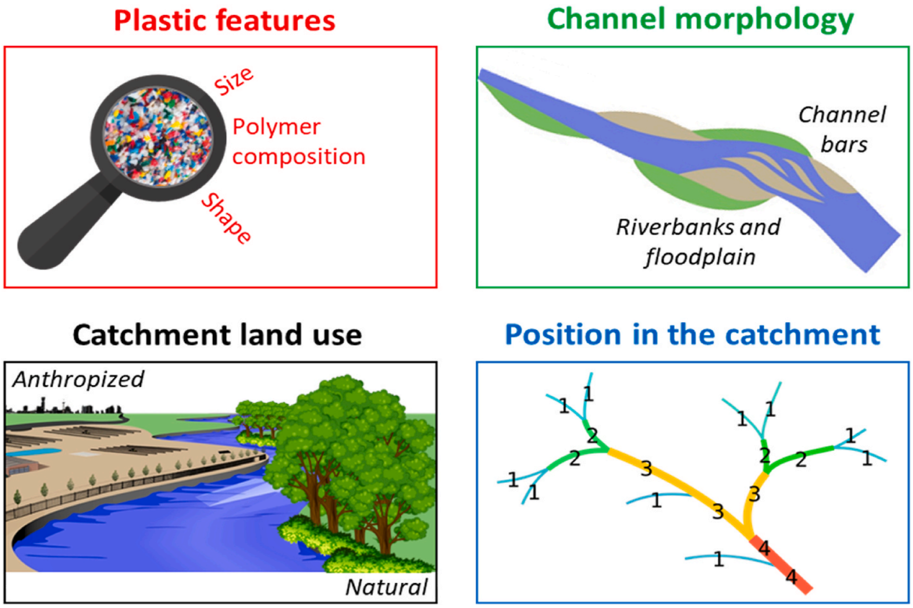

Fig. 1. Main factors influencing the relationship between microplastic (MP) concentration and river hydrology.

hydrologic conditions was observed. Similar results were obtained by Moses et al. (2023) who additionally found that the relationship between river discharge and MP concentration was significant only for the smallest MP fraction (10–500 μm). Generally, MPs smaller than 0.2 mm were not retained in the sediment, regardless of their density, while larger MPs with densities slightly higher than water could instead be retained and remobilized during high-flow periods (Mani et al., 2019; Nizzetto et al., 2016).

In a study by Lu et al. (2023), the application of particle tracking in conjunction with hydrodynamic modelling of the Hanjiang River (China) indicated that MP particles with high density have worse mobility in water and are more prone to deposition: polyethylene terephthalate (PET) is likely to be transported for a relatively shorter distance, while polypropylene (PP) has higher mobility and takes less time to reach the same point. Besides this, they found a general pattern of higher MP concentration in suspension and lower MP concentration in the sediment during high-flow periods. High water velocity allows MP particles to migrate for a longer distance, while high flow rates facilitate the transport of more MPs from source areas. Moreover, different polymers are colonized by microorganisms at varying rates, which directly affects MP transport dynamics. Polymer-specific biofilm can alter the MP sinking behavior: Vercauteren et al. (2024) found that sinking velocity is more likely to be modified in larger polystyrene (PS) than PET particles.

3.3. *Position in the catchment and channel morphology*

The relationship between atmospheric precipitations, hydrological conditions and MP concentrations can be modulated by the position within the catchment (Fig. 1) but how this occurs remains almost unclear. Mani and Burkhardt-Holm (2020) found that MP concentrations positively correlate with the long-term average water discharge and catchment size of the evaluated stream locations (Rhine basin, Switzerland-Germany). Moreover, MP concentrations were significantly higher at downstream pluvial sites compared to upstream nival ones. However, these concentrations showed no correlation with precipitation or water discharge in the preceding 72 h, nor did they exhibit consistent seasonal patterns. This suggests that temporal variations in MP fluxes to the sea are also shaped by varying plastic emission sources along rivers and catchments.

On the contrary, a positive relationship between precipitation and MP concentration was observed in Tamsui catchment (Taiwan, China) even if the strength of the correlation varied between rivers depending on the position from where the samples were taken (Wong et al., 2020). The increase of MPs in rivers during or shortly after precipitation can be due to the local reactivation of particles that have been previously deposited in areas of impeded river flow (riverbanks, floodplain, channel bars, riverbed; Hurley et al., 2018; Wagner et al., 2019). Channel morphology and plastic source location thus represent the fourth factor influencing the relationship between river hydrology and MP pollution (Fig. 1). Another factor is the presence of hydraulic infrastructure such as dams and reservoirs, as detailed in Chapter 4.

4. The role of reservoirs as microplastic sinks and sources

By utilizing hydrodynamic modeling of sediment transport, He et al. (2021) concluded that river sediments are more likely to serve as a sink for MPs rather than acting as carriers into the ocean. As mentioned in Chapter 3, highly dense MPs (e.g., PET and polyvinyl chloride, PVC) can quickly sink through the water column and mix with the sediments (Waldschläger et al., 2022). In contrast, less dense MPs (e.g., PP and polyethylene, PE) may be deposited after biofilm formation on their surfaces, which increases their density (Crawford and Quinn, 2017). Hydrodynamic conditions mainly influence the transport mechanisms of MPs in sediments, along with the physical properties of both the plastic materials and sediments (Yang et al., 2021). These factors affect the movement of MP particles and determine their retention period in the sediments. Some authors pointed out that the behavior of small plastic materials can be similar to that of sediment particles with hydraulically identical physical properties (Harris, 2020; Ockelford et al., 2020). Therefore, just as dams trap sediments, they can also effectively trap MPs.

The study by Watkins et al. (2019) provides evidence that MPs accumulate in the sediment behind dams. In surface water samples from six reservoirs in Ithaca (New York, USA), MP concentrations were significantly lower than in upstream rivers, while concentrations were higher in sediment samples. This suggests that MPs settle from surface waters in the slower-moving reservoir water, and this phenomenon depends on plastic shape: although plastic fibers were dominant in the studied rivers, less abundant shapes like fragments were found in higher proportions in the reservoir sediment. Liu et al. (2022) further confirmed that MPs in reservoir impoundments tend to accumulate in the front section of the reservoir and along the shoreline water. Additionally, the accumulation of free-floating plant residues in these reservoirs leads to the sinking of MPs, further affecting their distribution within the water body.

Dhivert et al. (2022) demonstrated the significant role of fine-grained sediments in trapping MPs. They found that MP levels and diversity were an order of magnitude higher in fine-grained deposits of transitional and lacustrine-like zones under controlled water levels, compared to coarser sediments in lotic zones. This suggests the existence of important MP stocks within fine-grained deposits favored by the water level regulation. Lower MP abundance in water has previously been associated with weak hydrodynamic conditions in a reservoir and was explained by the reduction in the vertical mixing of MPs in the water column, which leads to the deposition of suspended particles (Zhang et al., 2017).

However, studies on MPs in reservoirs have only emerged since 2015 (Zhang et al., 2015). A recent global meta-analysis summarized the results of 30 studies about the occurrence, and the temporal or spatial distribution of MPs in 43 reservoirs worldwide, almost half of which were in Asia and only six in Europe (Guo et al., 2021). MP abundance varies greatly in these reservoirs ranging over 2-6 orders of magnitude (from 0.28 to 181,928 p/m^3 in water and from 1.79 to 9,677 p/kg in sediment). By accumulating and fostering the MP settling, reservoirs can host important quantities of plastics even at substantial distances from their sources. Small-sized MPs (<1 mm) account for more than 60% of the total MPs found in reservoirs worldwide (Guo et al., 2021). The most frequently detected colors, shapes, and polymer types are transparent, fibers, and PP, respectively. Besides analytical methods, geographic location, seasonal variation, and land-use type (i.e., urbanization) are the main factors influencing MP abundance in reservoirs. Specifically, during the rainy season, reservoirs typically intercept small-sized MPs, with sediments acting as storage sites for terrestrial-sourced MPs. However, the relationship between season and MP concentration in reservoirs also depends on population density. In densely populated areas, MP levels are higher in the dry season, likely due to continuous input from anthropogenic sources and reduced water storage. In sparsely populated areas, MP concentrations increase during the rainy season, possibly due to wet deposition or MP resuspension caused by rainfall (Guo et al., 2021).

Gao et al. (2023) found a gradual increase in MP abundance over time (from 2008 to 2020) in the Three Gorges Dam (China) reservoir sediments, with preferential retention of small-sized (<300 μm) PE particles. Moreover, they estimated that the Three Gorges Dam retains 47 ± 44% (8,048 ± 7,494 tons/year) of the MP flux from the Yangtze River to the ocean. Rather than efficiently flushing out MP particles from the reservoir sediments, the catchment-wide flooding released from the Three Gorges Dam in 2020 significantly enhanced the accumulation of MPs behind the dam. The MP concentration in 2020 was approximately 1.7 times higher than in 2019, surpassing even the decade-long increments in accumulation. The elevated scouring force and increased water level during a flooding event could potentially result in the significant flushing of substantial amounts of MPs from both the upper reaches and the zone affected by water-level fluctuations into the reservoir bed. Specifically, the hydro-fluctuation belt can be an important MP sink when the water level is low, and the belt can turn into a potential source when the water level is high (Chen et al., 2022; Zhang et al., 2019). The MP enrichment can also be attributed to the enhanced downward transport of MPs by an intensive hydraulic disturbance in the reservoir bed. Although flood disturbances initially cause an endogenous release of sedimentary MPs, the dam further blocks the transport of MPs in the water, which intensifies their mixing, sinking, and vertical transport (Chen et al., 2022).

However, MPs can be released in large quantities from the reservoirs to downstream aquatic environments during sediment management operations. In recent decades, sediment accumulation emerged as a sustainability issue for many reservoirs, requiring such operations to recover reservoir capacity (George et al., 2016; Hauer et al., 2018; Kondolf et al., 2014). Among these operations, sediment flushing can help mitigate the storage loss due to siltation while simultaneously preserving downstream sediment flux through dams (Kondolf et al., 2014). Particularly, in the European Alps, where most of the dam buildings took place during the 1940–1970s, controlled sediment flushing operations are routinely performed moving thousands of tons of sediment from the reservoirs to the downstream rivers (Cattanéo et al., 2021; Espa et al., 2019). Although they allow rivers to recover from armoring, they can have a non-negligible ecological impact, including a possible increase of MP pollution (Espa et al., 2016) (Fig. 2). Currently, contamination risks for downstream sections are weakly evaluated, even if important MP release can be expected during management operations (at least downstream of substantial sources) (Song et al., 2020). Even river restoration programs such as dam removal can raise similar issues, hence there is an urgent need to consider MP pollution in sediment management operations.

5. Effects of climate change and water resource management on microplastic pollution

Despite being treated separately, plastic pollution and climate change are two fundamentally linked issues (Fig. 3): plastics contribute to greenhouse gas emissions from the beginning to the end of their life cycle, and climate changes exacerbate the spread of plastics in the natural environment (Ford et al., 2022). In addition to human activities, global warming is altering the water cycle by increasing the frequency of extreme weather events (Best and Darby, 2020; Coumou and Rahmstorf, 2012). Specifically, changes in temperature and rainfall patterns are modifying river flow regimes leading to severe droughts and large floods in many areas of the Earth (Messager et al., 2021), which subsequently affect the biodiversity and functioning of river ecosystems (Sabater et al., 2023), besides the water availability for humans (Ledger and Milner, 2015). Climate changes also trigger other catastrophic events such as landslides, storms, and tsunamis, which, along with floods, may transport additional plastic debris to rivers and oceans. This is caused by the increased initial mobilization of plastic waste, the remobilization of accumulated plastic debris, and the introduction of non-waste plastic items into aquatic ecosystems (van Emmerik and Schwarz, 2020).

