Microplastics in Inland Small Waterbodies

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Abstract Small waterbodies are the most numerous and widespread freshwater environments, and they play important roles in supporting freshwater biodiversity and ecosystem service delivery. There has been a considerable increase on research of environmental pollutants in small waterbodies, but only a few works have focused on microplastic (MP) occurrence and effects. MP pollution has been well documented in large freshwaters. Meanwhile, small waterbodies are also the receiving waters of MPs through stormwater runoff, atmospheric deposition, etc. In this chapter, we first introduce the definitions and characteristics of a range of small waterbodies and their ongoing threats. Next, we overview the distributions and

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characteristics of MPs in small waterbodies worldwide and offer some insights into their sources. Furthermore, we give a brief discussion about interactions of MPs with freshwater biota and describe the toxicity effects of MPs on amphibians in detail. Lastly, we demonstrate the current awareness of people about small waterbodies and provide potential approaches to minimize their MP pollution. Overall, high abundances of MPs are observed in water and sediment collected from various types of small waterbodies, and MPs pose a significant threat to the resident organisms and human health. Yet, less detailed information is available on small waterbodies' MPs at present. Therefore, we appeal more researchers and policy-makers to focus on the protection and management of small waterbodies.

Keywords Characteristics, Management, Microplastics, Risks, Small waterbodies

1 Introduction

1.1 Characteristics of Small Waterbodies

As an important part of the freshwater system, small waterbodies are the most numerous freshwater environments in the world and can be seen everywhere. Up to now, however, small waterbodies have no specific definition; they usually encompass ponds, small lakes, small rivers, streams, ditches, and springs [1, 2]. In general, small standing waters are defined according to the area of watershed. For example, small lakes vary in size from 1–5 ha to around 50–100 ha in area (but the Water Framework Directive (WFD) limit 50 ha) [1, 3], and the area of ponds ranges from 1 m^2 to about 2–5 ha [1, 4, 5]. At one extreme, the tiny puddle which forms after rain is classified into pond [1]. Small running waters such as small streams and small rivers are relatively harder to define, and the term small stream is often used interchangeably with the term headwater. Furse et al. [6] define the length of stream within 2.5 km from the source as headwater streams, while small linear headwaters are those with catchments less than 10 km^2 in the WFD terms [3]. In addition, other small waterbodies are distinguished mainly depending on their functions or hydrological characteristics. Ditches are man-made channels build primarily for agricultural or street drainage; normally the width of ditches is 1–3 m [7]. Spring is a strictly delimited place where the groundwater appears at the surface [8]. Furthermore, small waterbodies are naturally created or man-made and permanent or seasonal.

Small waterbodies are not only various but also numerous. The river network in Europe is more than five million kilometers long; more than 80% consist of small rivers, commonly known as headwaters, streams, creeks, or small rivers [9]. In addition, there are around 5–10 million small lakes and ponds in Europe and about 17 million ponds up to 1 ha in the United States, but the latter data omits the waters less than 1,000 m^2 [10]. However, half to two-thirds of all waterbodies are in the range 25–400 m^2 in some area (e.g., southeast Great Plains in the United States) [11]. Accordingly, the current global number of small waterbodies may be underestimated because of omitting those smaller ones [11]. For instance, there are approximately 32,000 and 120,000 ponds ranging from 100 m^2 to 5 ha in area in Switzerland and Denmark, respectively [12, 13]. Furthermore, ditches constructed for agriculture are likewise widespread. In England, ditch length is about 600,000 km and in Netherlands 300,000 km [7, 14, 15]. Overall, inland small waterbodies are globally abundant freshwater habitats.

Compared to the large waterbodies, small waterbodies, especially ponds and small lakes, are areas of high biodiversity [1]. Despite small waterbodies only occupy 2% of Earth's surface area, their species richness is nearly equal to marine environments [16]. Support for this idea comes from several studies which have surprisingly found that the ponds sustain a larger proportion of freshwater species than lakes or rivers [3, 17, 18]. In addition to the common freshwater species such as macrophytes and micro- and macroinvertebrates, there are specific species such as that of frogs and toads in small waterbodies [19, 20]. It has been suggested that the patchy and comparatively isolated nature of small waterbodies may be a reason of higher speciation rates [1]. Moreover, the dominant number, physicochemical heterogeneity, and low contamination rate of small waters may be another possible explanation of their high species richness [1, 18, 21].

With the increasing concern about small waterbodies, their ecosystem services are gradually recognized by researchers and policy-makers [1, 22]. Indeed, there are three main categories of ecosystem services: (1) provision, (2) regulation and maintenance, and (3) cultural support and entertainment [1]. For example, natural and man-made stormwater ponds provide a wide range of functions, including flood control, water supply, elimination of nutrients and pollutants, enjoyment and recreation, etc. [23]. Clearly, ditches constructed near the farmlands are mainly used for land drainage and irrigation [24]. The ecosystem services of small waterbodies have been highlighted within the literature [1, 2, 5].

1.2 Environmental Pollution in Inland Small Waterbodies

Because of their patches, small volumes, and catchments, small waterbodies are much more likely to fall entirely within unpolluted areas and to be less exposed to pollutants. Once they form in regions of frequent human activities such as development and intensive agriculture, however, they are easily contaminated by a variety of pollutants [1, 2]. Because small waterbodies have a considerably small water volume, there is less potential for dilution of contaminants. Therefore, they are exceptionally vulnerable to input of even small amounts of pollutants from their surroundings [25, 26].

Lots of studies show that small waterbodies are threatened by a range of pollutants due to the acceleration of urbanization and agriculture [25, 27, 28]. A typical problem of inland small waterbodies, particularly static waters, is "eutrophication" [18, 29–31]. Forty years ago, many researchers have started to study the causes and mechanisms underlying the process of eutrophication. To date, nutrient inputs such as nitrogen and phosphorus to inland waters are considered as the main causes of eutrophication [18, 29–31]. Dodds et al. [32] analyze the total nitrogen (TN) and phosphorus (TP) concentrations of rivers, streams, and lakes in the US Environmental Protection Agency (EPA) nutrient ecoregions and find median TN and TP values in the range of 0.248–3.372 mg L^{-1} and 0.012–0.184 mg L^{-1}, respectively, much higher than the reference median values. Likewise, the freshwater eutrophication is serious in developing countries. More than 80% of urban rivers are contaminated in China [33–35]. For instance, ammonium nitrogen concentrations of water collected from the black-odor rivers in Wenzhou are 1.17–18.51 mg L^{-1}, and TP concentrations range from 0.42 to 3.0 mg L^{-1} [33]. These values have shown us a high nutrient concentration in freshwater systems.

