Department
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Food & Rural Affairs

Evidence Reviews on Analysis, Prevalence & Impact of Microplastics in Freshwater and Estuarine Environments

Evidence Review 2

What are the sources of the microplastics found in freshwater environments?

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Executive Summary

This Rapid Evidence Assessment used the systematic review procedure to assess the current evidence available on the sources of the microplastics found in freshwater and estuarine environments. To fully comprehend the prevalence of microplastics in freshwater and estuarine environments, it is important to understand which sources contribute to the microplastics present and the relative importance of those sources. Furthermore, we need to understand the influence of any physical and biologically-mediated processes that affect the concentrations, characteristics and profile of the microplastic particles present, so that their influence can be taken into account when interpreting the microplastics present in terms of contributing sources.

A review was conducted of literature, including grey literature, which reported evidence of the sources of the microplastics found in freshwater and estuarine environments. The factors influencing the transport and modification of microplastics in freshwater and estuarine environments were also considered, noting in particular those that alter the profile of microplastics thus obscuring identification of sources. Publications released prior to April 2019 were included in this review.

Evidence was acquired according to a predefined set of questions, compiled into a database containing full details of the source and its relevance to the project questions, and the evidence analysed, taking into account reporting biases in the literature, to produce a digestible summary of the evidence base available to answer the main project question and sub-questions, namely,

What are the sources of microplastics reported to have been found in freshwater and estuarine environments?

> *a) Are these primary (i.e. manufactured) or secondary (i.e. degradation products) microplastics?*
> *b) Within studies reporting the predominant types of microplastics found, is there a link identified to local land use or industry?*
> *c) How are microplastics transported and modified in the freshwater and estuarine environments?*
> *d) Are microplastics from different sources prevalent in different matrices of the aquatic environment (biota, water, or sediment)?*

A set of pre-defined terms were used to search various databases and 2,450 potential evidence sources were identified. Further screening resulted in the identification of 125 unique sources that were used to provide evidence regarding the sources of microplastics found in freshwaters and estuaries, and the influence of transport pathways and processes. Sources are places where microplastics may originate, with a number of products potentially being the origin of the plastic material, whereas pathways are the routes along which microplastics are transported, where the profile of microplastics found has the potential of being affected by processes (e.g. deposition) as the particles move through the environment. The sources considered included primary microplastics (intentionally produced and/or used in products), secondary microplastics produced during an article's intended use (e.g. tyre wear) and secondary microplastics produced through environmental degradation of macroplastic after it has been lost to the environment.

What are the sources of microplastics reported to have been found in freshwater and estuarine environments?

Very few studies provided clear evidence identifying the original source(s) of the microplastics present in freshwater and estuarine environments. Most studies only provided putative identification of sources of microplastics, with no supporting evidence to confirm if the microplastics present were from those sources. Where sources were identified, it was typically though upstream-downstream comparison focussing on point sources, although such a study design did not always identify an effect of the source. Formal linking of sources to particles in the environment, using tracers or source apportionment, has not been undertaken to date. Available models do not consider the transport and fate of particles after emission, so it is not possible to relate modelled emissions to concentrations of microplastics in freshwaters and estuaries. Hence, considerable uncertainties remain concerning the main sources responsible for the microplastics present in freshwater and estuarine environments. The evidence available does not enable a robust assessment of the relative importance of different sources of the microplastics in freshwaters and estuaries.

Are these primary (i.e. manufactured) or secondary (i.e. degradation products) microplastics?

The majority of studies describing the microplastics present in freshwaters and estuaries did not discriminate between primary and secondary microplastic particles. Where studies did discriminate, most ascribed the particles to either a mixture of primary and secondary microplastics or to secondary microplastics. However, the characteristics used to discriminate between primary and secondary particles are not absolute. Although it appears that secondary microplastic particles are more abundant in freshwaters and estuaries than primary particles, confident attribution of the sources of the particles found in freshwaters and estuaries as either primary or secondary is not possible.

How are microplastics transported and modified in the freshwater and estuarine environments?

Of the release pathways of microplastics considered, most evidence available concerned release via wastewater, particularly through upstream-downstream comparison. However, the number of studies available does not necessarily reflect the relative importance of the different pathways.

Release via wastewater was the most studied pathway of release into flowing waters and estuaries, where studies focussed on either passage through treatment works or upstream-downstream comparisons of microplastics in waterbodies receiving effluent from treatment works. Passage through sewage treatment works resulted in a 79 to 99 % decrease in the abundance of particles in water compared with the concentration in influent water, dependent on the design of the works, and an increase in the concentration of microplastics in sedimented sludge. The influence of other pathways on the abundance of microplastics was more equivocal, with studies reporting an increase, decrease or no change.

Transport processes affect the profile of microplastics in freshwaters and estuaries. Of the studies that considered the effects of transport processes on the profile of microplastics, most considered the effect on total abundance. Deposition was associated with a decrease in abundance in water and an increase in sediment, and affects the profile of size, morphology and polymers. The influence of other processes (resuspension, aggregation and degradation) on total abundance was equivocal, although the number of studies was too low to provide a conclusive assessment. Nevertheless, the movement microplastics through the environment appears to follow the patterns expected for natural organic particles of equivalent size and density.

Particles degrade through the action of physical and biological processes, affecting the concentration and profile of microplastics.

Within studies reporting the predominant types of microplastics found, is there a link identified to local land use or industry?

Very few studies provided clear evidence identifying the source(s) of the microplastics present in freshwater and estuarine environments. The change in the profile of microplastics upstream to downstream such that a link to local land use or industry could be identified was equivocal. As such, at this time it is not possible to conclude that there is a link between local land use or industry and the predominant microplastics found in freshwaters and estuaries.

Are microplastics from different sources prevalent in different matrices of the aquatic environment (biota, water, or sediment)?

Notwithstanding the caveat that there are considerable uncertainties concerning the attribution of the sources of the microplastics present in freshwater and estuarine environments, there did not appear to be considerable distinction among the matrices of the aquatic environment in terms of the sources attributed. However, the attribution of sources may reflect the design and aims of the studies in question rather than a robust assessment of the relative importance of different sources.

In conclusion, at this time there is insufficient evidence to identify the sources of the microplastics found in freshwater and estuarine environments.

1 Introduction

1.1 Background

Plastics are synthetic polymers which can be made into a vast range of inexpensive, light-weight and durable products that bring numerous societal benefits by providing important components for a multitude of applications in modern life. Since the 1950s, the plastics industry has grown exponentially to a global usage of 348 million tonnes annum^{-1} in 2017 (Plastics*Europe* 2018). A great variety of polymers and products are encompassed within the term “plastics”, some of which a will have a long service life, whereas others (around 40% of all the plastic produced) are used for packaging, which is predominantly single use.