Several studies have demonstrated a significant increase in the abundance of beach MP debris after heavy rainfall and flash floods (Cheung et al., 2016; Rech et al., 2014; Yonkos et al., 2014). Tropical storms can disperse mismanaged waste between terrestrial, freshwater, and marine environments: after a typhoon, the abundance of MPs increased within seawater and sediments by as much as 40% in the Sanggou Bay (China) (Wang et al., 2019). Roebroek et al. (2021) showed a tenfold worldwide potential plastic mobilization increase, compared to non-flood conditions, even during low-severity floods (10-year return period). Similar results were obtained by Gündoğdu et al. (2018) who found a 14-fold increase of MP concentrations in the Mersin Bay (Turkey) after multiple floods. Moreover, increased rainfall, associated with monsoons, is estimated to increase monthly river plastic inputs into the ocean: MPs entering the Bay of Bengal (India) from the Ganges are approximately 1 billion per day during the pre-monsoon season and 3 billion per day during the post-monsoon season (Napper et al., 2021). Extreme events often co-occur leading to additional significant impacts (Zscheischler et al., 2018). For instance, a storm event associated with flooding in the Cooks River estuary (Australia) caused an increase of the MP abundance from 400 up to 17,383 p/m^3 (Hitchcock, 2020). The sequence of extreme events (such as droughts followed by floods) also impacts the magnitude and drivers of river water quality responses (van Vliet et al., 2023).

As mentioned in the Introduction (Chapter 1), water demand for multiple purposes is increasing under the pression of the human population growth, leading to an increasing regulation and impoundment of rivers, which often translates into large streamflow reduction (Quadroni

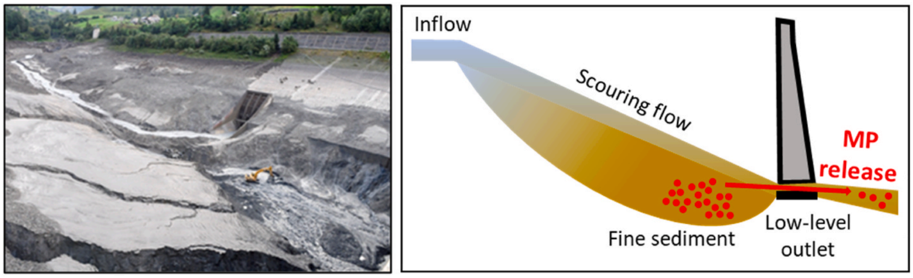

Fig. 2. Sediment flushing operations may cause relevant microplastic (MP) mobilization from reservoirs.

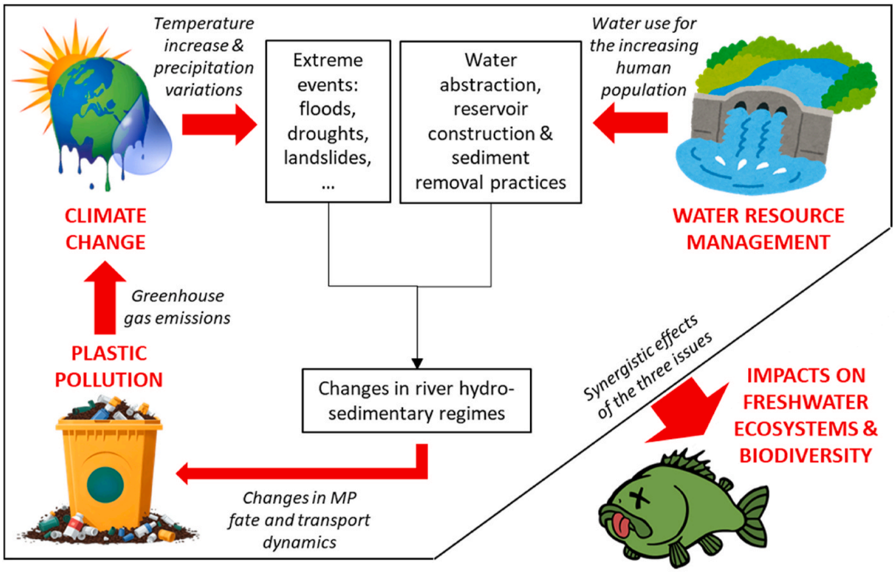

Fig. 3. Scheme on the interconnections between plastic pollution, climate change and water resource management, and their synergistic impacts on freshwater ecosystems and biodiversity. Red arrows mean "increases". (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

et al., 2017). Along with climate change, the increasing water abstraction is contributing to the current change of the hydrological regime of several rivers, from perennial to temporary, with detrimental effects on stream biodiversity and functionality (Piano et al., 2019; Skoulikidis et al., 2017). Unlike naturally intermittent rivers, where the drying phase is a part of the annual flow regime, water scarcity in perennial rivers, such as those present in the European Alps, represents a relatively recent phenomenon and poses a significant threat to their biodiversity (Doretto et al., 2020). Drought or low flow conditions could result in MP stranding, whose incidence is increased by obstructions in the river channel, which either directly trap litter (e.g., overhanging vegetation) or transfer the particles out of the main channel flow (e.g., bankside eddies) (Hurley et al., 2020). In the case of extreme drought, MPs would stay in the riverbed pores and aggregate similarly to what has been observed in soil (Haque and Fan, 2023), potentially increasing the negative effects of MP exposure on freshwater organisms (see Chapter 6) which are already under pressure from the other factors related to this environmental shift (Fig. 3). Moreover, the discharge of untreated wastewater during drought or low flow conditions may not only increase MP concentrations in rivers but may also influence the partitioning of MPs between the sediment and water phase, potentially creating hot-spots of MP contamination (Nel et al., 2018; Woodward et al., 2021). The potential significance of MP pollution is thus greatly influenced by local climate changes (Schell et al., 2021): regions that experience drying trends due to both climate change and water abstraction for socio-economic uses such as the Mediterranean area (Montaldo and Sarigu, 2017; Skoulikidis et al., 2017), may be characterized by a significant reduction in MP inputs (i.e., from precipitation and runoff) and greater interannual variability of MP concentrations.

Both climate change and anthropic activities are also contributing to increased sediment pulses to river systems (East and Sankey, 2020; Juracek and Fitzpatrick, 2022; Maruffi et al., 2022). These events can have natural (e.g., landslides, Clapuyt et al., 2019) or anthropogenic sources (e.g., sediment flushing - Espa et al., 2019, or dam removal - Major et al., 2017) or a combination of both (Salmaso et al., 2020). Specifically, in alpine areas, extreme precipitation events, which are by far the most important drivers of soil erosion, and landslides, will likely increase especially in the fall (Gobiet and Kotlarski, 2020). They could be key moments for MP contamination in rivers (Fig. 3) since MPs can be found at non-negligible concentrations (in the order of 100 p/m^2) even in remote areas (Allen et al., 2019; Bilal et al., 2023; Liu et al., 2023; Yang et al., 2021).

Given that the recorded number of natural disasters has more than doubled since 1980 (Cutter et al., 2015) and is expected to increase, strategies to manage these events and minimize the MP input into aquatic ecosystems are becoming increasingly important. Further research is thus needed to determine the mechanistic links between plastic pollution and climate change, and how both may interact to negatively impact ecosystems (Ford et al., 2022): for instance, Tong et al. (2021) recently found that the effects of climate change and increasing plastic usage would aggravate plastic pollution and accelerate its transport in tropical coastal waters.

6. Impacts of microplastic pollution on river and reservoir biocoenoses in a changing climate

MPs pose a significant threat to riverine communities, exerting a range of detrimental impacts on the delicate balance of aquatic ecosystems. All the different levels of biological organization are affected by MP pollution (Fig. 4). The most extensively observed and studied impact caused by MPs is their ingestion by aquatic organisms (de Sá et al., 2018; Galafassi et al., 2021). Plastic intake is governed by the particle-to-mouth size ratio, hence smaller items can generally interact with a wider range of organisms (Horton et al., 2017; Setälä et al., 2014). An allometric relationship between plastic consumption and animal size was highlighted by Jâms et al. (2020), suggesting a proportional ratio of approximately 20:1 between an animal's body length and the largest size of plastic it might ingest.

Besides the particle size, the possibility of ingesting MPs by organisms depends on their abundance, shape, density, and how these factors interact, as they influence MP positioning in the water column and/or sediments, ultimately affecting their bioavailability along with local hydraulic conditions (Almeida et al., 2023; Franzellitti et al., 2019). As sediments are considered sinks for MPs, benthic organisms are generally exposed to higher concentrations compared to pelagic and planktonic ones (Cera et al., 2020). In this context, bivalves, given their benthic nature and filter-feeding behavior, are considered excellent bioindicators of MPs, highlighting the extent of plastic pollution within aquatic systems (Cesarini et al., 2023b; Su et al., 2018).

6.1. *Impacts from subcellular to individual level*

Ingested MPs can cause physical harm, leading to blockages, internal injuries, and malnutrition as highlighted by diverse laboratory experiments on different organisms (Fu et al., 2020; Jemec et al., 2016; Lei et al., 2018; Shang et al., 2020). For example, exposures of *Chironomus tepperi* carried out at relevant environmental concentrations of PE MPs (500 p/kg sediment) revealed detrimental effects on its survival and growth (Ziajahromi et al., 2018). Similarly, at the concentration of 0.1 μg/L of PS copolymer, an increase in teratological frequency in the diatom *Cocconeis placentula* and a decrease in the regeneration rate in the cnidarian *Hydra vulgaris* were observed (Cesarini et al., 2023c).

MPs can also induce harmful effects on aquatic organisms through oxidative stress, leading to cellular damage, disruption of metabolic processes, and alterations in gene expression (Geremia et al., 2023). In fish and invertebrates, MPs can enter the circulatory system and disrupt haematological properties, altering blood physiology. MPs also induce an imbalance between the production of reactive oxygen species and the body's antioxidant defences, leading to oxidative damage. Additionally, MPs impact immune responses through both physical and chemical toxicity and can cause neurotoxicity by altering acetylcholinesterase activity (Kim et al., 2021). Furthermore, in microalgae, MPs may interfere with nutrient uptake and photosynthetic efficiency, which may also affect biological processes such as carbon fixation, lipid metabolism, and nucleic acid metabolism (Li et al., 2023).

6.2. *Impacts from population to ecosystem level*

The accumulation of MPs in riverbeds alters habitat structures, potentially disturbing nutrient cycles and the ecosystem balance (Sridharan et al., 2022). Moreover, MPs discharged into rivers and deposited on the bottom can cause habitat alteration for various species, affecting their breeding grounds, food sources, or shelter. Directly applied to the case of riverine environments, the case stability of caddisfly can be reduced by the presence of MP items (Ehlers et al., 2020; Gallitelli et al., 2021). As a result, the protective function of the cases can be diminished, making the larvae more vulnerable to predation, while the reduced weight of cases, partially or completely composed of MPs, increases the likelihood of being washed away and affects their drifting behavior (Ehlers et al., 2020). Similarly, the presence of MPs in the bottom can affect other benthic organisms' shelter and increase drift; for instance, mayflies burrow into substrates made of MPs, which are lighter than natural ones (Gallitelli et al., 2021). All the observed effects in the alteration of riverine habitats can reduce the population fitness of freshwater organisms and potentially trigger cascade effects on the entire riverine food web, ultimately altering the ecosystem functioning, albeit these aspects are seldom evaluated (Kong and Koelmans, 2019).