In addition to nutrients, heavy metals, organic matter, pesticides, and plastics also cause inland small waterbodies to suffer from toxic pollutions [34, 36, 37]. These pollutants may enter and accumulate in small waterbodies via rainfall runoff, atmospheric deposition, mismanagement, etc. For example, stormwater ponds used extensively in stormwater management receive a variety of pollutants from rainfall runoff [27]. Weinstein et al. [37] demonstrate that polycyclic aromatic hydrocarbons (PAHs) are pervasive in the sediments of 19 stormwater ponds located in coastal South Carolina, and the high PAH levels in 5 stormwater ponds suggest that there are moderate to high risks to organisms and humans. Moreover, due to extensive application of pesticides, streams and ditches near farmlands are commonly exposed to pesticides via spray drift, edge-of-field runoff, or drainage [36]. Nearly half of European waters are at risk from pesticides [38], and 26% of 2,369 sampling sites of small streams in Germany are found to have considerable exceedances of regulatory acceptable concentrations (RAC) [36].

With increasing plastic production and usage year by year, plastic trash becomes "huge" and "ubiquitous". Plastic pollution and risks have been gradually realized by the general public and reported by media [39]. Plastic litter entering the aquatic environment degrades to millions of smaller pieces [40–42], namely, MPs, which negatively impact waterbody ecosystems. Although MP pollution has been well documented in marine and large freshwater system, studies in small waterbodies are limited [28] (Fig. 1). So far, only a few papers have reported MP pollution in small waterbodies. Indeed, MPs can enter small waterbodies through sewage effluent and road runoff as well. Therefore, in this chapter, we will specifically introduce characteristics, risks, and management of MP pollution in inland small waterbodies.

Fig. 1 Plastic litter in a pond located in Hangzhou, China

2 Characteristics of Microplastics in Small Waterbodies

2.1 Sources of Microplastics in Small Waterbodies

Nowadays, activities involving plastics encompass packaging, textile, transportation, agriculture, electronics, and buildings and constructions, nearly covering all fields [43]. Human activities are considered as one of the major factors of MP pollution in freshwater environments [44, 45]. Particularly, plastic production, usage, and discard increase with the growing of population density, such as in Shanghai and Paris, both megacities [46, 47]. For example, Yonkos et al. [48] investigate MP contaminations in four estuarine rivers in Chesapeake Bay, USA, and find that the concentration of MPs is positively correlated with population density and proportion of urban/suburban development within the watersheds.

Illegal trash disposal and poor management may result in the increase of plastic trash from household and agricultural plastics in terrestrial environments, especially in developing countries. These plastic trashes enter small waterbodies directly or via wind transport, surface runoff, or agricultural fertilizers and then degrade into MPs, indicating a potential source of pollution for small waterbodies. For instance, lakes in tourism areas and ponds near residential areas or in parks are the recipient waters of plastic trash and MPs [28]. Another potential input of MPs to the pollution of small waterbodies may be the discharge of sewage comprising fibers from laundry wastewater [49] and microbeads from personal care products [50]. The effluent overflows into small waterbodies during storm events due to the limited treatment capacity of wastewater treatment plants (WWTPs) [51]. Some rivers in old cities are even the direct receiving waters of effluent from residential areas and factories. People still wash their garments directly in small waterbodies in some underdeveloped areas. In recent years, atmospheric fallout has been realized as a possible source of MPs, especially microfibers [46].

2.2 Occurrence of Microplastics

Up to now, to our knowledge, there are only a few papers about MP pollution in small waterbodies (Table 1). The average MP abundance in water and sediment samples varies greatly. This difference results from some key factors such as sampling sites and methods, human activities, and features of small waterbody [60].

Among these researches, MP abundance is the lowest (0.014 ± 0.009 items L^{-1}) in water collected from fish ponds and rivers of the European Carpathian Basin [54]. The different sampling methods might explain the low concentrations of MPs. In this study, the authors use a mobile sampling system which only retains MPs between 0.1 and 2 mm in size, resulting in the loss of larger and smaller MPs [54]. Similarly, Dikareva and Simon [58] collect plastics using a phytoplankton net (63 μm mesh) and find that MP abundance is in the range of 0.02–0.3 items L^{-1} in streams in Auckland, New Zealand. However, a bulk sampling approach is used in most of other studies. Generally, water is filtered through a mesh filter in small size (e.g., 10 or 20 μm), and MPs larger than this size are supposed to be collected [28, 52, 57]. Hu et al. [28] investigate MP occurrence in the waters of six types of small waterbodies in East China and find MP concentration in the puddles up to 15.7 ± 4.6 items L^{-1}. Usually, a puddle is a downfold that has a considerably small total water volume. The rainfall runoff with MPs enters the puddles, leading to a higher MP pollution. Of course, the MP abundances are also high as well in other types of small waterbodies in the same survey area [28]. The authors suggest that the high accumulation of MPs is related to the higher population density and more anthropogenic activity [28]. For example, Shanghai is currently the most populated city in China. Shanghai has a population of 24.2 million, a primary plastic product of 3807.3 thousand tones, and a chemical fiber product of 430.0 thousand tones [61]. Furthermore, most of the sampling sites of East China locate near residential areas and textile processing plants. Surprisingly, the highest MP concentration (270 items L^{-1}) is detected in a stormwater pond in Viborg, Denmark [57]. Possible explanations for the high MP abundance are that the stormwater retention time of the stormwater pond is about 10 days and its drainage area includes production industries, retailers, building supply stores, parking lots, as well as roads.