It has been discovered that microscopic particles of plastic, microplastics, have been released into the environment (Thompson et al. 2004). Here we use the European Chemical Agency working definition of microplastic as “any polymer, or polymer-containing, solid or semi-solid particle having a maximum size of 5 mm or less in any dimension” (ECHA 2018). Additionally, the definition includes both those microplastics that have been intentionally created (i.e. primary microplastic), and those that are derived from degradation of larger plastic particles (i.e. secondary microplastic). It is estimated that 12 billion tonnes of microplastic will be discarded globally by 2050 (Geyer et al. 2017), with additional particles derived through degradation of larger material, resulting in impacts on biota predicted to cost in excess of $13 billion annum^{-1} (Nizzetto et al. 2016a). Microplastics are now ubiquitous and microplastic particles have been reported from throughout the aquatic environment, from surface freshwaters (Hurley et al. 2018) to the deepest and most remote regions of the sea (Ivar do Sul and Costa 2014).

The sources of microplastics include primary microplastics (intentionally produced and/or used in products), secondary microplastics produced during an article’s intended use (e.g. tyre wear) and secondary microplastics produced through environmental degradation of macroplastic after it has been lost to the environment. As microplastics are likely to originate from a variety of sources they comprise a variety of different polymer types, including polyethylene (PE), polypropylene (PP), acrylic, polyacrylamide (PAM), polyamide (PA), polyester (PES), polytetrafluoroethylene (PTFE), and polystyrene (PS) amongst others. The amount of plastic produced and released into the environment varies among the different polymers dependent on their use in products (either as single polymers or combinations) and the fate of those products. Both the composition (polymer) and production (influence of processing) of plastics influences the rate at which they degrade and, thus, the rate at which microplastic particles are released from macroplastics. Furthermore, as with all particles, microplastics are potentially subject to a number of physical and biologically-mediated processes as they move through the environment: microplastics may be variously affected by these processes, such that the concentrations and profile of microplastics may vary substantially both in time and space. There is a need to further our understanding of which sources of microplastics are prevalent in freshwater systems, in what forms, and what their potential impacts on freshwater organisms and ecosystems might be. To fully comprehend the prevalence of microplastics in freshwater and estuarine environments, it is important to understand which sources contribute to the microplastics present and their relative importance. Furthermore, we need to understand the influence of any physical and biologically-mediated processes that affect the concentrations, characteristics and profile of the microplastic particles present, so that their influence can be taken into account when interpreting the microplastics present in terms of contributing sources.

Within the above wider context, this evidence review is one of three reviews that aim to provide a robust review of the evidence base for informing policy development. This evidence is needed to inform decision making to effectively manage any potential risks stemming from microplastics.

1.2 Objectives

The overarching aim of this evidence review, commissioned by Defra, was to improve our understanding of the sources of microplastics reported to have been found in freshwater and estuarine environments. The evidence available was assessed using the systematic review procedure.

The objectives were to:

1) undertake a Rapid Evidence Assessment for each of the primary research questions,

2) produce a database of evidence.

The objectives of the evidence review were delineated through the following Primary and Secondary questions.

Primary question:

What are the sources of microplastics reported to have been found in freshwater and estuarine environments?

Secondary questions:

a) Are these primary (i.e. manufactured) or secondary (i.e. degradation products) microplastics?

b) Within studies reporting the predominant types of microplastics found, is there a link identified to local land use or industry?

c) How are microplastics transported and modified in the freshwater and estuarine environments?

d) Are microplastics from different sources prevalent in different matrices of the aquatic environment (biota, water, or sediment)?

2 Methodology

2.1 Review methodology applied

This evidence review is a Rapid Evidence Assessment (REA) which aims "to provide an informed conclusion on the volume and characteristics of an evidence base together with a synthesis of what that evidence indicates following a critical appraisal of that evidence" (Collins et al., 2015). The review followed the methodology outlined in Collins et al. (2015). The primary and secondary questions that were considered (see Section 1), the PICO elements (Population, Intervention, Comparator, Outcome; Table 2.1) and search terms that were used were detailed in a protocol document, which was used to guide the review process. The REA work encompassed two components: a literature review and interviews with academic experts. Details of the approach proposed for the two REA components are provided in the Sections below.

Table 2.1 REA PICO elements

PICO element	PICO element for this REA
Population	Microplastics
Intervention	Identification of sources of micoplastics found in freshwater and estuarine environments
Comparator	Factors altering the profile of micoplastics found in freshwater and estuarine environments such that sources cannot be attributed
Outcome	Robust evidence base on the sources of the micoplastics found in freshwater and estuarine environments

2.2 Literature Review

The quality of the literature, including grey literature, which reported the sources of the microplastics found in freshwater and estuarine environments, were systematically reviewed and assessed. The factors influencing the transport and modification of microplastics in freshwater and estuarine environments were also considered, noting in particular those that alter the profile of microplastics thus obscuring identification of sources.

2.2.1 Capturing the evidence base

The first step in the evidence reviews on analysis, prevalence & impact of microplastics in freshwater and estuarine environments was to assess the overall evidence base detailing research on microplastics in freshwaters and estuarine (transitional) waters. A wide search using population search terms (Table 2.2) was used at this stage to capture as much of the evidence as possible, with the results of these searches saved and interrogated further to answer each of the three more detailed key questions and their sub-questions from the three evidence reviews on microplastics in freshwaters and estuaries (the second of which is relevant here), thus reducing the effort required to establish the evidence base for each evidence review.

Publications released prior to April 2019 were included in this review. As microplastics have only been studied relatively recently (Thompson et al. 2004), no earliest date was used to define the date range of publications included. An exception on the date range was made to include two works of high relevance to the UK that were released after April 2019, namely Ball et al. 2019 (Sink to River - River to Tap. A review of potential risks from nanoparticles and microplastics. UK Water Industry Research Limited Report No. EQ01A231) and Santillo et al. 2019 (Plastic pollution in UK's rivers: a 'snapshot' survey of macro- and micro-plastic contamination in surface waters of 13 river systems across England, Wales, Scotland and Northern Ireland. Greenpeace Research Laboratories Technical Report 04-2019).

Table 2.2 Population level search terms used with Boolean operators to identify the population of evidence available on microplastics in freshwaters and estuaries.