6.3. *Potential biomagnification and carrier role*

Once ingested, MPs can enter the riverine food web and be transferred across different trophic levels through predator-prey interactions. This transfer can potentially lead to biomagnification, where MP concentration increase from one trophic level to the next. Although in limited number, some studies have demonstrated the occurrence of trophic transfer of MPs in wild populations (e.g., Provencher et al., 2019) and in experimental set up (e.g., Mariani et al., 2023). Contrastingly, biomagnification remains unexplored, particularly in natural freshwater ecosystems (Provencher et al., 2019; Gallitelli et al., 2022;

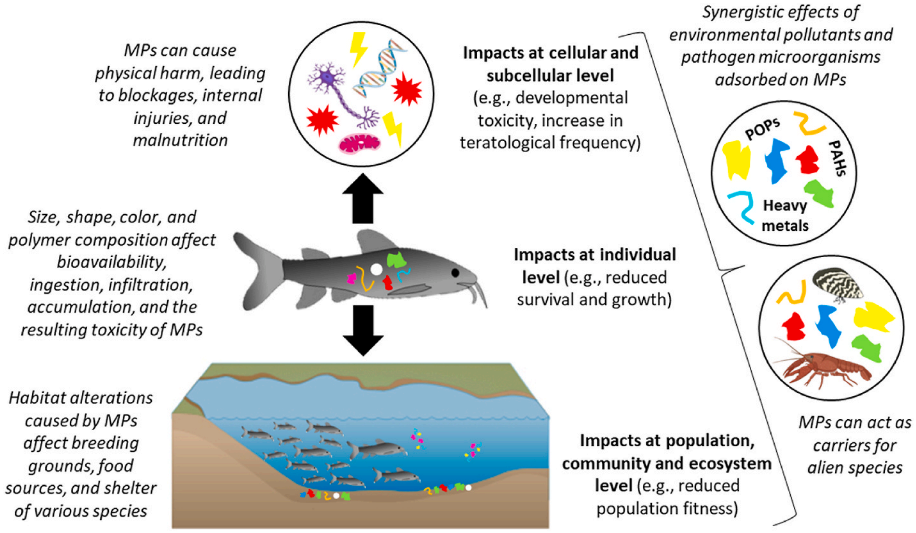

Fig. 4. Summary of the impacts of MPs and MP-related pollution from subcellular to ecosystem level. POPs = persistent organic pollutants, PAH = polycyclic aromatic hydrocarbons.

Bhatt and Chauhan, 2023); furthermore, O'Connor et al. (2022), applying a food web bioaccumulation model, did not find support for biomagnification processes in the river food web they modelled.

MPs can also act as carriers for environmental pollutants and pathogenic microorganisms, accumulating them from the surrounding environment and magnifying their toxicity along the food web (Amaral-Zettler et al., 2020; Nava et al., 2024; Wang et al., 2021; Bocci et al., 2024, Fig. 4). MPs can also act as carriers for alien species, such as eggs of invertebrates and other species, that can pose a serious ecological threat to the recipient system (Tumwesigye et al., 2023, Fig. 4). In freshwater ecosystems, the MP role of carrier is complicated by the simultaneous presence of several pollutants, ranging from chemical residues to heavy metals, leading to synergistic effects which can cause unpredictable consequences for the ecosystem's health (Menéndez-Pedriza and Jaumot, 2020; Sun et al., 2022).

6.4. Impact exacerbation in reservoirs

Reservoirs can exacerbate the negative effects of MP pollution on aquatic life through both direct exposure and indirect ecological changes. The hydrological modifications caused by reservoirs can result in increased MP concentrations, as the restricted water movement in reservoirs limits the natural dispersion and dilution processes (Chen et al., 2022). Consequently, aquatic organisms in these environments are exposed to higher levels of MPs for prolonged periods, which can lead to greater ingestion and accumulation of these pollutants (Hurt et al., 2020). Indeed, high concentrations of MPs were detected during the cool-dry season in both sediments (mean 224 vs. 189 p/kg dry weight) and Cladocera taxa (0.3 particles per individual) in a subtropical Austral reservoir (Themba et al., 2024). These findings highlight the role of reservoirs in retaining MPs, their potential uptake, and transfer through lower trophic levels. Moreover, the decrease in flow velocity in reservoirs promotes the precipitation of debris, including MPs, which interact mainly with benthic organisms (Cai et al., 2021). Therefore, organisms within the reservoir are likely to be exposed to higher MP concentration and consequently be at greater risk. Dam-induced changes in the food web structure affect the intensity of species interactions, which in turn alter the efficiency of MP transfer, further increasing MP concentration within reservoirs (Shen et al., 2023). Additionally, the lentic conditions in reservoirs foster warmer temperatures and lower oxygen levels, creating an environment that supports a higher and more diverse population of microorganisms, introducing potentially harmful microbial species that thrive in such altered habitats (Leiser et al., 2020).

6.5. Synergistic effects with other stressors

Combined effects of plastic pollution and other stressors, like climate change, can also exacerbate the detrimental effects creating a complex web of challenges: plastics not only pose direct threats to habitats and wildlife but could also interact synergistically with climate-related stressors, potentially magnifying their ecological impacts (Chowdhury et al., 2022; Sharma et al., 2023). This linkage has been until now only hypothesized for marine environments (Ford et al., 2022), remaining almost neglected for fresh waters (but see Parker et al., 2024). The increased temperature and the prolonged period of drought exacerbate the effects of MP pollution on freshwater organisms, leading to higher exposure concentrations and more frequent anoxia events (Cabral et al., 2019). Thus, addressing these combined effects becomes imperative in devising comprehensive strategies to safeguard aquatic ecosystems and mitigate the compounding risks posed by plastic pollution and climate change.

7. Current policies on plastic pollution, water resources and climate change

Policies matching the management of plastics, water resources and climate changes are currently underdeveloped, as these topics have mostly been treated separately (Fig. 5).

It was estimated that countries belonging to the Group of Twenty (G20), representing almost 75% of the world's population and 85% of global gross domestic product, generated over 261 million tons of plastic waste in 2019, with projections suggesting this could nearly double to 416 million tons by 2050 (Back to Blue Initiative, 2023). The G20 has taken steps towards transitioning manufacturing systems to circular processes, adopting the G20 Action Plan on Marine Litter in 2017 and its implementation framework in 2019. While these instruments have driven the conversation around existing production patterns and the need to create a sustainable consumption ecosystem, further action is mandatory. Notably, as the 2017 Action Plan title suggests, the focus has largely been on ocean and marine pollution, overlooking the critical role of rivers in plastic circulation. Despite river-dominated coasts account for only 0.87% of the global coast, they receive 52% of plastic pollution delivered by fluvial systems (Harris et al., 2021).

In addition to G20 actions on plastics, other actions have been planned at the global scale to counteract climate change. The 28th Conference of the Parties (i.e., an annual conference organized by the United Nations to agree on policies to limit global temperature rises and adapt to impacts associated with climate change) recently delivered an agreement that calls on nations for a transition away from fossil fuels in energy systems to achieve net zero by 2050. Meanwhile, delegates agreed to triple global renewable energy production by 2030 (Morton et al., 2023). This will lead to an increase of hydropower that still maintains a strategic role as a low CO_2 emission electricity generation process worldwide even if it strongly affects free-flowing rivers. It supplied around 16% of global power in 2019 – roughly three times the generation of wind power and six times that of solar power. Global electricity production from hydropower has increased by around two-thirds since 2000. At least 3,700 major dams, each with a capacity of more than 1 MW, are either planned or under construction, primarily in countries with emerging economies (Zarfl et al., 2015). In developed countries, investments are substantially favoring the construction of small hydropower plants (Lange et al., 2019), which are supposed to have fewer adverse ecological impacts than large hydropower plants without an adequate number of references (Scotti et al., 2022). Thus, hydropower challenges the world's efforts to meet climate targets while simultaneously achieving other Sustainable Development Goals. Strategies to achieve the needed renewable energy expansion while sustaining the diverse social and environmental benefits of rivers should be implemented (Opperman et al., 2023), also accounting for plastic

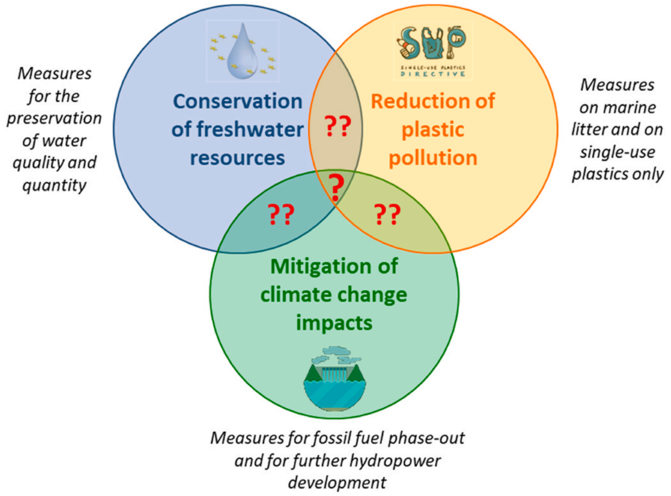

Fig. 5. Representation of the current lack of connectivity and shared goals between policies on plastic pollution, water resources and climate change at both global and regional scale.

pollution.

Even policies on water resources completely ignore plastic pollution. Taking the European Union (EU) as an example, to date, two different directives have been set up to manage these issues. The EU Water Framework Directive 2000/60/EC (WFD) states that an ecological flow (e-flow), i.e., a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies, should be released downstream of water diversions (European Commission, 2015a). The WFD's environmental objectives include achieving good ecological status (GES) of water bodies, preventing the deterioration of their status, and ensuring compliance with standards and objectives for protected areas (e.g., Natura 2000 sites within Birds 79/409/EEC and Habitats 92/43/EEC Directives). Each EU Member State is required to implement and integrate into the River Basin Management Plans a methodology for the determination of e-flows, ensuring that rivers can achieve and maintain the GES. However, in most cases, the general methodology adopted is still based on simple hydrological approaches (Moccia et al., 2020). In many regulated rivers, for most of the year, the discharge is 10% (or even less) of the mean annual natural flow (Quadroni et al., 2017, 2021; Salmaso et al., 2018, 2021). Moreover, less than 50% of the classified EU rivers (approximately two thirds of the total) currently meet the GES (European Environment Agency, 2018), with alteration of the hydrological regime being one of the main causes of the deterioration of the hydrographic networks (WWF Italia, 2022).

In addition to hydrological pressure, the alteration of the sediment regime is receiving growing attention, primarily due to the need to recover reservoir capacity as water-storage infrastructures age (George et al., 2016; Hauer et al., 2018), and secondarily because of the growing expectation for environmental improvement (Gabbud and Lane, 2016; Wohl et al., 2015). Nevertheless, specific policies at EU scale have not yet been set up, while local regulations aimed at limiting the ecological impact of sediment management operations (i.e., the non-deterioration of the ecological status of rivers in the long term) have been developed (Espa et al., 2019; Folegot et al., 2021).