Similarly, the trend of MP abundance in sediment is consistent with that in water (Table 1). The lowest abundance of MPs in sediment is detected in European fish ponds and rivers (0.8 ± 0.4 items kg^{-1}) [54], and the highest MP density is determined in a stormwater pond in Viborg, Denmark (9.5×10^5 items kg^{-1}) [57]. These indicate that the functions of small waterbodies probably influence their MP abundances. Stormwater retention ponds are versatile in terms of MP

Table 1 Microplastic pollution in small waterbodies worldwide

Location	Abundance	Shape	Size	Polymer type	Reference
Water	Items, L^{-1}				
Creeks in Shanghai, China	0.44–4.13	88% fiber, 7% fragment, 4% film, 1% pellet	Majority: 0.1–1 mm	PES, rayon, PP	[52]
Ponds in East China	4.3 ± 7.0	88% fiber	Majority: <0.5 mm	79% PES, 7% PP	[28]
Ditches in East China	7.6 ± 7.0				
Puddles in East China	15.7 ± 4.6				
Riceland in East China	4.7 ± 3.2				
River in East China	9.0				
Lake in East China	12.5				
Riceland in Shanghai, China	0–0.7 ± 0.3	Dominant: film and fiber	Majority: 0.1–1 mm	68% PP, 32% PE	[53]
Fish ponds and rivers in the Carpathian basin, Europe	0.014 ± 0.009	–	Range: 0.1–2 mm	PP, PE, PES, PS	[54]
Stormwater ponds in Durham, USA	0.8 ± 1.0–1.7 ± 1.2	Dominant: fiber	Majority: <0.5 mm	35% PES, 30% PP	[55]
Stormwater ponds in Denmark	0.49–22.9	–	<1.03 mm	72% PP, 9% PE, 7%PVC	[56]
A stormwater pond in Viborg, Denmark	270	–	0.01–0.5 mm	PES, PP, acrylic, PA, PE, PS	[57]
Streams in Auckland, New Zealand	0.02–0.3	39% fragment, 34% fiber	Majority: <0.5 mm	PE, PP	[58]
Sediment	Items, kg^{-1}				
Urban river in Shanghai, China	802 ± 594	89% pellet, 8% fiber, 3% fragment	Majority: 0.1–0.5 mm	57% PP, 17% PES, 11% rayon	[47]
Edgbaston Pool in central Birmingham, UK	250–300 (maximum)	Dominant: fiber and film	–	–	[59]
Ponds in East China	693.9 ± 1005.0	55% fragments, 43% fibers	Majority: <0.5 mm	76% PP, 11% PE, 9.1% PES	[28]
Ditches in East China	583.5 ± 961.7				
Puddles in East China	609.8 ± 70.5				
Riceland in East China	607.9 ± 344.8				
Lake in East China	148.6				
Riceland in Shanghai, China	1.7 ± 0.9–41.3 ± 15.3	Dominant: fiber	Majority: 0.1–1 mm	61% PE, 35% PP, 4% PVC	[53]
Stormwater ponds in Durham, USA	97.5 ± 85.1–274.8 ± 193.5	Dominant: fragment	Majority: <0.5 mm	61% PP, 16% PE, 14%PS	[55]
Fish ponds and rivers in the Carpathian basin, Europe	0.8 ± 0.4	–		PP, PE, PES, PS	[54]
A stormwater pond in Viborg, Denmark	9.5×10^5	–	0.01–0.5 mm	PP, PE, PES, PS, acrylic, PA	[57]
Streams in Auckland, New Zealand	9–80	79% fragment, 20% fiber	Majority: <0.5 mm	PE, PP	[58]

PA polyamide, *PE* polyethylene, *PES* polyester, *PP* polypropylene, *PS* polystyrene, *PVC* polyvinylchloride input pathways, and it is likely that they are important sinks for MPs. In addition, MP abundances in sediment samples collected from other types of small waterbodies are approximately hundreds per kilogram (Table 1). To sum up, MPs are abundant in small waterbodies, and such waterbodies play a role in receiving diffuse MP pollution from urban and highway areas.

2.3 Shape and Size of Microplastics

The literature in Table 1 demonstrates that MPs in small waterbodies are commonly categorized into four types according to their shapes: fiber (elongated), fragments (small irregular pieces), film (thin flat), and granule/pellet (spherical and ovoid pieces). Fibers are dominant in water. For instance, Luo et al. [52] and Hu et al. [28] find fibers to be the most abundant, accounting for 88% of the total MPs. Compared with MPs in water, the shape distribution of MPs in sediment significantly varies. Pellets are predominant in samples from urban river in Shanghai [47], fibers are prevalent in riceland [53] and Edgbaston Pool [59], while fragments are more abundant in small waterbodies in East China, United States, and New Zealand [28, 55, 58]. The morphological characteristics of MPs can be used to indicate their potential sources. For example, the pellets in urban river possibly originate from personal care products, and the potential sources of fragments in stormwater ponds are stormwater runoff containing road plastic debris.

Small size (<5 mm) is another key parameter of MPs involving their bioavailability [62]. Various sampling methods and size classifications are used in fieldworks, which make it difficult to compare data from different studies. Therefore, in this review, our concern is the main size of MPs in small waterbodies. Results show that 0.1–1 mm MPs are most abundant in small waterbodies (Table 1). On one hand, <0.1 mm MPs are hard to observe under microscopes. On the other hand, MP abundance generally increases with the decreasing of their sizes [28, 63]. Thus, these may be the reason that 0.1–1 mm MPs are dominant in these studies.

2.4 Polymer Types of Microplastics

Plastics are made from a wide range of polymers. The polymer types affect MP density, longevity, and performance and indicate their probable origins [43]. In the studies (Table 1), MPs in water and sediment samples are randomly selected to identify their polymer types using Fourier Transform Infrared spectroscopy (FT-IR). Overall, polypropylene (PP), polyester (PES), and polyethylene (PE) are the most common polymers in small waterbodies (Table 1). A larger global demand for these three types of polymer makes them more widespread in the environment [64]. Specifically, PES and PP are the dominant polymers found in water, while PP and PE are the most abundant polymers in sediment, which is consistent with the results from studies of large freshwater environments [65, 66].