Population			
plastic*	freshwater*	wetland	potable
micro*	river*	marsh	reservoir
microplastic	stream*	swamp	aquifer
nanoplastic	brook	wastewater*	groundwater
*plastic	lake*	drinking water	sewage
	pool	aquatic	outfall
	pond	ecosystem*	
	estuar*		
	transitional		

The databases used for the searches, which encompass both published and grey literature, included:

BioOne, COPAC, DART-Europe E-theses Portal, EBSCO Open dissertations, EThOS: Electronic Theses Online Service, European Commission Research Publications, European Sources Online, GoogleScholar, MedLine, JStor, SciFinder, Open Access

Theses and Dissertations, OpenGrey, PubMed, PLoS, Scopus, SciFinder, Web of Science.

To capture grey literature, additional to that included in the list of databases to be searched (i.e. databases detailing unpublished theses and reports) undertook directed searches of holdings of relevant environmental regulators (e.g. Rijkswaterstaat (Dutch water authorities): http://www.rws.nl, Vlaamse Milieumaatschappij (Flemish Environmental Agency): http://www.vmm.be Bundesanstalt für Gewässerkunde (German Federal Institute of Hydrology): http://www.bafg.de RIVM (Dutch Environment Agency): http://www.rivm.nl).

The results of all searches were a) downloaded and saved in a searchable database for use in further searches and b) used to map the evidence record.

The overall evidence base on microplastics in freshwaters captured 3456 unique sources. The search engines Scopas, Scifinder and Web of Science produced the most hits. Some of the terms used produced a large number of hits, e.g. the combination micro AND plastic, but a brief inspection revealed that a large proportion of these sources were not relevant, so these terms were only used further in combination with other qualifying terms. Of the retained searches, *microplastic* produced the most hits (total across all engines 11,636).

To capture the evidence base to address the primary and secondary questions of this evidence review, the overall evidence base on microplastics in freshwaters and estuaries captured in the first phase were searched further using search terms specific to the questions of this evidence review (Table 2.3).

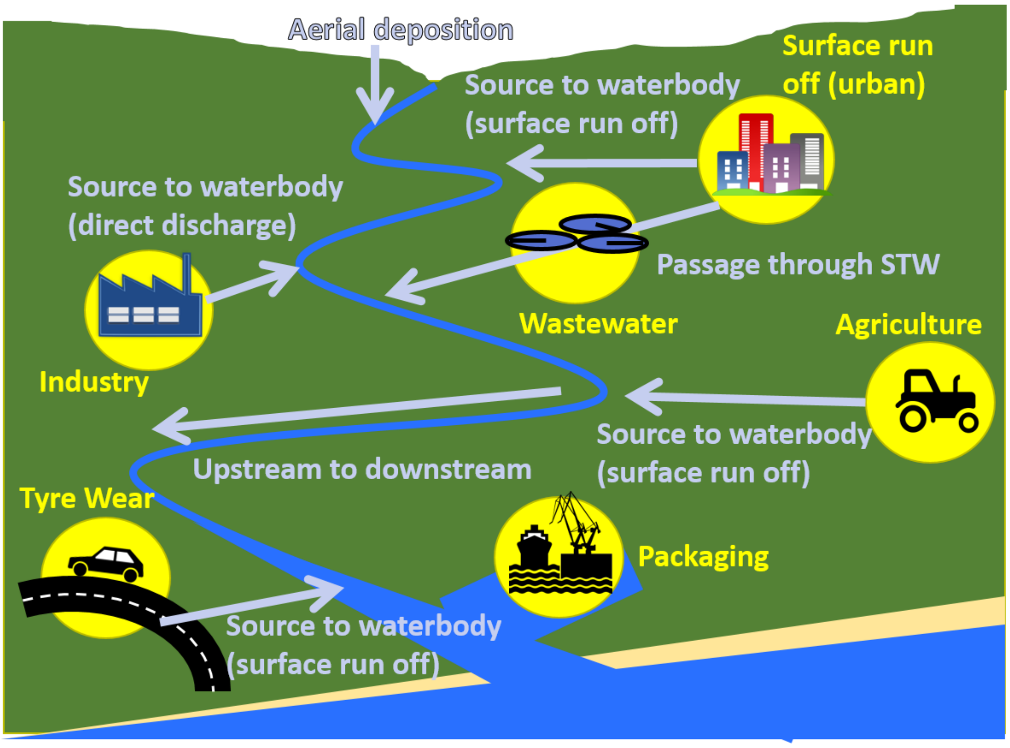

Fig 1. Schematic to illustrate sources (yellow circles and text) and pathways (pale blue arrows and text).

This review compiled evidence on sources, pathways and processes. Sources are places where microplastics may originate, with a number of products potentially being the origin of the plastic material (e.g. personal care products), whereas pathways are the routes along which microplastics are transported, where the profile of microplastics found has the potential of being affected by processes (e.g. deposition) as the particles move through the environment (Fig 1).

Table 2.3 Search terms used to identify the evidence available on sources of microplastics found in freshwaters and estuaries, and the processes and pathways affecting their transport and fate.

Population	Intervention	Comparator	Outcome
debris	personal care	fraction*	character*
litter	cosmetic	heteroaggregat*	acrylic
primary	industr*	colloid*	polyester
secondary	agricultur*	floc*	polystyrene
virgin	sewage	plankton*	polypropylene
*fibre	tyre wear	sediment*	polyamide
*fiber	tire wear	microb*	polyacrylamide
*bead	road wear	filter*	polymer
nurdle	paint	feeding*	PVC
dust	textile*	detritiv*	PET
beached	wet wipe	abrasi*	
pellet*		fragment*	
flake*		sorption	
additive*		uptake	
contamina*		bioaccumulation	
		accumulation	
		consump*	
		aging	
		deposit*	
		erode	
		erosi*	
		suspen*	
		resuspen*	
		consump*	

The results of all searches were saved for further use and used to map the evidence record. Those evidence sources that were identified by searches for ER1 and scored as potentially relevant to Q2 during the screening process were transferred to an MS Excel spreadsheet formatted with columns corresponding to information fields relevant to the key question and sub-questions being addressed (See ER2_Capture.xls) for consideration in this review. The information fields of the evidence capture form included information relevant to

1. The evidence
2. The influence of pathways on the profile of microplastics,
3. The influence of processes on the profile of microplastics
4. The sources of microplastics identified
5. The location of the study

Those evidence sources that had not been identified by searches as potentially relevant to ER1 were also transferred to the evidence capture form, but subject to screening before being included in ER2. The evidence base potentially relevant to Q2 identified through the searches was divided among the members of the Q2 review team in such a way that 10% of records were allocated twice (for quality assurance purposes). The reviewers screened the evidence and completed the evidence capture form. The evidence capture form comprised two steps. The first initial screen of evidence sources not considered for ER1 was used to:

a) Identify reviews, which were used for further identification of evidence sources, but not included in data capture *per se*, unless some novel data was presented.