Finally, neither plastic pollution is considered in the assessment of the ecological status of water bodies nor MPs are listed as priority substances in the assessment of chemical status. The first calls for an EU strategy for plastics were made in 2015 within the Circular Economy Action Plan (European Commission, 2015b) but only in 2018 the European Strategy for Plastics in the Circular Economy was published (European Commission, 2018). Within the transition plan to a circular economy, the European Commission aims at a state in which all plastic packaging will be recyclable by 2030. The Single-Use Plastics (SUP) Directive 2019/904/EU on the reduction of the impact of SUP products on the environment, is a first step towards the creation of this new economy (Kasznik and Łapniewska, 2023). Since an estimated 40% of global plastic products are SUPs designed to be discarded after one use and are a major contributor to global solid waste (Walker et al., 2021), their ban should guarantee the improvement of ecosystem health. However, this policy alone can be insufficient to address the leakage of SUPs into the environment (Baxter et al., 2022), and controversy has already risen among environmental organizations (e.g., Greenpeace) on its adequate implementation and thus its efficacy for achieving the scope (Azzurro, 2021).

In recent years, various treatment and management strategies have been developed to reduce MP pollution, including mechanical, chemical, and biological techniques. While these techniques are promising, their scalability and efficiency in diverse environments are still under active research. For a more comprehensive overview of these methods, see recent reviews and research on the topic (Zhang et al., 2021a, 2021b).

8. Conclusions

This review summarizes the state of the art about MP pollution in rivers, considering the influence of current water management practices and climate change. The complex interplay between river hydrology and MP pollution has been analyzed, highlighting that it is mainly governed by four factors: catchment land use, position in the catchment, channel morphology and plastic features. Besides these factors, ecological features such as vegetation cover and structure along the riverbanks and the colonization of MPs by micro-organisms may significantly influence this relationship, underscoring the complexity of studying and understanding MP pollution.

Furthermore, the crucial role played by reservoirs in MP transport dynamics within river catchments was examined. Reservoirs primarily act as sinks, slowing down MP movements towards the ocean even if sediment management strategies may cause the massive release of MPs into the downstream aquatic ecosystems. The investigation into the effects of climate change and water resource management on MP pollution revealed that both the increased frequency of catastrophic events and the prolonged droughts caused by their combined action severely impact MP distribution, exacerbating pollution levels. Higher concentrations of MPs increase exposure for aquatic organisms capable of ingesting them, causing significant harm that ranges from subcellular effects to impacts on community dynamics, potentially impairing overall ecosystem functioning. The biological and ecological impacts of MPs are more severe for benthic species inhabiting rivers and reservoirs, especially if MP pollution interacts synergistically with climate-related stressors. Finally, the review of the current policies on plastic pollution, water resources and climate change highlight a substantial lack of integration among these issues, which contributes to the inefficacy of single topic-oriented mitigation measures.

9. Perspectives

The scarce number of studies on most of the topics addressed in this review (see Table 1) highlights the urgent need for further research on plastic pollution in river ecosystems. MP pollution is highly dynamic across watershed, from headwater tributaries to lowland rivers. Future research should focus on how extreme weather events and anthropogenic changes in hydro-sedimentary regimes impact MP dynamics. Addressing these knowledge gaps is crucial to enhance our predictive capabilities regarding MP pollution across various watershed conditions and climate change scenarios. Given the rapid global changes affecting these ecosystems, interdisciplinary research that combines hydrology, ecology, and social sciences will be crucial for identifying sustainable solutions and garnering public support for local, national and international policies. For instance, if a succession of drought and flood periods will become the norm in the river catchments of temperate regions, ecological (water and sediment) flows should also guarantee the respect of MP thresholds specifically set to mitigate detrimental effects on aquatic biocoenoses. Additionally, effective mitigation of MP pollution in freshwater ecosystems will require a catchment-scale approach to plastic waste management, aimed at reducing plastic inputs into river channels. Sustainable sediment management in reservoirs is essential to prevent downstream release of accumulated plastic waste. If plastic sources at catchment scale will be reduced, water management practices should preserve rivers mainly during dry periods avoiding prolonged droughts and thus the effects of local high MP concentrations affecting aquatic biota. Conservation efforts should prioritize sensitive species, with a particular focus on benthic organisms, whose habitats are heavily impacted by high MP concentrations and dry periods. Although existing protection policies are insufficient to address the freshwater and biodiversity crises facing the world's rivers, they provide valuable frameworks for guiding the development and expansion of protective measures (Hödl, 2018; Perry et al., 2021). Strengthening policy collaboration among pollution control, water management, and climate adaptation sectors could unlock more adaptive, ecosystem-centered solutions that would ultimately create more resilient riverine environments.

CRediT authorship contribution statement

Silvia Quadroni: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Giulia Cesarini:** Writing – review & editing, Writing – original draft, Investigation. **Vanessa De Santis:** Writing – review & editing, Writing – original draft, Investigation. **Silvia Galafassi:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

E-flow	ecological flow
EU	European Union
G20	Group of Twenty
GES	good ecological status
MPs	microplastics
PA	polyamide
PAH	polycyclic aromatic hydrocarbons
PAN	polyacrylonitrile
PE	polyethylene
PET	polyethylene terephthalate
PO	polyolefin
POPs	persistent organic pollutants
PP	polypropylene
PS	polystyrene
PVC	polyvinyl chloride
SIL	silicone
SUP	Single-Use Plastics
TDI-PUR	toluene diisocyanate - polyurethane
WFD	Water Framework Directive 2000/60/EC
WoS	Web of Science

Data availability

Data will be made available on request.

References

Alfonso, M.B., Arias, A.H., Ronda, A.C., Piccolo, M.C., 2021. Continental microplastics: presence, features, and environmental transport pathways. Sci. Total Environ. 799, 149447. https://doi.org/10.1016/j.scitotenv.2021.149447.

Allen, S., Allen, D., Phoenix, V.R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S., Galop, D., 2019. Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nat. Geosci. 12, 339–344. https://doi.org/10.1038/s41561-019-0335-5.

Almeida, M.P. de, Gaylarde, C., Pompermayer, F.C., Lima, L. da S., Delgado, J. de F., Scott, D., Neves, C.V., Vieira, K.S., Baptista Neto, J.A., Fonseca, E.M., 2023. The complex dynamics of microplastic migration through different aquatic environments: subsidies for a better understanding of its environmental dispersion. Microplastics 2, 62–77. https://doi.org/10.3390/microplastics2010005.

Amaral-Zettler, L.A., Zettler, E.R., Mincer, T.J., 2020. Ecology of the plastisphere. Nat. Rev. Microbiol. 18, 139–151. https://doi.org/10.1038/s41579-019-0308-0.

Azzurro, P., 2021. Dalla riduzione del monouso in plastica alla riduzione del monouso: indicazioni per il recepimento della direttiva SUP in Italia. Documento per Greepece Italia. https://www.greenpeace.org/static/planet4-italy-stateless/2021/04/c9c8f418-direttiva-sup-greenpeace.pdf. (Accessed 7 January 2024).

Back to Blue Initiative, 2023. Peak plastics: bending the consumption curve: evaluating the effectiveness of policy mechanisms to reduce plastic use. https://backtoblueinitiative.com/wp-content/uploads/2023/02/ECO172-Back-to-Blue-Peak-Plastic-Methodology-Note-3.pdf. (Accessed 7 January 2024).

Baldwin, A.K., Corsi, S.R., Mason, S.A., 2016. Plastic debris in 29 Great lakes tributaries: relations to watershed attributes and hydrology. Environ. Sci. Technol. 50, 10377–10385. https://doi.org/10.1021/ACS.EST.6B02917/ASSET/IMAGES/LARGE/ES-2016-02917N_0006.JPEG.

Barrows, A.P.W., Christiansen, K.S., Bode, E.T., Hoellein, T.J., 2018. A watershed-scale, citizen science approach to quantifying microplastic concentration in a mixed land-use river. Water Res. 147, 382–392. https://doi.org/10.1016/J.WATRES.2018.10.013.

Bhatt, V., Chauhan, J.S., 2023. Microplastic in freshwater ecosystem: bioaccumulation, trophic transfer, and biomagnification. Environ. Sci. Pollut. Res. 30, 9389–9400. https://doi.org/10.1007/s11356-022-24529-w.

Baxter, L., Lucas, Z., Walker, T.R., 2022. Evaluating Canada’s single-use plastic mitigation policies via brand audit and beach cleanup data to reduce plastic pollution. Mar. Pollut. Bull. 176, 113460. https://doi.org/10.1016/j.marpolbul.2022.113460.

Bellasi, A., Binda, G., Pozzi, A., Galafassi, S., Volta, P., Bettinetti, R., 2020. Microplastic contamination in freshwater environments: a review, focusing on interactions with sediments and benthic organisms. Environments 7, 30. https://doi.org/10.3390/environments7040030.

Belletti, B., Garcia de Leaniz, C., Jones, J., Bizzi, S., Börger, L., Segura, G., Castelletti, A., van de Bund, W., Aarestrup, K., Barry, J., Belka, K., Berkhuysen, A., Birnie-Gauvin, K., Bussettini, M., Carolli, M., Consuegra, S., Dopico, E., Feierfeil, T., Fernández, S., Fernandez Garrido, P., Garcia-Vazquez, E., Garrido, S., Giannico, G., Gough, P., Jepsen, N., Jones, P.E., Kemp, P., Kerr, J., King, J., Łapińska, M., Lázaro, G., Lucas, M.C., Marcello, L., Martin, P., McGinnity, P., O’Hanley, J., Olivo del Amo, R., Parasiewicz, P., Pusch, M., Rincon, G., Rodriguez, C., Royte, J., Schneider, C.T., Tummers, J.S., Vallesi, S., Vowles, A., Verspoor, E., Wanningen, H., Wantzen, K.M., Wildman, L., Zalewski, M., 2020. More than one million barriers fragment Europe’s rivers. Nature 588, 436–441. https://doi.org/10.1038/s41586-020-3005-2.

Best, J., Darby, S.E., 2020. The pace of human-induced change inbilal large rivers: stresses, resilience, and vulnerability to extreme events. One Earth 2, 510–514. https://doi.org/10.1016/j.oneear.2020.05.021.

Bilal, M., Qadir, A., Yaqub, A., Hassan, H.U., Irfan, M., Aslam, M., 2023. Microplastics in water, sediments, and fish at Alpine River, originating from the Hindu Kush Mountain, Pakistan: implications for conservation. Environ. Sci. Pollut. Res. 30, 727–738. https://doi.org/10.1007/S11356-022-22212-8/FIGURES/5.

Bocci, V., Galafassi, S., Levantesi, C., Crognale, S., Amalfitano, S., Congestri, R., Matturro, B., Rossetti, S., Di Pippo, F., 2024. Freshwater plastisphere: a review on biodiversity, risks, and biodegradation potential with implications for the aquatic ecosystem health. Front. Microbiol. 15, 1395401. https://doi.org/10.3389/fmicb.2024.1395401.

Cabral, H., Fonseca, V., Sousa, T., Leal, M.C., 2019. Synergistic effects of climate change and marine pollution: an overlooked interaction in coastal and estuarine areas. International Journal of Environ. Res. Public Health 16, 2737. https://doi.org/10.3390/ijerph16152737.