3 Occurrence of Microplastics in Freshwater Biota from Small Waterbodies

Organisms in the aquatic environment are believed to be impacted by MP ingestion [62]. Based on the above data, MP contamination is pervasive in small waterbodies of high biodiversity. Therefore, exploring MP pollution in freshwater biota in small waterbodies is necessary. Here we summarize the related researches in Table 2. Six papers investigate the uptake of MPs by fish. Results show that MPs have a relatively low detection rate and concentration, except for a high concentration of MPs (3.3 ± 0.5 items individual^{-1}) in eels [53], and a fuzzy data by Olesen et al. [57] indicate that the average MP abundance in three-spined sticklebacks and young newts is 65 items individual^{-1} (340 items g^{-1}). In the study by Lv et al. [53], MPs found in crayfish (2.5 ± 0.6 items individual^{-1}) and loach (1.8 ± 0.5 items individual^{-1}) are likewise high. Additionally, MP contaminations are widely found in different species of tadpoles, especially *Rana limnochari* and *Microhyla ornata*, with great abundance expressed in terms of weight [28].

The difference of MPs in organisms may result from MP contamination of habitats and organismal feeding strategies [28, 70, 71]. For example, Setälä et al. [71] expose a range of animals (bivalves, free-swimming crustaceans and benthic, deposit-feeding animals) to microbeads with different concentrations (5, 50, and 250 beads mL^{-1}). Results show that the amount of microbeads in animals is concentration dependent and free-swimming crustaceans ingest more microbeads compared with benthic animals. In addition, Mizraji et al. [70] observe that herbivorous or carnivorous fish have a lower MP concentration than omnivorous ones, which have a wider range of food sources. On the other hand, the number of MPs ingested by organisms is related to the MP bioavailability as well [72], just as some invertebrate species with a wide feeding size range have been demonstrated to selectively forage on specific sizes when expose to multiple size particles.

Fibers <1 mm are the most abundant MP type in most of organisms in small waterbodies (Table 2). Furthermore, PES and rayon are the prevalent polymers, with exception of the study by Lv et al. [53]. The authors identify that PE dominate in organisms; this result is similar to that found in sediment samples. The authors deduce that the ingestion of MPs in eels, crayfish, and loach might be related to their habits. These three animals are considered as typical benthic organisms, which commonly forage and live in the bottom. Conversely, Hu et al. [28] find that the shape and polymer distributions of MPs ingested by tadpoles are most similar to that found in water, mainly resulting from tadpoles ingesting MPs when they swim through the water column.

Table 2 Microplastic pollution in organisms from small waterbodies

Species	Location	Abundance		Shape	Size	Polymer type	Reference
		Items individual^{-1}	Items g^{-1}				
Fish							
Freshwater fish	Streams within Texas, USA	Occurred in 8.2% fish		Filament, fragment, film	–	–	[67]
Eel	Riceland in Shanghai, China	3.3 ± 0.5	–	Dominant: fiber	Majority: 0.1–1 mm	91% PE, 9% PP	[53]
Gambusia affinis	Urban rivers in Shanghai, China	0.4–1.1	0.6–6.1	58% fragment, 41.5% fiber, 0.5% pellet	Majority: 0.02–1 mm	PES, rayon	[68]
Gambusia affinis	Small waterbodies in East China	0–0.2 ± 0.1	0–1.9 ± 1.0	–	–	–	[55]
Gambusia holbrooki	Australian urban wetlands	0.18–1.13	0.52–4.4	Dominant: fiber	Majority: <1 mm	25.7% PES, 10.1% rayon, 7.3% PA, 5.5% PP	[69]
Gasterosteus aculeatus	Stormwater ponds in Viborg, Denmark	65 (average)	340 (average)	Dominant: fragment	0.01–0.5 mm	PES, PP, PA, PE	[57]
Newts							
Tadpole							
Rana limnochari	Small waterbodies in East China	0–2.7 ± 0.8	0–168.5 ± 52.0	82.9% fiber, 24.3% fragment	Majority: <0.5 mm	71.5% PES, 9.6% PP	[28]
Bufo gargarizans		0.2–1.9	2.4–56.9				
Microhyla ornata		0.5–2.6	35.2–157.9				
Pelophylax nigromaculatus		1.3–1.8	3.0–4.5				
Crayfish	Riceland in Shanghai, China	2.5 ± 0.6	–	Dominant: fiber	Majority: 0.1–1 mm	91% PE, 9% PP	[53]
Loach		1.8 ± 0.5	–				

PA polyamide, *PE* polyethylene, *PP* polypropylene, *PES* polyester

Small waterbodies provide habitats for a variety of organisms and are areas of high biodiversity. Once they are polluted, their resident organisms will be affected by the pollutants. Here, we demonstrate that MPs are ingested by animals in small waterbodies such as amphibians which could transport MPs from aquatic to terrestrial food webs. However, the study area and species are limited. Hence, in the future, more surveys will need to be carried out in order to widely investigate MP contamination in the creatures of small waterbodies.

4 Effects of Microplastics on Freshwater Biota

Field studies have proved that MPs are widely detected in aquatic ecosystems, which increases the attention to adverse impacts on freshwater ecosystems. Scherer et al. [72] have summarized laboratory studies about the interactions of MPs with freshwater biota. They discuss biotic and abiotic factors affecting MP ingestion. Biotic factors focus on the feeding type of invertebrates and vertebrates, particularly invertebrates (e.g., flagellate, rotifers, cladocerans, blackworm, bivalves, etc.). Abiotic factors include microparticle size, shape, and taste, which affect the bioavailability of MPs. Next, the effects of MPs on freshwater organisms have been summed up by Scherer et al. [72]. A variety of physical impacts induced by MPs to algae, *Daphnia magna*, bivalves, gastropods, and fish include blockages, reduced dietary intake, and internal injuries [62]. In addition, MPs can act as carriers of chemicals and microorganisms, aggravating the adverse effects of MPs to the organisms [73–75].

Amphibians are typical animals living in small waterbodies. At present, a field work completed by Hu et al. [28] has confirmed that tadpoles can ingest MPs from their living environment. However, limited information regarding MP ingestion and its effects on amphibians is available in the laboratory. Currently, thereby, we mainly described the ingestion and effects of MPs on amphibians.