b) Remove evidence sources specific to marine waters and not relevant to freshwaters or estuarine (transitional) waters.

c) Identify evidence sources that were likely to be relevant to Evidence Review 1 (sampling and analytical methodology) and/or Evidence Review 3 (biotic impacts, uptake and biological consequences).

d) Of the 2,450 evidence sources identified as potentially relevant, the initial screening identified 371 as likely to be relevant to the question of ER2 and, of these, 103 were considered likely to contain evidence relevant to freshwaters and 72 likely to contain evidence relevant to transitional waters, and 60 to both environments (Fig. 2).

e) Those evidence sources that passed the initial screen were searched in detail to capture the evidence relevant to the question and sub-questions, and any relevant information recorded under the appropriate fields on the evidence capture form (Appendix 2: ER2_Capture.xls). In particular, numerical information was captured where effects were quantified in the literature (e.g. proportions of microplastics from different sources). These evidence sources were supplemented with sources identified as relevant to the questions of this review through the searches undertaken in ER1 and ER3, together with a highly relevant report that was released after April 2019 (Ball et al. 2019).

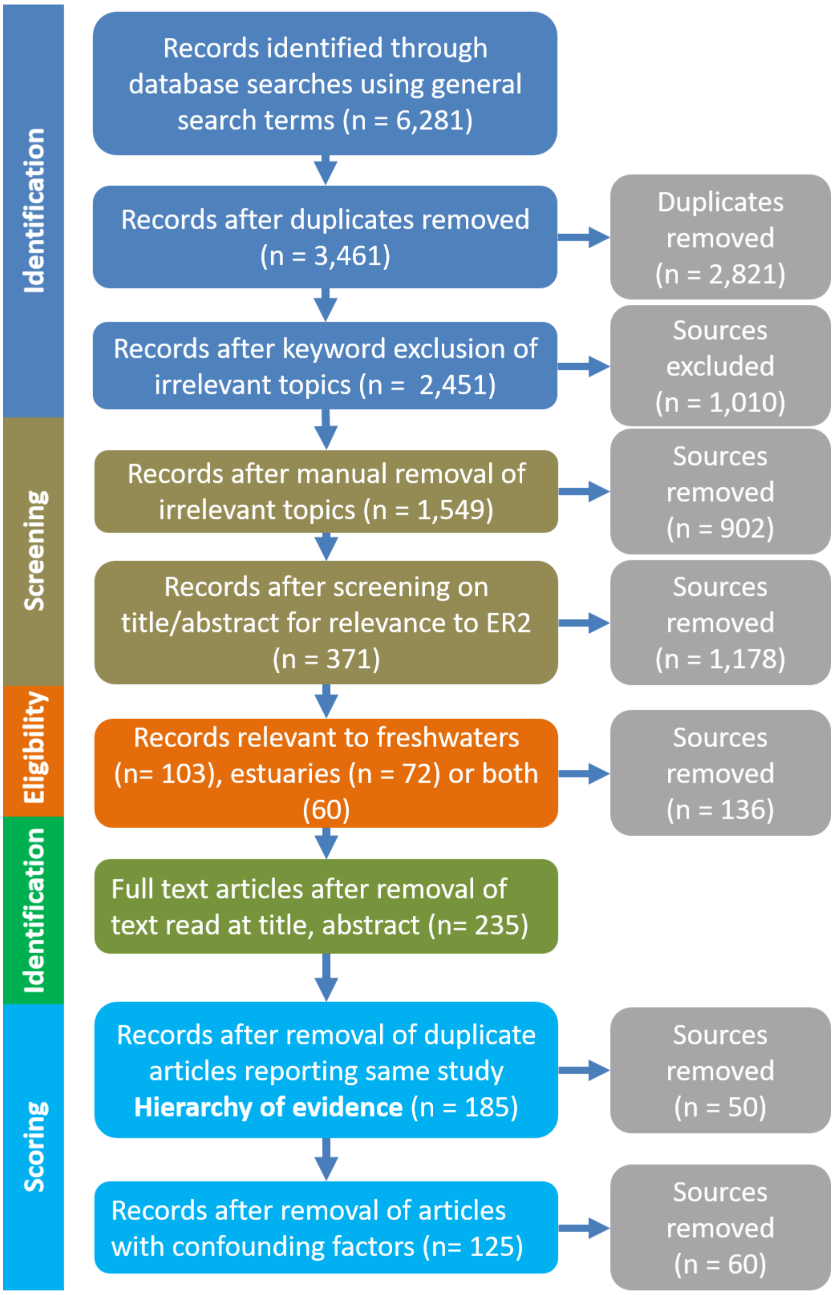

Fig. 2 Map of evidence identified as relevant to ER2 during initial screening.

Of the sources likely to contain evidence relevant to freshwaters and estuaries, 125 unique sources were used to extract evidence (Fig. 2). Of these, 74 unique sources contained evidence from running or standing freshwaters, 38 from other freshwaters, mostly effluent from sewage treatment works and 19 unique evidence sources were used where the evidence was from estuaries. Six sources contained evidence that was relevant to more than one habitats.

All the evidence was transferred from the evidence capture form into a searchable MS Access relational database, which was spatially referenced where appropriate (i.e. linked to a GIS data layer illustrating the field locations where evidence was obtained from). This database linked literature sources to the key questions and was used to produce extractable summaries of the evidence base underlying each of the key questions and sub questions. After evidence capture, the total evidence base was compiled and quantified, and meta-analyses undertaken where appropriate.