Campanale, C., Stock, F., Massarelli, C., Kochleus, C., Bagnuolo, G., Reifferscheid, G., Uricchio, V.F., 2020. Microplastics and their possible sources: the example of Ofanto river in southeast Italy. Environmental Pollution 258, 113284. https://doi.org/10.1016/j.envpol.2019.113284.

Cai, Y., Li, C., Zhao, Y., 2021. A review of the migration and transformation of microplastics in inland water systems. International journal of Environ. Res. Public Health 19, 148. https://doi.org/10.3390/ijerph19010148.

Cattanéo, F., Guillard, J., Diouf, S., O’Rourke, J., Grimardias, D., 2021. Mitigation of ecological impacts on fish of large reservoir sediment management through controlled flushing – the case of the Verbois dam (Rhône River, Switzerland). Sci. Total Environ. 756, 144053. https://doi.org/10.1016/J.SCITOTENV.2020.144053.

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

Cesarini, G., Crosti, R., Secco, S., Gallitelli, L., Scalici, M., 2023a. From city to sea: spatiotemporal dynamics of floating macrolitter in the Tiber River. Sci. Total Environ. 857, 159713. https://doi.org/10.1016/J.SCITOTENV.2022.159713.

Cesarini, G., Corami, F., Rosso, B., Scalici, M., 2023b. Microplastics, additives, and plasticizers in freshwater bivalves: preliminary research of biomonitoring. Water 15, 2647. https://doi.org/10.3390/W15142647/S1.

Cesarini, G., Secco, S., Taurozzi, D., Venditti, I., Battocchio, C., Marcheggiani, S., Mancini, L., Fratoddi, I., Scalici, M., Puccinelli, C., 2023c. Teratogenic effects of environmental concentration of plastic particles on freshwater organisms. Sci. Total Environ. 898, 165564. https://doi.org/10.1016/J.SCITOTENV.2023.165564.

Chen, Y., Gao, B., Xu, D., Sun, K., Li, Y., 2022. Catchment-wide flooding significantly altered microplastics organization in the hydro-fluctuation belt of the reservoir. iScience 25. https://doi.org/10.1016/j.isci.2022.104401.

Cheung, P.K., Cheung, L.T.O., Fok, L., 2016. Seasonal variation in the abundance of marine plastic debris in the estuary of a subtropical macro-scale drainage basin in South China. Sci. Total Environ. 562, 658–665. https://doi.org/10.1016/J.SCITOTENV.2016.04.048.

Chowdhury, G.W., Koldewey, H.J., Niloy, M.N.H., Sarker, S., 2022. The ecological impact of plastic pollution in a changing climate. Emerg. Top. Life Sci. 6, 389–402. https://doi.org/10.1042/ETLS20220016.

Clapuyt, F., Vanacker, V., Christl, M., Van Oost, K., Schlunegger, F., 2019. Spatio-temporal dynamics of sediment transfer systems in landslide-prone Alpine catchments. Solid Earth 10, 1489–1503. https://doi.org/10.5194/SE-10-1489-2019.

Coumou, D., Rahmstorf, S., 2012. A decade of weather extremes. Nat. Clim. Change 2, 491–496. https://doi.org/10.1038/nclimate1452.

Crawford, C.B., Quinn, B., 2017. Microplastic identification techniques. In: Microplastic Pollutants, vol. 10. Elsevier, Amsterdam, pp. 219–267.

Crist, E., Mora, C., Engelman, R., 2017. The interaction of human population, food production, and biodiversity protection. Science 356, 260–264. https://doi.org/10.1126/SCIENCE.AAL2011.

Cutter, S.L., Ismail-Zadeh, A., Alcántara-Ayala, I., Altan, O., Baker, D.N., Briceño, S., Gupta, H., Holloway, A., Johnston, D., McBean, G.A., Ogawa, Y., Paton, D., Porio, E., Silbereisen, R.K., Takeuchi, K., Valsecchi, G.B., Vogel, C., Wu, G., 2015. Global risks: pool knowledge to stem losses from disasters. Nature 522 (7556 522), 277–279. https://doi.org/10.1038/522277a, 2015.

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. Sci. Total Environ. 769, 144479. https://doi.org/10.1016/j.scitotenv.2020.144479.

de Sá, L.C., Oliveira, M., Ribeiro, F., Rocha, T.L., Futter, M.N., 2018. Studies of the effects of microplastics on aquatic organisms: what do we know and where should we focus our efforts in the future? Sci. Total Environ. 645, 1029–1039. https://doi.org/10.1016/j.scitotenv.2018.07.207.

Dendievel, A.M., Wazne, M., Vallier, M., Mermillod-Blondin, F., Mourier, B., Piégay, H., Winiarski, T., Krause, S., Simon, L., 2023. Environmental and land use controls of microplastic pollution along the gravel-bed Ain River (France) and its "Plastic Valley". Water Res. 230, 119518. https://doi.org/10.1016/j.watres.2022.119518.

Dhivert, E., Phuong, N.N., Mourier, B., Grosbois, C., Gasperi, J., 2022. Microplastic trapping in dam reservoirs driven by complex hydrosedimentary processes (Villerest Reservoir, Loire River, France). Water Res. 225, 119187. https://doi.org/10.1016/J.WATRES.2022.119187.

Doretto, A., Bona, F., Falasco, E., Morandini, D., Piano, E., Fenoglio, S., 2020. Stay with the flow: how macroinvertebrate communities recover during the rewetting phase in Alpine streams affected by an exceptional drought. River Res. Appl. 36, 91–101. https://doi.org/10.1002/RRA.3563.

Dudgeon, D., 2019. Multiple threats imperil freshwater biodiversity in the Anthropocene. Curr. Biol. 29, R960–R967. https://doi.org/10.1016/j.cub.2019.08.002.

East, A.E., Sankey, J.B., 2020. Geomorphic and sedimentary effects of modern climate change: current and anticipated future conditions in the western United States. Rev. Geophys. 58, e2019RG000692. https://doi.org/10.1029/2019RG000692.

Ehlers, S.M., Al Najjar, T., Taupp, T., Koop, J.H.E., 2020. PVC and PET microplastics in caddisfly (Lepidostoma basale) cases reduce case stability. Environ. Sci. Pollut. Res. 27, 22380–22389. https://doi.org/10.1007/S11356-020-08790-5/FIGURES/9.

Eibes, P.M., Gabel, F., 2022. Floating microplastic debris in a rural river in Germany: distribution, types and potential sources and sinks. Sci. Total Environ. 816, 151641. https://doi.org/10.1016/j.scitotenv.2021.151641.

Eo, S., Hong, S.H., Song, Y.K., Han, G.M., Shim, W.J., 2019. Spatiotemporal distribution and annual load of microplastics in the Nakdong River, South Korea. Water Res. 160, 228–237.

Espa, P., Batalla, R.J., Brignoli, M.L., Crosa, G., Gentili, G., Quadroni, S., 2019. Tackling reservoir siltation by controlled sediment flushing: impact on downstream fauna and related management issues. PLoS One 14, e0218822. https://doi.org/10.1371/JOURNAL.PONE.0218822.

Espa, P., Brignoli, M.L., Crosa, G., Gentili, G., Quadroni, S., 2016. Controlled sediment flushing at the Cancano Reservoir (Italian Alps): management of the operation and downstream environmental impact. J. Environ. Manage. 182, 1–12. https://doi.org/10.1016/J.JENVMAN.2016.07.021.

European Commission, 2015a. Ecological flows in the implementation of the water framework directive 108. https://doi.org/10.2779/775712.

European Commission, 2015b. Closing the Loop - an EU Action Plan for the Circular Economy COM/2015/0614 Final.

European Commission, 2018. A European Strategy for Plastics in a circular economy. European Comission 24.

European Environment Agency, 2018. European Waters: Assessment of Status and Pressures 2018 (EEA Report No 7/2018), Parents and Children Communicating with Society: Managing Relationships outside of Home. Publications Office of the European Union, Luxembourg. https://doi.org/10.2800/303664.

Faure, F., Demars, C., Wieser, O., Kunz, M., De Alencastro, L.F., 2015. Plastic pollution in Swiss surface waters: nature and concentrations, interaction with pollutants. Environ. Chem. 12, 582–591. https://doi.org/10.1071/EN14218.

Folegot, S., Bruno, M.C., Larsen, S., Kaffas, K., Pisaturo, G.R., Andreoli, A., Comiti, F., Maurizio, R., 2021. The effects of a sediment flushing on Alpine macroinvertebrate communities. Hydrobiologia 848, 3921–3941. https://doi.org/10.1007/S10750-021-04608-8/FIGURES/7.

Ford, H.V., Jones, N.H., Davies, A.J., Godley, B.J., Jambeck, J.R., Napper, I.E., Suckling, C.C., Williams, G.J., Woodall, L.C., Koldewey, H.J., 2022. The fundamental links between climate change and marine plastic pollution. Sci. Total Environ. 806, 150392.

Franzellitti, S., Canesi, L., Auguste, M., Wathsala, R.H.G.R., Fabbri, E., 2019. Microplastic exposure and effects in aquatic organisms: a physiological perspective. Environ. Toxicol. Pharmacol. 68, 37–51. https://doi.org/10.1016/j.etap.2019.03.009.

Fu, Y., Wu, G., Bian, X., Zeng, J., Weng, Y., 2020. Biodegradation behavior of poly (butylene adipate-Co-terephthalate) (PBAT), poly(lactic acid) (PLA), and their blend in freshwater with sediment. Molecules 25. https://doi.org/10.3390/MOLECULES25173946. Page 3946 25, 3946.

Gabbud, C., Lane, S.N., 2016. Ecosystem impacts of Alpine water intakes for hydropower: the challenge of sediment management. WIRES Water 3, 41–61. https://doi.org/10.1002/WAT2.1124.

Galafassi, S., Nizzetto, L., Volta, P., 2019. Plastic sources: a survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Sci. Total Environ. 693, 133499. https://doi.org/10.1016/J.SCITOTENV.2019.07.305.

Galafassi, S., Sighicelli, M., Pusceddu, A., Bettinetti, R., Cau, A., Temperini, M.E., Gillibert, R., Ortolani, M., Pietrelli, L., Zaupa, S., Volta, P., 2021. Microplastic pollution in perch (Perca fluviatilis, Linnaeus 1758) from Italian south-alpine lakes. Environ. Pollut. 288, 117782. https://doi.org/10.1016/J.ENVPOL.2021.117782.

Gallitelli, L., Cera, A., Cesarini, G., Pietrelli, L., Scalici, M., 2021. Preliminary indoor evidences of microplastic effects on freshwater benthic macroinvertebrates. Sci. Rep. 11, 1–11. https://doi.org/10.1038/s41598-020-80606-5.

Gallitelli, L., Battisti, C., Pietrelli, L., Scalici, M., 2022. Anthropogenic particles in coypu (Myocastor coypus; Mammalia, Rodentia)'faeces: first evidence and considerations about their use as track for detecting microplastic pollution. Environ. Sci. Pollut. Res. 29 (36), 55293–55301. https://doi.org/10.1007/s11356-022-21032-0.

Gao, B., Chen, Y., Xu, D., Sun, K., Xing, B., 2023. Substantial burial of terrestrial microplastics in the three Gorges reservoir, China. Commun. Earth Environ. 4, 1–9. https://doi.org/10.1038/s43247-023-00701-z.