As representatives of amphibians, *Xenopus laevis/tropicalis* are always used as model organisms in the world. The tadpoles of *Xenopus laevis/tropicalis* are filter feeders which are supposed to be especially prone to MP ingestion because of their extensive feeding activities [76, 77]. Multiple studies have shown that MPs ingested by *Xenopus* tadpoles accumulated in the gills, alimentary canal, stomach, and gut, and nano-plastics are also detected in the blood, cytoplasm, nucleus, and periphery of digestive gut cells [77–80]. Moreover, micro- and nano-plastics are potential threats for the growth and development of *Xenopus* larvae. The embryos of *Xenopus laevis* exposed to 50 nm polystyrene nanoparticles display numerous malformations including disorders in pigmentation distribution; anomalies of the head, eyes, intestine, and tail; edema in ventral anterior zone; and a stunted body [79]. Additionally, embryo mortality rate exhibits a dose-dependent relationship with MP exposure [79]. However, De Felice et al. [78] expose *Xenopus* tadpoles to polystyrene MPs (2.75 ± 0.09 μm of diameter) at different concentrations (1×10^5–8.7×10^5 particles mL^{-1}) and find that neither body growth nor swimming activity of tadpoles are affected. These differences among the researches may be induced by organismal development stage, exposure time, MP concentration, etc. Thus, further studies will need to be performed in order to fully explore MP toxic effects and risks on amphibians.

5 Management of Small Waterbodies

To sum up, small waterbodies are a critical but vulnerable part of freshwater ecosystems. Their functions are of equal importance to the larger waters, but they are more susceptible to many human activities (e.g., development and intensive agriculture, pollutant discharge) and climate change [1]. Despite this, nevertheless, small waterbodies are still the least studied part of the freshwater environment and are largely excluded from freshwater management planning, even rarely recognized by people in developing countries. In recent years, more and more countries and organizations recognize the importance of small waterbodies and pay attention to their pollution and management [1–3, 9]. For example, in 2013, a workshop organized by the European Environmental Bureau (EEB) took place in Brussels to discuss possible ways to better protect and manage small waterbodies. In 2015, a special session on “Small waterbodies – knowledge base, importance, threats, and future research priorities” was carried out at the 9th Symposium for European Freshwater Sciences (SEFS) in Geneva. This session emphasized the importance of small waterbodies and aimed to refocus research attention on these resources.

Nowadays, there is a broad consensus that small waterbodies are reservoirs of biodiversity and significantly contribute to catchment diversity and that they should be integrated into the existing legislative framework to get better protection and management [1, 2]. While there are lots of gaps in our knowledge of small waterbodies, compared to larger waterbodies. Therefore, first and foremost, more scholars should be appealed to conduct relevant researches about small waterbodies, and to reduce the gaps in knowledge. In addition, sufficient research and activity funds should be provided for environmental action. Because small waterbodies are globally abundant, this may signify a significant financial and administrative burden if they are included in the legislative framework process more extensively.

Since it is very hard to remove MPs from the environment, plastic source control and management may be an excellent way to reduce MP pollution in small waterbodies [81]. Firstly, we should take measures to reduce the use of plastics such as the ban of microbeads in personal care products, increasing the production and use of cotton clothing, replacing non-biodegradable plastics with biodegradable ones, etc. [50, 82]. Secondly, comprehensive implementation of garbage classification conduces to waste management and the mitigation of MP diffuse pollution from rainfall runoff and agricultural fertilizers [83, 84]. Finally, we should enhance the ability of wastewater treatment plants to remove MPs and avoid the release of untreated effluent directly into the receiving waters [51, 85, 86]. MP contamination in small waterbodies should be reduced through the above measures applied.

In conclusion, small waterbodies are the most numerous freshwater environments worldwide and are under all the threats affecting larger waters, but they are largely excluded from water management planning. This section introduces small waterbodies and reports their MP distribution, characteristics, and toxic effects. It suggests that MPs are prevalent in water, sediment, and resident animals, especially in the form of <1 mm fibers, probably due to human activities nearby. In addition, we discuss the potential adverse effects caused by MP exposures to resident animals, particularly amphibians. Corresponding high abundances and potential adverse effects of MPs strongly suggest the need for increasing attention and researches, reducing inputs of plastic waste, and supporting protection and effective management of small waterbodies.

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References

1. Biggs J, von Fumetti S, Kelly-Quinn M (2017) The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. Hydrobiologia 793 (1):3–39. https://doi.org/10.1007/s10750-016-3007-0
2. Riley WD, Potter ECE, Biggs J, Collins AL, Jarvie HP, Jones JI, Kelly-Quinn M, Ormerod SJ, Sear DA, Wilby RL, Broadmeadow S, Brown CD, Chanin P, Copp GH, Cowx IG, Grogan A, Hornby DD, Huggett D, Kelly MG, Naura M, Newman JR, Siriwardena GM (2018) Small water bodies in Great Britain and Ireland: ecosystem function, human-generated degradation, and options for restorative action. Sci Total Environ 645:1598–1616. https://doi.org/10.1016/j.scitotenv.2018.07.243
3. Biggs J, Nicolet P, Mlinaric M, Lalanne T (2014) Report of the workshop on the protection and management of Small Water Bodies. Brussels, 14th November 2013: The European Environmental Bureau (EEB) and the Freshwater Habitats Trust
4. Collinson NH, Biggs J, Corfield A, Hodson MJ, Walker D, Whitfield M, Williams PJ (1995) Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. Biol Conserv 74(2):125–133
5. Cereghino R, Biggs J, Oertli B, Declerck S (2008) The ecology of European ponds: defining the characteristics of a neglected freshwater habitat. Hydrobiologia 597(1):1–6. https://doi.org/10.1007/s10750-007-9225-8
6. Furse MT, Grieve NJ, Gunn RJM, Symes KL, Winder JM, Blackburn JH (1993) The faunal richness of headwater streams. Stage 2 – Catchment Studies, National Rivers Authority R&D Note 221. National Rivers Authority, Bristol
7. Brown CD, Turner N, Hollis J, Bellamy P, Biggs J, Williams P, Arnold D, Pepper T, Maund S (2006) Morphological and physico-chemical properties of British aquatic habitats potentially exposed to pesticides. Agric Ecosyst Environ 113(1–4):307–319. https://doi.org/10.1016/j.agee.2005.10.015
8. Cantonati M, Gerecke R, Bertuzzi E (2006) Springs of the Alps – sensitive ecosystems to environmental change: from biodiversity assessments to long-term studies. Hydrobiologia 562 (1):59–96. https://doi.org/10.1007/s10750-005-1806-9
9. Kristensen P, Globevnik L (2014) European small water bodies. Biol Environ Proc Roy Ir Acad 114B(3):281. https://doi.org/10.3318/bioe.2014.13