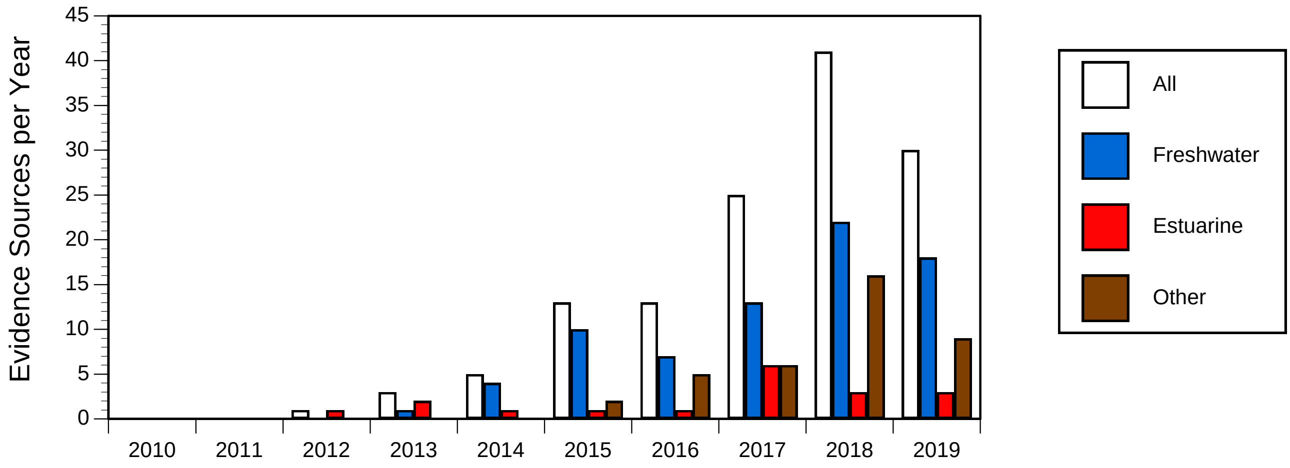

Fig 3. Number of evidence sources per year.

2.2.2 Reliability scores

Additional information on the reliability of the evidence provided by the source was captured using a separate spreadsheet, based on the methods of Hermsen et al. (2018) and Koelmans et al. (2019). The quality assessment was made up of ten criteria: (1) sampling method and strategy, (2) sample size, (3) sample processing and storage, (4) laboratory preparation, (5) clean air conditions, (6) negative controls, (7) positive controls, (8) target component (for biota), (9) sample (pre-)treatment, and (10) polymer identification. For each criterion, a score of 0, 1, or 2 was assigned to the evidence source under review. Scores signified the following: 2 = reliable without restrictions, 1 = somewhat reliable but with restrictions, 0 = not reliable. If information was lacking on certain aspects in the evidence source, this was considered unreliable, leading to a lower score. For each evidence source the Total Accumulated Score was calculated by adding scores for individual criteria (maximum 18 points for water and sediment, 20 for biota). For the data provided by an evidence source to be considered sufficiently reliable, it should preferably have no ‘zero’ values for any of the individual scores. To assess the overall reliability of the evidence sources, the number of zeros was calculated for each. Furthermore, the product of the scores in all relevant criteria was calculated, following the methods of Hermsen et al. (2018), to give a potential maximum reliability score of 512 (or 1024 for biota), but where any one criterion was evaluated as “not reliable” (0 points) the overall reliability score of the study was 0.

Table 2.4 Criteria used to assess reliability of evidence sources.

1. Sampling methods	Location - Date - Matrix specific methods should be recorded.
2. Sample size	A suitable sample size - Surface waters: ≥ 500 L, WwTP effluent: ≥ 500 L, Sediment: ≥ 5 L, Biota: ≥ 50 individuals per taxa.
3. Sample processing and storage	Prior rinsing of sample pots in filtered/deionised water. No plastic materials used. Justification for any fixatives added.
4. Laboratory preparation	All materials, equipment, and laboratory surfaces need to be thoroughly washed and rinsed.
5. Clean air conditions	The handling of samples should be performed in clean air facilities.
6. Negative control	A replicate of 3 negative controls is advised that are included for each batch of samples and treated in parallel to the sample treatment.
7. Positive controls	A replicate of 3 is advised in which microplastics of known polymer identity and of targeted sizes are added to "clean" samples, which are then treated and analyzed the same way as the actual samples. The particle recoveries calculated.
8. Target component (for Biota only)	To capture all ingested microplastic, the full gastrointestinal tract (esophagus to vent) of fish and the entire body of smaller species, e.g. bivalves, should be examined.
9. Sample treatment	A digestion step must be included to dissolve organic matter, and associated loss of polymers considered. Digestion without such consideration scores 1.
10. Polymer identification	Polymer identify needs to be confirmed by FTIR, Raman or GCMS on at least a representative subsample of ≥ 50 particles or ≥ 25% of filter area. Score 1 if polymer identity was determined on smaller sub-sample or using SEM.

2.3 Interviews

Interviews with academics working in the field of microplastics were conducted to get their expert opinion on the primary and secondary questions. Four academic experts were consulted:

Dr Alice Horton, Centre for Ecology & Hydrology, Wallingford, UK

Prof Dr Bernd Nowack, Empa-Swiss Federal Laboratories for Materials Science and Technology, Zürich, Switzerland

Prof Dr Annemarie van Wezel, University of Amsterdam and the Dutch research institute for drinkingwater, Amsterdam, the Netherlands

Dr Gaël Durand, Labocea, Brest, France

Interviews (lasting 30-45 minutes) were held via phone with all the academics above. During the telephone interviews, the academics were requested to: provide their expert view on each of the primary and secondary questions; comment on key published literature relating to the questions; and provide information on ongoing or unpublished work relating to this evidence review, if applicable. The interviewee responses were recorded as notes during the interviews. The key messages/highlights derived from the interviews are outlined in Section 3.

3 Key messages from interviews with academic experts

What are the sources of microplastics reported to have been found in freshwater and estuarine environments?

All four academic experts interviewed indicated that there is considerable uncertainty regarding the sources of the microplastic particles found in freshwater and estuarine environments. All the academic experts said that waste water treatment plants were a source of microplastics, but the importance of this source, compared with other sources, was not established. Other contributing sources suggested by the academic experts interviewed were tyre wear and road run off (including litter, paint and other car parts), the recycling industry, other industries, agriculture, construction and the degradation of litter to microplastics. The experts indicated that we know that fibres from textiles and tyre are present in the environment, but there are many sources which emit microplastics into the environment for which we know nothing. The academic experts were of the opinion that models can estimate the rate of emission, but that we know little about the fate of microplastics once they are released. The experts were also of the opinion that the main sources of microplastics in freshwaters and estuaries are likely to vary spatially, dependent on the types of activities undertaken in the catchment of the waterbody.

All experts agreed that the main sources of the microplastics found in freshwaters and estuaries are as yet not known.

Secondary questions:

a) Are these primary (i.e. manufactured) or secondary (i.e. degradation products) microplastics?

All four experts were of the opinion that sources that release secondary microplastic particles are likely to be far more important than those that release primary microplastics.

b) Within studies reporting the predominant types of microplastics found, is there a link identified to local land use or industry?

The academic experts were in agreement that there should be variation in the types of microplastics found in freshwaters and estuaries, dependent on the activities undertaken in the catchment. However, their opinion was that the evidence linking the microplastics found to specific sources is weak and only applicable to point sources: most inputs are likely to be diffuse.

c) How are microplastics transported and modified in freshwater and estuarine environments?