George, M.W., Hotchkiss, R.H., Huffaker, R., 2016. Reservoir sustainability and sediment management. J. Water Resour. Plan. Manag. 143, 04016077. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000720.

Geremia, E., Muscari Tomajoli, M.T., Murano, C., Petito, A., Fasciolo, G., 2023. The impact of micro-and nanoplastics on aquatic organisms: mechanisms of oxidative stress and implications for human health—a review. Environments 10 (9), 161. https://doi.org/10.3390/environments10090161.

Gobiet, A., Kotlarski, S., 2020. Future climate change in the European Alps. Oxford Research Encyclopedia of Climate Science. https://doi.org/10.1093/ACREFORE/9780190228620.013.767.

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Ehalt Macedo, H., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z., Lip, B., McClain, M.E., Meng, J., Mulligan, M., Nilsson, C., Olden, J.D., Opperman, J.J., Petry, P., Reidy Liermann, C., Sáenz, L., Salinas-Rodríguez, S., Schelle, P., Schmitt, R.J.P., Snider, J., Tan, F., Tockner, K., Valdujo, P. H., van Soesbergen, A., Zarfl, C., 2019. Mapping the world's free-flowing rivers. Nature 569, 215–221. https://doi.org/10.1038/s41586-019-1111-9.

Gündoğdu, S., Çevik, C., Ayat, B., Aydoğan, B., Karaca, S., 2018. How microplastics quantities increase with flood events? An example from Mersin Bay NE Levantine coast of Turkey. Environ. Pollut. 239, 342–350.

Guo, Z., Boeing, W.J., Xu, Y., Borgomeo, E., Mason, S.A., Zhu, Y.G., 2021. Global meta-analysis of microplastic contamination in reservoirs with a novel framework. Water Res. 207, 117828. https://doi.org/10.1016/J.WATRES.2021.117828.

Haque, F., Fan, C., 2023. Fate of microplastics under the influence of climate change. iScience 26, 107649. https://doi.org/10.1016/J.ISCI.2023.107649.

Harris, P.T., 2020. The fate of microplastic in marine sedimentary environments: a review and synthesis. Mar. Pollut. Bull. 158, 111398. https://doi.org/10.1016/j.marpolbul.2020.111398.

Harris, P.T., Westerveld, L., Nyberg, B., Maes, T., Macmillan-Lawler, M., Appelquist, L.R., 2021. Exposure of coastal environments to river-sourced plastic pollution. Sci. Total Environ. 769, 145222. https://doi.org/10.1016/j.scitotenv.2021.145222.

Hauer, C., Wagner, B., Aigner, J., Holzapfel, P., Flödl, P., Liedermann, M., Tritthart, M., Sindelar, C., Pulg, U., Klösch, M., Haimann, M., Donnum, B.O., Stickler, M., Habersack, H., 2018. State of the art, shortcomings and future challenges for a sustainable sediment management in hydropower: a review. Renewable Sustainable Energy Rev. 98, 40–55. https://doi.org/10.1016/J.RSER.2018.08.031.

He, B., Smith, M., Egodawatta, P., Ayoko, G.A., Rintoul, L., Goonetilleke, A., 2021. Dispersal and transport of microplastics in river sediments. Environ. Pollut. 279, 116884. https://doi.org/10.1016/j.envpol.2021.116884.

He, B., Wijesiri, B., Ayoko, G.A., Egodawatta, P., Rintoul, L., Goonetilleke, A., 2020. Influential factors on microplastics occurrence in river sediments. Sci. Total Environ. 738, 139901. https://doi.org/10.1016/j.scitotenv.2020.139901.

Hitchcock, J.N., 2020. Storm events as key moments of microplastic contamination in aquatic ecosystems. Sci. Total Environ. 734, 139436. https://doi.org/10.1016/J.SCITOTENV.2020.139436.

Hödl, E., 2018. Legislative framework for river ecosystem management on international and European level. In: Schmutz, S., Sendzimir, J. (Eds.), Riverine Ecosystem Management: Science for Governing towards a Sustainable Future. Springer Nature, pp. 325–345, 2018.

Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci. Total Environ. 586, 127–141. https://doi.org/10.1016/J.SCITOTENV.2017.01.190.

Hurley, R., Horton, A., Lusher, A., Nizzetto, L., 2020. Plastic waste in the terrestrial environment. In: Plastic Waste and Recycling: Environmental Impact, Societal Issues, Prevention, and Solutions. Academic Press, pp. 163–193. https://doi.org/10.1016/B978-0-12-817880-5.00007-4.

Hurley, R., Woodward, J., Rothwell, J.J., 2018. Microplastic contamination of river beds significantly reduced by catchment-wide flooding. Nat. Geosci. 11, 251–257. https://doi.org/10.1038/s41561-018-0080-1.

Hurt, R., O'Reilly, C.M., Perry, W.L., 2020. Microplastic prevalence in two fish species in two US reservoirs. Limnology and oceanography letters 5, 147–153. https://doi.org/10.1002/lol2.10140.

ICOLD, 2023. International commission on large dams. https://www.icold-cigb.org. (Accessed 30 May 2023).

Jâms, I.B., Windsor, F.M., Poudevigne-Durance, T., Ormerod, S.J., Durance, I., 2020. Estimating the size distribution of plastics ingested by animals. Nat. Commun. 11, 1–7. https://doi.org/10.1038/s41467-020-15406-6.

Jemec, A., Horvat, P., Kunej, U., Bele, M., Kržan, A., 2016. Uptake and effects of microplastic textile fibers on freshwater crustacean Daphnia magna. Environ. Pollut. 219, 201–209. https://doi.org/10.1016/j.envpol.2016.10.037.

Juracek, K.E., Fitzpatrick, F.A., 2022. Geomorphic responses of fluvial systems to climate change: a habitat perspective. River Res. Appl. 38, 757–775. https://doi.org/10.1002/RRA.3938.

Kabir, A.E., Sekine, M., Imai, T., Yamamoto, K., Kanno, A., Higuchi, T., 2021. Assessing small-scale freshwater microplastics pollution, land-use, source-to-sink conduits, and pollution risks: perspectives from Japanese rivers polluted with microplastics. Sci. Total Environ. 768, 144655. https://doi.org/10.1016/j.scitotenv.2020.144655.

Kapp, K.J., Yeatman, E., 2018. Microplastic hotspots in the snake and lower columbia rivers: a journey from the greater yellowstone ecosystem to the pacific ocean. Environ. Pollut. 241, 1082–1090. https://doi.org/10.1016/j.envpol.2018.06.033.

Kasznik, D., Łapniewska, Z., 2023. The end of plastic? The EU's directive on single-use plastics and its implementation in Poland. Environ. Sci. Policy 145, 151–163. https://doi.org/10.1016/j.envsci.2023.04.005.

Kim, J.H., Yu, Y.B., Choi, J.H., 2021. Toxic effects on bioaccumulation, hematological parameters, oxidative stress, immune responses and neurotoxicity in fish exposed to microplastics: a review. J. Hazard Mater. 413, 125423. https://doi.org/10.1016/j.jhazmat.2021.125423.

Kondolf, G.M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.-W., Wang, Z., Wei, Z., Wu, B., Wu, C., Yang, C.T., 2014. Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. Earth's Future 2, 256–280. https://doi.org/10.1002/2013EF000184.

Kong, X., Koelmans, A.A., 2019. Modeling decreased resilience of shallow lake ecosystems toward eutrophication due to microplastic ingestion across the food web. Environ. Sci. Technol. 53, 13822–13831. https://doi.org/10.1021/ACS.EST.9B03905/SUPPL_FILE/ES9B03905_SI_001.PDF.

Kunz, A., Schneider, F., Anthony, N., Lin, H.T., 2023. Microplastics in rivers along an urban-rural gradient in an urban agglomeration: correlation with land use, potential sources and pathways. Environ. Pollut. 321, 121096. https://doi.org/10.1016/j.envpol.2023.121096.

Lange, K., Wehrli, B., Åberg, U., Bätz, N., Brodersen, J., Fischer, M., Hermoso, V., Liermann, C.R., Schmid, M., Wilmsmeier, L., Weber, C., 2019. Small hydropower goes unchecked. Front. Ecol. Environ. 17, 256–258. https://doi.org/10.1002/fee.2049.

Lebreton, L.C.M., Van Der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A., Reisser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8, 1–10. https://doi.org/10.1038/ncomms15611.

Ledger, M.E., Milner, A.M., 2015. Extreme events in running waters. Freshw. Biol. 60, 2455–2460. https://doi.org/10.1111/FWB.12673.

Lehner, B., Liermann, C.R., Revenga, C., Vörömsmarty, C., Fekete, B., Crouzet, P., Döll, P., Endejan, M., Frenken, K., Magome, J., Nilsson, C., Robertson, J.C., Rödel, R., Sindorf, N., Wisser, D., 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. Front. Ecol. Environ. 9, 494–502. https://doi.org/10.1890/100125.

Lei, L., Wu, S., Lu, S., Liu, M., Song, Y., Fu, Z., Shi, H., Raley-Susman, K.M., He, D., 2018. Microplastic particles cause intestinal damage and other adverse effects in zebrafish Danio rerio and nematode *Caenorhabditis elegans*. Sci. Total Environ.cience of the total environment 619–620, 1–8. https://doi.org/10.1016/j.scitotenv.2017.11.103.

Leiser, R., Wu, G.M., Neu, T.R., Wendt-Potthoff, K., 2020. Biofouling, metal sorption and aggregation are related to sinking of microplastics in a stratified reservoir. Water Res. 176, 115748. https://doi.org/10.1016/j.watres.2020.115748.

Li, J., Zheng, X., Liu, X., Zhang, L., Zhang, S., Li, Y., Zhang, W., Li, Q., Zhao, Y., Chen, X., 2023. Effect and mechanism of microplastics exposure against microalgae: photosynthesis and oxidative stress. Sci. Total Environ. 905, 167017. https://doi.org/10.1016/j.scitotenv.2023.167017.

Liu, Q., Xiong, X., Wang, K., Wang, H., Ling, Y., Li, Q., Xu, F., Wu, C., 2023. Homogenization of microplastics in alpine rivers: analysis of microplastic abundance and characteristics in rivers of Qilian Mountain, China. J. Environ. Manage. 340, 118011. https://doi.org/10.1016/J.JENVMAN.2023.118011.

Liu, Y., Cao, W., Hu, Y., Zhang, J., Shen, W., 2022. Horizontal and vertical distribution of microplastics in dam reservoir after impoundment. Sci. Total Environ. 832, 154962. https://doi.org/10.1016/J.SCITOTENV.2022.154962.

Lu, X., Wang, X., Liu, X., Singh, V.P., 2023. Dispersal and transport of microplastic particles under different flow conditions in riverine ecosystem. J. Hazard Mater. 442, 130033. https://doi.org/10.1016/J.JHAZMAT.2022.130033.

Major, J.J., East, A.E., O'Connor, J.E., Grant, G.E., Wilcox, A.C., Magirl, C.S., Collins, M.J., Tullos, D.D., 2017. Geomorphic responses to dam removal in the United States – a two-decade perspective. Gravel-Bed Rivers: Process and Disasters 355–383. https://doi.org/10.1002/9781118971437.CH13.