10. McDonald CP, Rover JA, Stets EG, Striegl RG (2012) The regional abundance and size distribution of lakes and reservoirs in the United States and implications for estimates of global lake extent. Limnol Oceanogr 57(2):597–606. https://doi.org/10.4319/lo.2012.57.2.0597
11. Chumchal MM, Drenner RW, Adams KJ (2016) Abundance and size distribution of permanent and temporary farm ponds in the southeastern Great Plains. Inland Waters 6(2):258–264. https://doi.org/10.5268/Iw-6.2.954
12. Oertli B, Auderset Joye D, Castella E, Juge R, Lehmann A, Lachavanne J-B (2005) PLOCH: a standardized method for sampling and assessing the biodiversity in ponds. Aquat Conserv Mar Freshwat Ecosyst 15(6):665–679. https://doi.org/10.1002/aqc.744
13. Søndergaard M, Jeppesen E, Jensen JP (2005) Pond or lake: does it make any difference? Arch Hydrobiol 162(2):143–165. https://doi.org/10.1127/0003-9136/2005/0162-0143
14. Maltby E, Ormerod S, Acreman M, Blackwell M, Durance I, Everard M, Morris J, Spray C (2011) Freshwaters – openwaters, wetlands and floodplains. In: Assessment UNE (ed) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge, pp 295–360
15. Verdonschot RCM (2012) Drainage ditches, biodiversity hotspots for aquatic invertebrates. Radboud University Nijmegen, Wageningen
16. Wiens JJ (2015) Faster diversification on land than sea helps explain global biodiversity patterns among habitats and animal phyla. Ecol Lett 18(11):1234–1241. https://doi.org/10.1111/ele.12503
17. Martínez-Sanz C, Cenzano CSS, Fernández-Aláez M, García-Criado F (2012) Relative contribution of small mountain ponds to regional richness of littoral macroinvertebrates and the implications for conservation. Aquat Conserv Mar Freshwat Ecosyst 22(2):155–164. https://doi.org/10.1002/aqc.2227
18. Williams P, Whitfield M, Biggs J, Bray S, Fox G, Nicolet P, Sear D (2004) Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biol Conserv 115(2):329–341. https://doi.org/10.1016/S0006-3207(03)00153-8
19. Davies BR, Biggs J, Williams PJ, Lee JT, Thompson S (2007) A comparison of the catchment sizes of rivers, streams, ponds, ditches and lakes: implications for protecting aquatic biodiversity in an agricultural landscape. Hydrobiologia 597(1):7–17. https://doi.org/10.1007/s10750-007-9227-6
20. Pittman SE, Osbourn MS, Semlitsch RD (2014) Movement ecology of amphibians: a missing component for understanding population declines. Biol Conserv 169:44–53. https://doi.org/10.1016/j.biocon.2013.10.020
21. Gooderham JPR, Barmuta LA, Davies PE (2007) Upstream heterogeneous zones: small stream systems structured by a lack of competence? J N Am Benthol Soc 26(3):365–374. https://doi.org/10.1899/06-067.1
22. Thornhill IA, Biggs J, Hill MJ, Briers R, Gledhill D, Wood PJ, Gee JHR, Ledger M, Hassall C (2018) The functional response and resilience in small waterbodies along land-use and environmental gradients. Glob Chang Biol 24(7):3079–3092. https://doi.org/10.1111/gcb.14149
23. Bernhardt ES, Band LE, Walsh CJ, Berke PE (2008) Understanding, managing, and minimizing urban impacts on surface water nitrogen loading. Ann N Y Acad Sci 1134(1):61–96. https://doi.org/10.1196/annals.1439.014
24. Smedema LK, Vlotman WF, Rycroft D (2014) Modern land drainage: planning, design and management of agricultural drainage systems. CRC Press, London
25. Beketov MA, Kefford BJ, Schafer RB, Liess M (2013) Pesticides reduce regional biodiversity of stream invertebrates. Proc Natl Acad Sci U S A 110(27):11039–11043. https://doi.org/10.1073/pnas.1305618110
26. Rasmussen JJ, Wiberg-Larsen P, Baattrup-Pedersen A, Friberg N, Kronvang B (2012) Stream habitat structure influences macroinvertebrate response to pesticides. Environ Pollut 164:142–149. https://doi.org/10.1016/j.envpol.2012.01.007
27. Brown JN, Peake BM (2006) Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. Sci Total Environ 359(1–3):145–155. https://doi.org/10.1016/j.scitotenv.2005.05.016