The four academic experts were of the opinion that, although we know little about the fate of microplastics once released into the environment at the current time, the processes that transport naturally occurring particles through the environment are likely to play a key role, in particular, those processes driven by precipitation. Transport by wind will also play a role. The experts indicated that difficulties arise as data are typically in terms of numbers of particles rather than mass, presenting challenges for estimation from mass balance. The experts were of the opinion that modification of particles is likely to be driven by physical degradation (including the effect of UV exposure) as well as biological degradation by fungi and bacteria, although little is known about the process and rate of degradation from macroplastics to microplastics under environmental conditions.

All four academic experts interviewed were of the opinion that there is little evidence on the fate of microplastics once released.

d) Are microplastics from different sources prevalent in different matrices of the aquatic environment (biota, water, or sediment)?

The academic experts were of the opinion that there would be differences in the microplastics present in the different matrices, with those in sediment and biota originating from (and being a subset of) those in water. The experts stated that microplastics in sediment are likely to be of denser polymers than those in water. The experts were also of the opinion that selectivity in which microplastics are consumed (based on size, shape, colour and the mode of feeding) is likely to influence the microplastics found in biota. However, all experts indicated that there is insufficient evidence to confidently define any differences among the matrices, or the mechanisms that lead to such differences.

4 Literature Review

The outcomes of the literature review undertaken are outlined below, the structure being based on the primary and secondary questions. At the end of each question, a summary of the evidence is provided in a text box for clarity. The findings presented are summaries of the evidence available and, therefore, are influenced by the reliability of the primary literature, including grey literature, on which this report is based. An assessment of the reliability of the 125 studies included in this review was undertaken (see section 4.6). However, this assessment of reliability was not used to exclude studies from the review, which was based on all 125 evidence sources.

4.1 Primary question: What are the sources of microplastics reported to have been found in freshwater and estuarine environments?

Very few studies provided clear evidence identifying the original source(s) of the microplastics present in freshwater and estuarine environments (Fig 4). Most studies only provided putative identification of sources of microplastics, with no supporting evidence to confirm if the microplastics present were from those sources. Where sources were identified, it was typically through upstream-downstream comparison focussing on point sources. Formal linking of sources to particles in the environment, using tracers or source apportionment, has not been undertaken to date. The small number of studies that identified the sources of the microplastics in freshwaters and estuaries, together with their design (constrained spatially and focussed on specific point sources), do not enable a robust assessment of the relative importance of different sources either within or among habitat types.

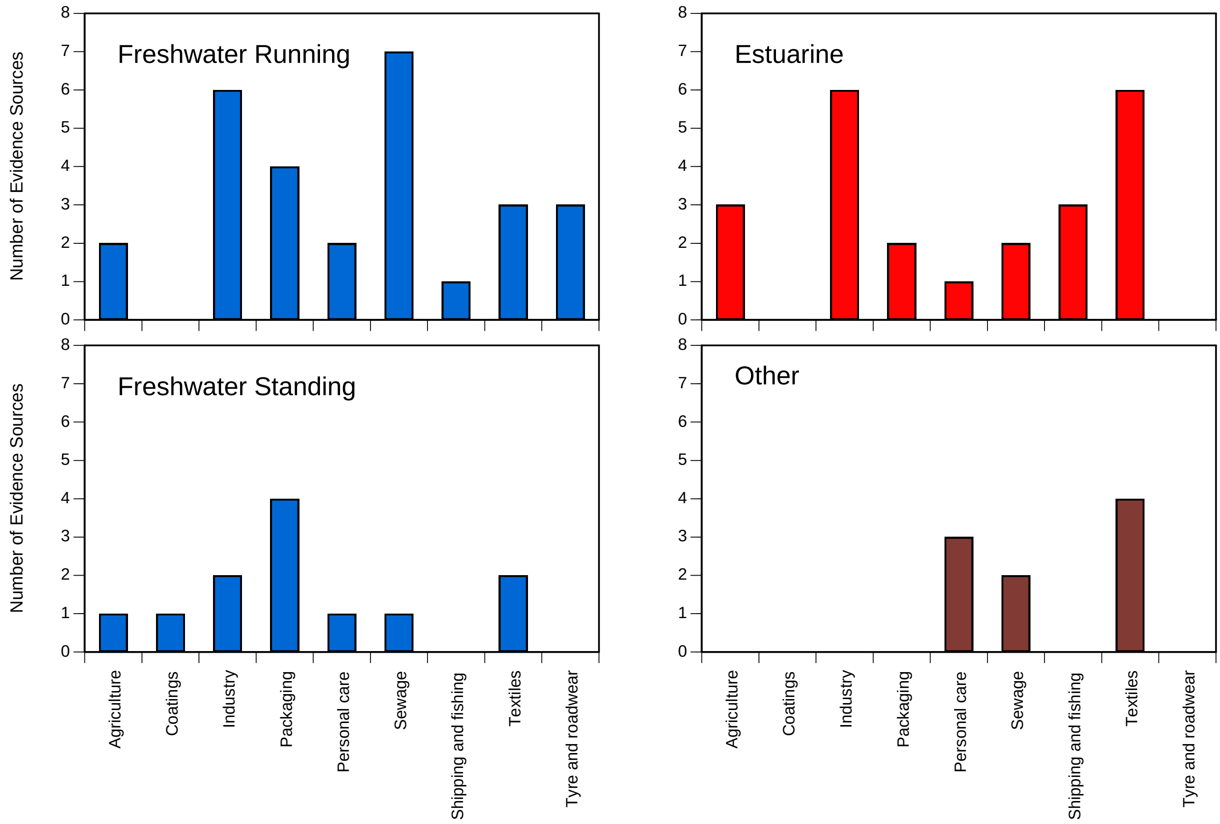

Fig. 4 Sources of microplastics reported to have been found by habitat.

Estimates of the emissions of microplastics from different sources to the marine environment have been variously made based on estimated loss rates (Sundt et al. 2014, Essel et al. 2015, Lassen et al. 2015, Magnusson et al. 2016, Boucher and Friot 2017, Bertling et al. 2018, Hann et al. 2018), but provide no specific estimates of losses to freshwaters or estuaries. In these studies, the contribution of fragmentation of larger macroplastics to the load of microplastics was either not considered or estimated as a proportion of mismanaged waste. A modelling study has been undertaken for Switzerland which gave estimates of emissions to freshwaters (Table 2.5) based on probabilistic estimates of material flows and assumed emissions of microplastic (and macroplastic) particles from various sources (Kawecki and Nowack 2019). Nevertheless, processes that affect the transport and fate of microplastic (and macroplastic) particles after emission were not included in this model (nor any other emission based models), so it is not possible to relate modelled emissions to concentrations of microplastics in freshwaters and estuaries. Furthermore, verification of many of the assumptions on which such models are based is lacking to date. Hence, considerable uncertainties remain concerning the main sources responsible for the microplastics present in freshwater and estuarine environments.