Mani, T., Burkhardt-Holm, P., 2020. Seasonal microplastics variation in nival and pluvial stretches of the Rhine River – from the Swiss catchment towards the North Sea. Sci. Total Environ. 707, 135579. https://doi.org/10.1016/J.SCITOTENV.2019.135579.

Mani, T., Primpke, S., Lorenz, C., Gerdts, G., Burkhardt-Holm, P., 2019. Microplastic pollution in benthic midstream sediments of the rhine river. Environ. Sci. Technol. 53, 6053–6062. https://doi.org/10.1021/ACS.EST.9B01363/SUPPL_FILE/ES9B01363_SI_002.XLSX.

Mariani, F., Di Lernia, D., Venditti, I., Pelella, E., Muzzi, M., Di Giulio, A., Ceschin, S., 2023. Trophic transfer of microplastics from producer (*Lemna minuta*) to primary consumer (*Cataclysta lemnata*) in a freshwater food chain. Sci. Total Environ. 891, 164459. https://doi.org/10.1016/j.scitotenv.2023.164459.

Maruffi, L., Stucchi, L., Casale, F., Bocchiola, D., 2022. Soil erosion and sediment transport under climate change for Mera River, in Italian Alps of Valchiavenna. Sci. Total Environ. 806, 150651. https://doi.org/10.1016/J.SCITOTENV.2021.150651.

Meijer, L.J.J., van Emmerik, T., van der Ent, R., Schmidt, C., Lebreton, L., 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Sci. Adv. 7. https://doi.org/10.1126/sciadv.aaz5803.

Menéndez-Pedriza, A., Jaumot, J., 2020. Interaction of environmental pollutants with microplastics: a critical review of sorption factors, bioaccumulation and ecotoxicological effects. Toxics 8, 40. https://doi.org/10.3390/TOXICS8020040.

Messager, M.L., Lehner, B., Cockburn, C., Lamouroux, N., Pella, H., Snelder, T., Tockner, K., Trautmann, T., Watt, C., Datry, T., 2021. Global prevalence of non-perennial rivers and streams. Nature 594, 391–397. https://doi.org/10.1038/s41586-021-03565-5.

Moccia, D., Salvadori, L., Ferrari, S., Carucci, A., Pusceddu, A., 2020. Implementation of the EU ecological flow policy in Italy with a focus on Sardinia. Adv. Oceanogr. Limnol. 11, 22–34. https://doi.org/10.4081/aiol.2020.8781.

Montaldo, N., Sarigu, A., 2017. Potential links between the North Atlantic Oscillation and decreasing precipitation and runoff on a Mediterranean area. J. Hydrol. 553, 419–437. https://doi.org/10.1016/J.JHYDROL.2017.08.018.

Moore, C.J., Lattin, G.L., Zellers, A.F., 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. Revista de Gestão Costeira Integrada 11, 65–73. https://doi.org/10.5894/rgci194.

Morton, A., Harvey, F., Greenfield, P., 2023. Cop28 landmark deal agreed to 'transition away' from fossil fuels. Guardian ISSN 0261-3077. https://www.theguardian.com/environment/2023/dec/13/cop28-landmark-deal-agreed-to-transition-away-from-fossil-fuels. (Accessed 13 December 2023).

Moses, S.R., Löder, M.G.J., Herrmann, F., Laforsch, C., 2023. Seasonal variations of microplastic pollution in the German River Weser. Sci. Total Environ. 902, 166463. https://doi.org/10.1016/J.SCITOTENV.2023.166463.

Mulligan, M., van Soesbergen, A., Sáenz, L., 2020. GOODD, a global dataset of more than 38,000 georeferenced dams. Sci. Data 7, 1–8. https://doi.org/10.1038/s41597-020-0362-5.

Napper, I.E., Baroth, A., Barrett, A.C., Bhola, S., Chowdhury, G.W., Davies, B.F.R., Duncan, E.M., Kumar, S., Nelms, S.E., Hasan Niloy, M.N., Nishat, B., Maddalene, T., Thompson, R.C., Koldewey, H., 2021. The abundance and characteristics of microplastics in surface water in the transboundary Ganges River. Environ. Pollut. 274, 116348. https://doi.org/10.1016/J.ENVPOL.2020.116348.

Nava, V., Dar, J., De Santis, V., Fehlinger, L., Pasqualini, J., Adekolurejo, O.A., Burri, B., Cabrerizo, M.J., Chonova, T., Cour, M., Dory, F., Drost, M., Figler, A., Gionchetta, G., Halabowski, D., Harvey, D.R., Manzanares-Vázquez, V., Misteli, B., Mori-Bazzano, L., Moser, V., Rotta, F., Schmid-Paech, B., Touchet, C.M., Gostyńska, J., 2024. Zooming in the plastisphere: the ecological interface for phytoplankton–plastic interactions in aquatic ecosystems. Biol. Rev. https://doi.org/10.1111/brv.13164.

Nel, H.A., Dalu, T., Wasserman, R.J., 2018. Sinks and sources: assessing microplastic abundance in river sediment and deposit feeders in an Austral temperate urban river system. Sci. Total Environ. 612, 950–956. https://doi.org/10.1016/J.SCITOTENV.2017.08.298.

Nizzetto, L., Bussi, G., Futter, M.N., Butterfield, D., Whitehead, P.G., 2016. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. Environ. Sci.: Process. Impacts 18, 1050–1059. https://doi.org/10.1039/c6em00206d.

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.

Ockelford, A., Cundy, A., Ebdon, J.E., 2020. Storm response of fluvial sedimentary microplastics. Sci. Rep. 10, 1865. https://doi.org/10.1038/s41598-020-58765-2.

Opperman, J.J., Carvallo, J.P., Kelman, R., Schmitt, R.J.P., Almeida, R., Chapin, E., Flecker, A., Goichot, M., Grill, G., Harou, J.J., Hartmann, J., Higgins, J., Kammen, D., Martin, E., Martins, T., Newsock, A., Rogéliz, C., Raepple, J., Sada, R., Thieme, M.L., Harrison, D., 2023. Balancing renewable energy and river resources by moving from individual assessments of hydropower projects to energy system planning. Front. Environ. Sci. 10, 1036653. https://doi.org/10.3389/fenvs.2022.1036653.

Parker, B., Britton, J.R., Green, I.D., Jackson, M.C., Andreou, D., 2024. Microplastic-stressor responses are rarely synergistic in freshwater fishes: a meta-analysis. Sci. Total Environ. 174566. https://doi.org/10.1016/j.scitotenv.2024.174566.

Perry, D., Harrison, I., Fernandes, S., Burnham, S., Nichols, A., 2021. Global analysis of durable policies for free-flowing river protections. Sustainability 13 (4), 2347. https://doi.org/10.3390/su13042347.

Piano, E., Doretto, A., Falasco, E., Fenoglio, S., Gruppuso, L., Nizzoli, D., Viaroli, P., Bona, F., 2019. If Alpine streams run dry: the drought memory of benthic communities. Aquat. Sci. 81, 1–14. https://doi.org/10.1007/S00027-019-0629-0/FIGURES/6.

Provencher, J.F., Ammendolia, J., Rochman, C.M., Mallory, M.L., 2019. Assessing plastic debris in aquatic food webs: what we know and don't know about uptake and trophic transfer. Environ. Rev. 27 (3), 304–317. https://doi.org/10.1139/er-2018-0079.

Quadroni, S., Crosa, G., Gentili, G., Espa, P., 2017. Response of stream benthic macroinvertebrates to current water management in Alpine catchments massively developed for hydropower. Sci. Total Environ. 609, 484–496. https://doi.org/10.1016/J.SCITOTENV.2017.07.099.

Quadroni, S., Salmaso, F., Gentili, G., Crosa, G., Espa, P., 2021. Response of benthic macroinvertebrates to different hydropower off-stream diversion schemes. Ecohydrology 14, e2267. https://doi.org/10.1002/ECO.2267.

Rech, S., Macaya-Caquilpán, V., Pantoja, J.F., Rivadeneira, M.M., Jofre Madariaga, D., Thiel, M., 2014. Rivers as a source of marine litter – a study from the SE Pacific. Mar. Pollut. Bull. 82, 66–75. https://doi.org/10.1016/J.MARPOLBUL.2014.03.019.

Roebroek, C.T.J., Harrigan, S., Van Emmerik, T.H.M., Baugh, C., Eilander, D., Prudhomme, C., Pappenberger, F., 2021. Plastic in global rivers: are floods making it worse? Environ. Res. Lett. 16, 025003. https://doi.org/10.1088/1748-9326/ABD5DF.

Sabater, S., Freixa, A., Jiménez, L., López-Doval, J., Pace, G., Pascoal, C., Perujo, N., Craven, D., González-Trujillo, J.D., 2023. Extreme weather events threaten biodiversity and functions of river ecosystems: evidence from a meta-analysis. Biol. Rev. 98, 450–461. https://doi.org/10.1111/BRV.12914.

Salmaso, F., Crosa, G., Espa, P., Gentili, G., Quadroni, S., 2020. The year after an extraordinary sedimentation event in a regulated Alpine river: the impact on benthic macroinvertebrate communities. River Res. Appl. 36, 1656–1667. https://doi.org/10.1002/RRA.3664.

Salmaso, F., Crosa, G., Espa, P., Gentili, G., Quadroni, S., Zaccara, S., 2018. Benthic macroinvertebrates response to water management in a lowland river: effects of hydro-power vs irrigation off-stream diversions. Environ. Monit. Assess. 190, 1–12. https://doi.org/10.1007/S10661-017-6390-8/FIGURES/6.

Salmaso, F., Crosa, G., Espa, P., Quadroni, S., 2021. Climate change and water exploitation as co-impact sources on river benthic macroinvertebrates. Water 13, 2778. https://doi.org/10.3390/W13192778/S1.

Schell, T., Hurley, R., Nizzetto, L., Rico, A., Vighi, M., 2021. Spatio-temporal distribution of microplastics in a Mediterranean river catchment: the importance of wastewater as an environmental pathway. J. Hazard Mater. 420, 126481. https://doi.org/10.1016/J.JHAZMAT.2021.126481.

Scotti, A., Jacobsen, D., Ştefan, V., Tappeiner, U., Bottarin, R., 2022. Small hydropower—small ecological footprint? A multi-annual environmental impact analysis using aquatic macroinvertebrates as bioindicators. Part 1: effects on community structure. Front. Environ. Sci. 10, 902603. https://doi.org/10.3389/fenvs.2022.902603.

Setälä, O., Fleming-Lehtinen, V., Lehtiniemi, M., 2014. Ingestion and transfer of microplastics in the planktonic food web. Environ. Pollut. 185, 77–83. https://doi.org/10.1016/J.ENVPOL.2013.10.013.

Shang, X., Lu, J., Feng, C., Ying, Y., He, Y., Fang, S., Lin, Y., Dahlgren, R., Ju, J., 2020. Microplastic (1 and 5 μm) exposure disturbs lifespan and intestine function in the nematode Caenorhabditis elegans. Sci. Total Environ. 705, 135837. https://doi.org/10.1016/J.SCITOTENV.2019.135837.

Sharma, S., Sharma, V., Chatterjee, S., 2023. Contribution of plastic and microplastic to global climate change and their conjoining impacts on the environment - a review. Sci. Total Environ. 875, 162627. https://doi.org/10.1016/J.SCITOTENV.2023.162627.