28. Hu L, Chernick M, Hinton DE, Shi H (2018) Microplastics in small waterbodies and tadpoles from Yangtze River Delta, China. Environ Sci Technol 52(15):8885–8893. https://doi.org/10.1021/acs.est.8b02279
29. Blaszczak JR, Steele MK, Badgley BD, Heffernan JB, Hobbie SE, Morse JL, Rivers EN, Hall SJ, Neill C, Pataki DE, Groffman PM, Groffman PM (2018) Sediment chemistry of urban stormwater ponds and controls on denitrification. Ecosphere 9(6):e02318
30. Dodds W, Smith V (2016) Nitrogen, phosphorus, and eutrophication in streams. Inland Waters 6(2):155–164. https://doi.org/10.5268/iw-6.2.909
31. Phillips G, Willby N, Moss B (2016) Submerged macrophyte decline in shallow lakes: what have we learnt in the last forty years? Aquat Bot 135:37–45. https://doi.org/10.1016/j.aquabot.2016.04.004
32. Dodds WK, Bouska WW, Eitzmann JL, Pilger TJ, Pitts KL, Riley AJ, Schloesser JT, Thornbrugh DJ (2009) Eutrophication of U.S. freshwaters: analysis of potential economic damages. Environ Sci Technol 43(1):12–19. https://doi.org/10.1021/es801217q
33. He D, Chen R, Zhu E, Chen N, Yang B, Shi H, Huang M (2015) Toxicity bioassays for water from black-odor rivers in Wenzhou, China. Environ Sci Pollut Res Int 22(3):1731–1741. https://doi.org/10.1007/s11356-013-2484-1
34. Ji X, Zhang W, Jiang M, He J, Zheng Z (2017) Black-odor water analysis and heavy metal distribution of Yitong River in Northeast China. Water Sci Technol 76(7–8):2051–2064. https://doi.org/10.2166/wst.2017.372
35. Zhu L, Li X, Zhang C, Duan Z (2017) Pollutants' release, redistribution and remediation of black smelly river sediment based on re-suspension and deep aeration of sediment. Int J Environ Res Public Health 14(4). https://doi.org/10.3390/ijerph14040374
36. Szocs E, Brinke M, Karaoglan B, Schafer RB (2017) Large scale risks from agricultural pesticides in small streams. Environ Sci Technol 51(13):7378–7385. https://doi.org/10.1021/acs.est.7b00933
37. Weinstein JE, Crawford KD, Garner TR, Flemming AJ (2010) Screening-level ecological and human health risk assessment of polycyclic aromatic hydrocarbons in stormwater detention pond sediments of Coastal South Carolina, USA. J Hazard Mater 178(1–3):906–916. https://doi.org/10.1016/j.jhazmat.2010.02.024
38. Malaj E, von der Ohe PC, Grote M, Kuhne R, Mondy CP, Usseglio-Polatera P, Brack W, Schafer RB (2014) Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. Proc Natl Acad Sci U S A 111(26):9549–9554. https://doi.org/10.1073/pnas.1321082111
39. Blettler MCM, Wantzen KM (2019) Threats underestimated in freshwater plastic pollution: mini-review. Water Air Soil Pollut 230(7). https://doi.org/10.1007/s11270-019-4220-z
40. O'Brine T, Thompson RC (2010) Degradation of plastic carrier bags in the marine environment. Mar Pollut Bull 60(12):2279–2283. https://doi.org/10.1016/j.marpolbul.2010.08.005
41. Lambert S, Wagner M (2016) Characterisation of nanoplastics during the degradation of polystyrene. Chemosphere 145:265–268. https://doi.org/10.1016/j.chemosphere.2015.11.078
42. Lambert S, Wagner M (2016) Formation of microscopic particles during the degradation of different polymers. Chemosphere 161:510–517. https://doi.org/10.1016/j.chemosphere.2016.07.042
43. PlasticsEurope (2017) An analysis of European plastics production, demand and waste data. In: Plastics – the facts 2017. https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf
44. Horton AA, Svendsen C, Williams RJ, Spurgeon DJ, Lahive E (2017) Large microplastic particles in sediments of tributaries of the River Thames, UK - Abundance, sources and methods for effective quantification. Mar Pollut Bull 114(1):218–226. https://doi.org/10.1016/j.marpolbul.2016.09.004
45. Horton AA, Walton A, Spurgeon DJ, 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

46. Dris R, Gasperi J, Tassin B (2018) Sources and fate of microplastics in urban areas: a focus on Paris megacity. In: Wagner M, Lambert S (eds) Freshwater microplastics: emerging environmental contaminants? Springer, Cham, pp 69–83. https://doi.org/10.1007/978-3-319-61615-5_4
47. Peng G, Xu P, Zhu B, Bai M, Li D (2017) Microplastics in freshwater river sediments in Shanghai, China: A case study of risk assessment in mega-cities. Environ Pollut 234:448–456. https://doi.org/10.1016/j.envpol.2017.11.034
48. Yonkos LT, Friedel EA, Perez-Reyes AC, Ghosal S, Arthur CD (2014) Microplastics in four estuarine rivers in the Chesapeake Bay, U.S.A. Environ Sci Technol 48(24):14195–14202. https://doi.org/10.1021/es5036317
49. Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, Thompson R (2011) Accumulation of microplastic on shorelines worldwide: sources and sinks. Environ Sci Technol 45(21):9175–9179. https://doi.org/10.1021/es201811s
50. Duis K, Coors A (2016) Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environ Sci Eur 28(1):2. https://doi.org/10.1186/s12302-015-0069-y
51. Kay P, Hiscoe R, Moberley I, Bajic L, McKenna N (2018) Wastewater treatment plants as a source of microplastics in river catchments. Environ Sci Pollut Res Int 25(20):20264–20267. https://doi.org/10.1007/s11356-018-2070-7
52. Luo W, Su L, Craig NJ, Du F, Wu C, Shi H (2019) Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environ Pollut 246:174–182. https://doi.org/10.1016/j.envpol.2018.11.081
53. Lv W, Zhou W, Lu S, Huang W, Yuan Q, Tian M, Lv W, He D (2019) Microplastic pollution in rice-fish co-culture system: a report of three farmland stations in Shanghai, China. Sci Total Environ 652:1209–1218. https://doi.org/10.1016/j.scitotenv.2018.10.321
54. Bordós G, Urbányi B, Micsinai A, Kriszt B, Palotai Z, Szabó I, Hantosi Z, Szoboszlay S (2019) Identification of microplastics in fish ponds and natural freshwater environments of the Carpathian basin, Europe. Chemosphere 216:110–116. https://doi.org/10.1016/j.chemosphere.2018.10.110
55. Hu L (2019) Microplastic pollution in small waterbodies and its toxicity effects on aquatic organisms. East China Normal University, Shanghai
56. Liu F, Olesen KB, Borregaard AR, Vollertsen J (2019) Microplastics in urban and highway stormwater retention ponds. Sci Total Environ 671:992–1000. https://doi.org/10.1016/j.scitotenv.2019.03.416
57. Olesen KB, Stephansen DA, Alst NV, Vollertsen J (2019) Microplastics in a stormwater pond. Water 11(7):1466. https://doi.org/10.3390/w11071466
58. Dikareva N, Simon KS (2019) Microplastic pollution in streams spanning an urbanisation gradient. Environ Pollut 250:292–299. https://doi.org/10.1016/j.envpol.2019.03.105
59. Vaughan R, Turner SD, Rose NL (2017) Microplastics in the sediments of a UK urban lake. Environ Pollut 229:10–18. https://doi.org/10.1016/j.envpol.2017.05.057
60. Eerkes-Medrano D, Thompson RC, Aldridge DC (2015) Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. Water Res 75:63–82. https://doi.org/10.1016/j.watres.2015.02.012
61. Press. NdbCS (2016) National Bureau of Statistics, China. http://www.stats.gov.cn/tjsj/ndsj/2016/indexeh.htm
62. Wright SL, Thompson RC, Galloway TS (2013) The physical impacts of microplastics on marine organisms: a review. Environ Pollut 178:483–492. https://doi.org/10.1016/j.envpol.2013.02.031
63. Wagner M, Lambert S (2018) Freshwater microplastics emerging environmental contaminants? Springer Nature, Heidelberg
64. Wright SL, Kelly FJ (2017) Plastic and human health: a micro issue? Environ Sci Technol 51(12):6634–6647. https://doi.org/10.1021/acs.est.7b00423