Table 2.5 Modelled total emissions of microplastics to surface waters and to all compartments in Switzerland by polymer (Kawecki and Nowack 2019)

Polymer	**Total emissions of microplastics to surface waters**	**Total emissions of microplastics to all compartments**
Low-density polyethylene (LDPE)	0.41 ± 0.2	141 ± 78
High-density polyethylene (HDPE)	3.7 ± 3.1	98 ± 24
Polypropylene (PP)	3.1 ± 2.2	162 ± 48
Polystyrene (PS)	0.59 ± 0.32	20.2 ± 5.3
Expanded polystyrene (EPS)	0.181 ± 0.086	6.6 ± 1.8
Polyvinyl chloride (PVC)	2.8 ± 1.7	112 ± 34
Polyethylene terephthalate (PET)	4.1 ± 6.7	71 ± 47

Estimates are mean ± standard deviation as tonnes per annum for Switzerland. NB tyre wear particles were not included in the model.

Considerable uncertainties remain concerning the main sources responsible for the microplastics present in freshwater and estuarine environments. A robust assessment of the relative importance of different sources contributing to the microplastics found in freshwaters and estuaries is not possible with the evidence currently available.

4.2 Secondary question: Are these primary (i.e. manufactured) or secondary (i.e. degradation products) microplastics?

The majority of studies describing the microplastics present in freshwaters and estuaries did not discriminate between primary and secondary microplastic particles. Where studies did discriminate, most ascribed the particles to either a mixture of primary and secondary microplastics or to secondary microplastics (Fig 5). This pattern was replicated across the different habitats, with the exception of other freshwaters (largely outflows from treatment works) where most studies ascribed particles to secondary particles (Fig 6). A similar pattern was evident among the different matrices, where most studies of water and sediment ascribed microplastic particles to a mixture of both primary and secondary, whereas most studies of biota (albeit very few) ascribed them to secondary.

The studies that did discriminate between primary and secondary microplastic particles variously used shape, surface texture (determined using scanning electron microscopy) and surface oxidation (determined using FTIR). Spherical or near-spherical shaped particles were assumed to be primary microplastic particles whereas other morphologies were assumed to be secondary particles, and surface damage or surface oxidation was assumed to indicate that the particle was a secondary particle. Yet, none of these characteristics are absolute at discriminating between primary and secondary particles.

Spherical or near-spherical shaped secondary particles could arise through abrasion or incomplete combustion of larger particles, and the surfaces of primary particles become damaged and oxidised with age once they have entered the environment (Chauhan et al. 2018). Furthermore, primary microplastics are not necessarily spherical with smooth surfaces (Kalčíková et al. 2017). Using the data compiled during ER1, it was apparent that the likelihood of particles being described as primary microplastics was correlated with the size of the particles being considered (Fig 7). Confident attribution of the sources of the particles found in freshwaters and estuaries as either primary or secondary is not possible. Nevertheless, the modelling study of Kawecki and Nowack (2019) indicated that the majority of microplastics released are from secondary sources.

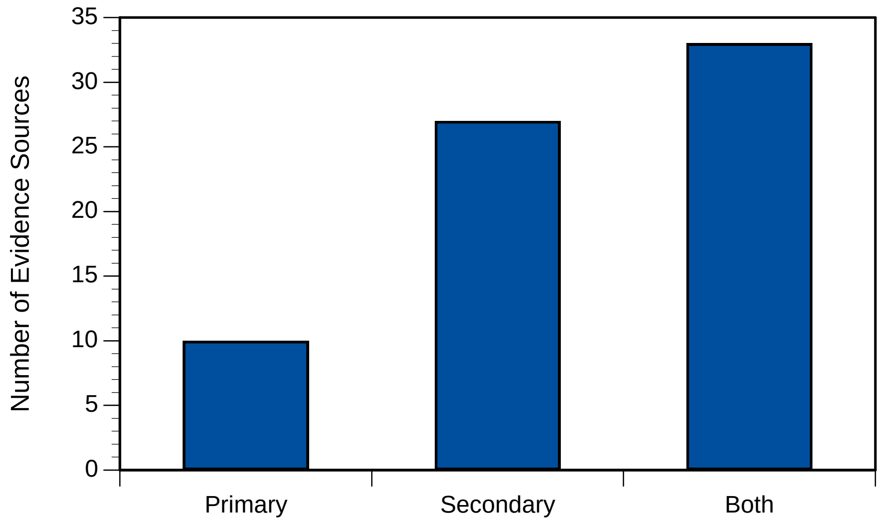

Fig 5. Type of microplastic particles, primary or secondary, identified in freshwaters and estuaries.