Shen, J., Gu, X., Liu, R., Feng, H., Li, D., Liu, Y., Jiang, X., Qin, G., An, S., Li, N., Leng, X., 2023. Damming has changed the migration process of microplastics and increased the pollution risk in the reservoirs in the Shaying River Basin. J. Hazard Mater. 443, 130067. https://doi.org/10.1016/j.jhazmat.2022.130067.

Skoulikidis, N.T., Sabater, S., Datry, T., Morais, M.M., Buffagni, A., Dörflinger, G., Zogaris, S., del Mar Sánchez-Montoya, M., Bonada, N., Kalogianni, E., Rosado, J., Vardakas, L., De Girolamo, A.M., Tockner, K., 2017. Non-perennial Mediterranean rivers in Europe: status, pressures, and challenges for research and management. Sci. Total Environ. 577, 1–18. https://doi.org/10.1016/J.SCITOTENV.2016.10.147.

Song, J., Hou, C., Zhou, Y., Liu, Q., Wu, X., Wang, Y., Yi, Y., 2020. The flowing of microplastics was accelerated under the influence of artificial flood generated by hydropower station. J. Clean. Prod. 255, 120174. https://doi.org/10.1016/J.JCLEPRO.2020.120174.

Sridharan, S., Kumar, M., Saha, M., Kirkham, M.B., Singh, L., Bolan, N.S., 2022. The polymers and their additives in particulate plastics: what makes them hazardous to the fauna? Sci. Total Environ. 824, 153828. https://doi.org/10.1016/j.scitotenv.2022.153828.

Su, L., Cai, H., Kolandhasamy, P., Wu, C., Rochman, C.M., Shi, H., 2018. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. Environ. Pollut. 234, 347–355. https://doi.org/10.1016/J.ENVPOL.2017.11.075.

Sun, T., Wang, S., Ji, C., Li, F., Wu, H., 2022. Microplastics aggravate the bioaccumulation and toxicity of coexisting contaminants in aquatic organisms: a synergistic health hazard. J. Hazard Mater. 424, 127533. https://doi.org/10.1016/J.JHAZMAT.2021.127533.

Themba, N.N., Dondofema, F., Cuthbert, R.N., Munyai, L.F., Dalu, T., 2024. Abundance and distribution of microplastics in benthic sediments and Cladocera taxa in a subtropical Austral reservoir. Integr. Environ. Assess. Manag. https://doi.org/10.1002/ieam.4977.

Tong, X., Jong, M.C., Zhang, J., You, L., Gin, K.Y.H., 2021. Modelling the spatial and seasonal distribution, fate and transport of floating plastics in tropical coastal waters. J. Hazard Mater. 414, 125502. https://doi.org/10.1016/J.JHAZMAT.2021.125502.

Tumwesigye, E., Felicitas Nnadozie, C., C Akamagwuna, F., Siwe Noundou, X., William Nyakairu, G., Odume, O.N., 2023. Microplastics as vectors of chemical contaminants and biological agents in freshwater ecosystems: current knowledge status and future perspectives. Environ. Pollut. 330, 121829. https://doi.org/10.1016/J.ENVPOL.2023.121829.

van Emmerik, T., Kieu-Le, T.C., Loozen, M., Oeveren, K. van, Strady, E., Bui, X.T., Egger, M., Gasperi, J., Lebreton, L., Nguyen, P.D., Schwarz, A., Slat, B., Tassin, B., 2018. A methodology to characterize riverine macroplastic emission into the ocean. Front. Mar. Sci. 5, 409981. https://doi.org/10.3389/FMARS.2018.00372/BIBTEX.

van Emmerik, T., Schwarz, A., 2020. Plastic debris in rivers. WIRES Water 7, 1–24. https://doi.org/10.1002/wat2.1398.

van Emmerik, T., Strady, E., Kieu-Le, T.C., Nguyen, L., Gratiot, N., 2019. Seasonality of riverine macroplastic transport. Sci. Rep. 9 (1 9), 1–9. https://doi.org/10.1038/s41598-019-50096-1, 2019.

van Vliet, M.T.H., Thorslund, J., Strokal, M., Hofstra, N., Flörke, M., Ehalt Macedo, H., Nkwasa, A., Tang, T., Kaushal, S.S., Kumar, R., van Griensven, A., Bouwman, L., Mosley, L.M., 2023. Global river water quality under climate change and hydroclimatic extremes. Nat. Rev. Earth Environ. 4, 687–702. https://doi.org/10.1038/s43017-023-00472-3.

Vercauteren, M., Lambert, S., Hoogerwerf, E., Janssen, C.R., Asselman, J., 2024. Microplastic-specific biofilm growth determines the vertical transport of plastics in freshwater. Sci. Total Environ. 910, 168399. https://doi.org/10.1016/J.SCITOTENV.2023.168399.

Wagner, S., Klöckner, P., Stier, B., Römer, M., Seiwert, B., Reemtsma, T., Schmidt, C., 2019. Relationship between discharge and river plastic concentrations in a rural and an urban catchment. Environ. Sci. Technol. 53, 10082–10091. https://doi.org/10.1021/ACS.EST.9B03048/SUPPL_FILE/ES9B03048_SI_001.PDF.

Waldschläger, K., Brückner, M.Z.M., Carney Almroth, B., Hackney, C.R., Adyel, T.M., Alimi, O.S., Belontz, S.L., Cowger, W., Doyle, D., Gray, A., Kane, I., Kooi, M., Kramer, M., Lechthaler, S., Michie, L., Nordam, T., Pohl, F., Russell, C., Thit, A., Umar, W., Valero, D., Varrani, A., Warrier, A.K., Woodall, L.C., Wu, N., 2022. Learning from natural sediments to tackle microplastics challenges: a multidisciplinary perspective. Earth Sci. Rev. 228, 104021. https://doi.org/10.1016/j.earscirev.2022.104021.

Walker, T.R., McGuinty, E., Charlebois, S., Music, J., 2021. Single-use plastic packaging in the Canadian food industry: consumer behavior and perceptions. Humanit. Soc. Sci. Commun. 8, 80. https://doi.org/10.1057/s41599-021-00747-4.

Wang, C., Zhao, J., Xing, B., 2021. Environmental source, fate, and toxicity of microplastics. J. Hazard Mater. 407, 124357. https://doi.org/10.1016/J.JHAZMAT.2020.124357.

Wang, J., Lu, L., Wang, M., Jiang, T., Liu, X., Ru, S., 2019. Typhoons increase the abundance of microplastics in the marine environment and cultured organisms: a case study in Sanggou Bay. China. Sci. Total Environ. 667, 1–8. https://doi.org/10.1016/J.SCITOTENV.2019.02.367.

Watkins, L., McGrattan, S., Sullivan, P.J., Walter, M.T., 2019. The effect of dams on river transport of microplastic pollution. Sci. Total Environ. 664, 834–840. https://doi.org/10.1016/J.SCITOTENV.2019.02.028.

Windsor, F.M., Durance, I., Horton, A.A., Thompson, R.C., Tyler, C.R., Ormerod, S.J., 2019. A catchment-scale perspective of plastic pollution. Glob. Change Biol. 25, 1207–1221. https://doi.org/10.1111/gcb.14572.

Wohl, E., Bledsoe, B.P., Jacobson, R.B., Poff, N.L., Rathburn, S.L., Walters, D.M., Wilcox, A.C., 2015. The natural sediment regime in rivers: broadening the foundation for ecosystem management. Bioscience 65, 358–371. https://doi.org/10.1093/BIOSCI/BIV002.

Wong, G., Löwemark, L., Kunz, A., 2020. Microplastic pollution of the Tamsui River and its tributaries in northern Taiwan: spatial heterogeneity and correlation with precipitation. Environ. Pollut. 260, 113935. https://doi.org/10.1016/J.ENVPOL.2020.113935.

Woodward, J., Li, J., Rothwell, J., Hurley, R., 2021. Acute riverine microplastic contamination due to avoidable releases of untreated wastewater. Nat. Sustain. 4, 793–802. https://doi.org/10.1038/s41893-021-00718-2.

WWF Italia, 2022. Fiumi, la minaccia arriva da insetticidi e plastica. https://www.wwf.it/cosa-facciamo/pubblicazioni/fiumi-la-minaccia-arriva-da-insetticidi-e-plastica/, 1.4.24.

Yang, L., Luo, W., Zhao, P., Zhang, Y., Kang, S., Giesy, J.P., Zhang, F., 2021. Microplastics in the Koshi River, a remote alpine river crossing the Himalayas from China to Nepal. Environ. Pollut. 290, 118121. https://doi.org/10.1016/J.ENVPOL.2021.118121.

Yonkos, L.T., Friedel, E.A., Perez-Reyes, A.C., Ghosal, S., Arthur, C.D., 2014. Microplastics in four estuarine rivers in the chesapeake bay. U.S.A. Environ. Sci. Technol. 48, 14195–14202. https://doi.org/10.1021/ES5036317/SUPPL_FILE/ES5036317_SI_001.PDF.

Zarfl, C., Lumsdon, A.E., Berlekamp, J., Tydecks, L., Tockner, K., 2015. A global boom in hydropower dam construction. Aquat. Sci. 77, 161–170. https://doi.org/10.1007/S00027-014-0377-0/FIGURES/4.

Zhang, K., Chen, X., Xiong, X., Ruan, Y., Zhou, H., Wu, C., Lam, P.K.S., 2019. The hydro-fluctuation belt of the Three Gorges Reservoir: source or sink of microplastics in the water? Environ. Pollut. 248, 279–285. https://doi.org/10.1016/J.ENVPOL.2019.02.043.

Zhang, K., Gong, W., Lv, J., Xiong, X., Wu, C., 2015. Accumulation of floating microplastics behind the three Gorges dam. Environ. Pollut. 204, 117–123. https://doi.org/10.1016/J.ENVPOL.2015.04.023.

Zhang, K., Xiong, X., Hu, H., Wu, C., Bi, Y., Wu, Y., Zhou, B., Lam, P.K.S., Liu, J., 2017. Occurrence and characteristics of microplastic pollution in xiangxi bay of three Gorges reservoir, China. Environ. Sci. Technol. 51, 3794–3801. https://doi.org/10.1021/acs.est.7b00369.

Zhang, Y., Jiang, H., Bian, K., Wang, H., Wang, C., 2021a. A critical review of control and removal strategies for microplastics from aquatic environments. J. Environ. Chem. Eng. 9, 105463. https://doi.org/10.1016/j.jece.2021.105463.

Zhang, Y., Jiang, H., Bian, K., Wang, H., Wang, C., 2021b. Is froth flotation a potential scheme for microplastics removal? Analysis on flotation kinetics and surface characteristics. Sci. Tot. Environ. 792, 148345. https://doi.org/10.1016/j.scitotenv.2021.148345.

Ziajahromi, S., Kumar, A., Neale, P.A., Leusch, F.D.L., 2018. Environmentally relevant concentrations of polyethylene microplastics negatively impact the survival, growth and emergence of sediment-dwelling invertebrates. Environ. Pollut. 236, 425–431. https://doi.org/10.1016/J.ENVPOL.2018.01.094.

Zscheischler, J., Westra, S., Van Den Hurk, B.J.J.M., Seneviratne, S.I., Ward, P.J., Pitman, A., Aghakouchak, A., Bresch, D.N., Leonard, M., Wahl, T., Zhang, X., 2018. Future climate risk from compound events. Nat. Clim. Change 8, 469–477. https://doi.org/10.1038/s41558-018-0156-3.