65. Su L, Cai H, Kolandhasamy P, Wu C, Rochman CM, 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
66. Xiong X, Zhang K, Chen X, Shi H, Luo Z, Wu C (2018) Sources and distribution of microplastics in China's largest inland lake – Qinghai Lake. Environ Pollut 235:899–906. https://doi.org/10.1016/j.envpol.2017.12.081
67. Phillips MB, Bonner TH (2015) Occurrence and amount of microplastic ingested by fishes in watersheds of the Gulf of Mexico. Mar Pollut Bull 100(1):264–269. https://doi.org/10.1016/j.marpolbul.2015.08.041
68. Jabeen K (2018) Characteristics of microplastics in fish from coastal and fresh waters of China. East China Normal University, Shanghai
69. Su L, Nan B, Hassell KL, Craig NJ, Pettigrove V (2019) Microplastics biomonitoring in Australian urban wetlands using a common noxious fish (*Gambusia holbrooki*). Chemosphere 228:65–74. https://doi.org/10.1016/j.chemosphere.2019.04.114
70. Mizraji R, Ahrendt C, Perez-Venegas D, Vargas J, Pulgar J, Aldana M, Patricio Ojeda F, Duarte C, Galban-Malagon C (2017) Is the feeding type related with the content of microplastics in intertidal fish gut? Mar Pollut Bull 116(1–2):498–500. https://doi.org/10.1016/j.marpolbul.2017.01.008
71. Setälä O, Norkko J, Lehtiniemi M (2016) Feeding type affects microplastic ingestion in a coastal invertebrate community. Mar Pollut Bull 102(1):95–101. https://doi.org/10.1016/j.marpolbul.2015.11.053
72. Scherer C, Weber A, Lambert S, Wagner M (2018) Interactions of microplastics with freshwater biota. In: Wagner M, Lambert S (eds) Freshwater microplastics: emerging environmental contaminants? Springer, Cham, pp 153–180. https://doi.org/10.1007/978-3-319-61615-5_8
73. Koelmans AA, Besseling E, Wegner A, Foekema EM (2013) Plastic as a carrier of POPs to aquatic organisms: a model analysis. Environ Sci Technol 47(14):7812–7820. https://doi.org/10.1021/es401169n
74. Koelmans AA, Bakir A, Burton GA, Janssen CR (2016) Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environ Sci Technol 50(7):3315–3326. https://doi.org/10.1021/acs.est.5b06069
75. Besseling E, Wegner A, Foekema EM, van den Heuvel-Greve MJ, Koelmans AA (2013) Effects of microplastic on fitness and PCB bioaccumulation by the lugworm *Arenicola marina* (L.). Environ Sci Technol 47(1):593–600. https://doi.org/10.1021/es302763x
76. Fei L, Ye CY, Jiang JP (2012) Colored atlas of Chinese amphibians and their distributions. Henan Science and Technology Press, Henan
77. Hu L, Su L, Xue Y, Mu J, Zhu J, Xu J, Shi H (2016) Uptake, accumulation and elimination of polystyrene microspheres in tadpoles of *Xenopus tropicalis*. Chemosphere 164:611–617. https://doi.org/10.1016/j.chemosphere.2016.09.002
78. De Felice B, Bacchetta R, Santo N, Tremolada P, Parolini M (2018) Polystyrene microplastics did not affect body growth and swimming activity in Xenopus laevis tadpoles. Environ Sci Pollut Res Int 25(34):34644–34651. https://doi.org/10.1007/s11356-018-3408-x
79. Tussellino M, Ronca R, Formiggini F, De Marco N, Fusco S, Netti PA, Carotenuto R (2015) Polystyrene nanoparticles affect *Xenopus laevis* development. J Nanopart Res 17(2):70. https://doi.org/10.1007/s11051-015-2876-x
80. Webster CA, Di Silvio D, Devarajan A, Bigini P, Micotti E, Giudice C, Salmona M, Wheeler GN, Sherwood V, Bombelli FB (2016) An early developmental vertebrate model for nanomaterial safety: bridging cell-based and mammalian toxicity assessment. Nanomedicine (Lond) 11(6):643–656
81. Fahrenfeld NL, Arbuckle-Keil G, Naderi Beni N, Bartelt-Hunt SL (2018) Source tracking microplastics in the freshwater environment. TrAC Trends Anal Chem. https://doi.org/10.1016/j.trac.2018.11.030
82. Rochman CM (2018) Microplastics research – from sink to source. Science 360(6384):28–29. https://doi.org/10.1126/science.aar7734

83. Nicolas Weithmann JNM, Löder MGJ, Piehl S, Laforsch C, Freitag R (2018) Organic fertilizer as a vehicle for the entry of microplastic into the environment. Sci Adv 4(4):eaap8060. https://doi.org/10.1126/sciadv.aap8060
84. Magnusson K, Eliasson K, Fråne A, Haikonen K, Hultén J, Olshammar M, Stadmark J, Voisin A (2017) Swedish sources and pathways for microplastics to the marine environment. Swedish Environmental Protection Agency, Stockholm
85. Murphy F, Ewins C, Carbonnier F, Quinn B (2016) Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environ Sci Technol 50(11):5800–5808. https://doi.org/10.1021/acs.est.5b05416
86. Ziajahromi S, Neale PA, Rintoul L, Leusch FD (2017) Wastewater treatment plants as a pathway for microplastics: development of a new approach to sample wastewater-based microplastics. Water Res 112:93–99. https://doi.org/10.1016/j.watres.2017.01.042