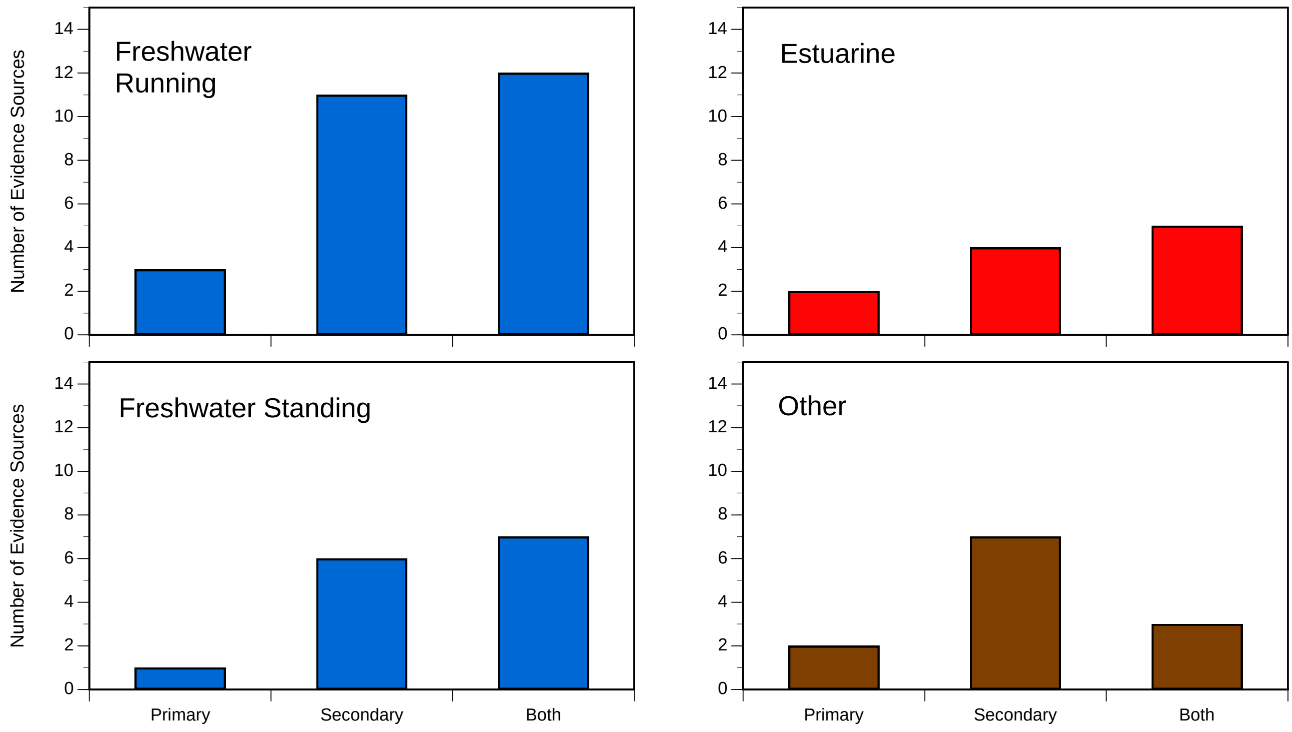

Fig 6. Number of studies which identified microplastic particles as primary or secondary by habitat.

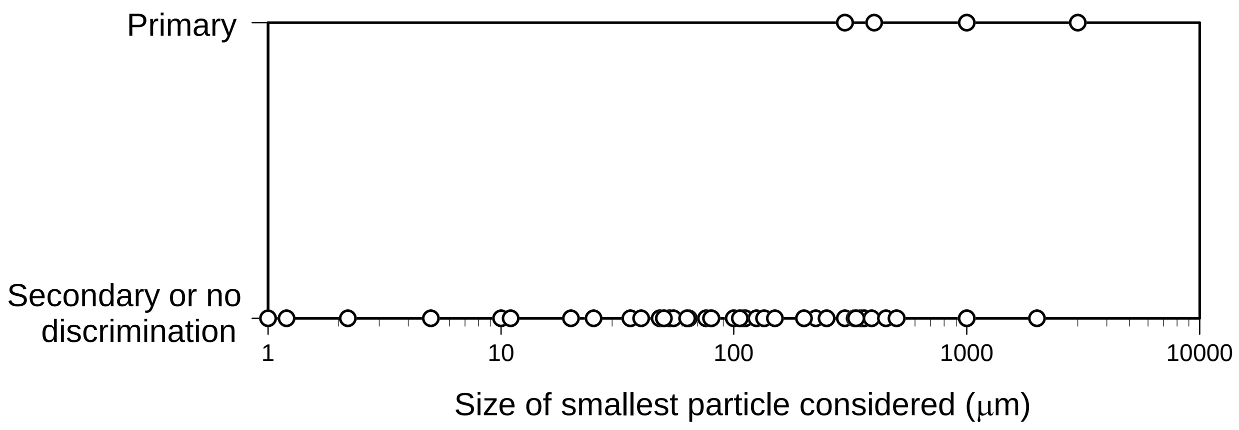

Fig 7. Relationship between size of particles and attribution to either primary or secondary microplastics (or no discrimination).

> Although it appears that secondary microplastic particles are more abundant in freshwaters and estuaries than primary particles, confident attribution of the sources of the particles found in freshwaters and estuaries as either primary or secondary is not possible.

4.3 Secondary question: How are microplastics transported and modified in freshwater and estuarine environments?

To address this question data were captured on both pathways and processes that potentially transport and modify the profile of microplastic particles considered by the studies.

4.3.1 Pathways

Of the release pathways of microplastics considered, most evidence available concerned release via wastewater (Fig 8). Other release pathways considered included, surface run off, direct inputs to surface waters from terrestrial sources, inputs via tributaries, direct inputs from fisheries and aquaculture, and aerial deposition (in decreasing order of number of studies). Only two studies considered inputs via aerial deposition. The number of studies available does not necessarily reflect the relative importance of the different pathways. Release via wastewater was the most studied pathway of release into flowing waters and estuaries, where studies focussed on either passage through treatment works or upstream-downstream comparisons of microplastics in waterbodies receiving effluent from treatment works.

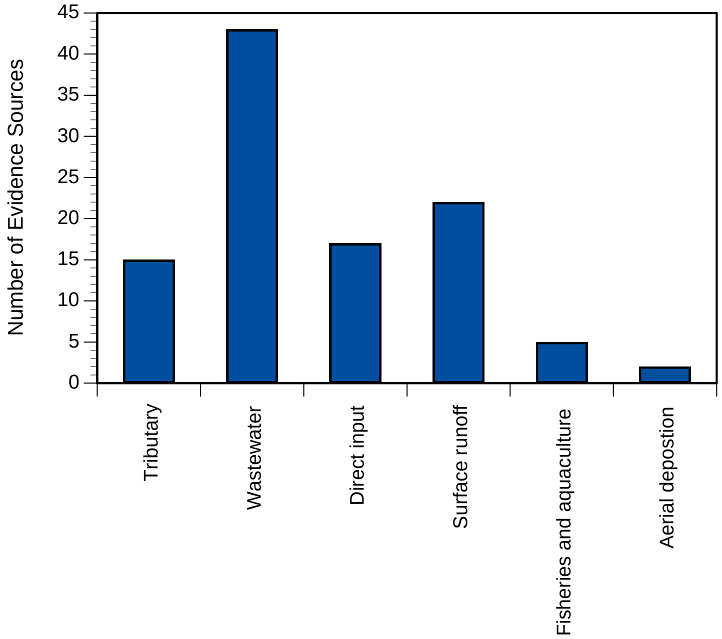

Fig 8. Pathways of release of microplastics to freshwaters and estuaries.

In terms of the effect of transport pathways on the profile of microplastics, most evidence was available on the effect of transport from upstream to downstream, with the second highest number of studies concerned with the passage through sewage treatment works (Fig 9).

Most studies considering the passage through sewage treatment works reported a decrease in the total abundance of microplastics (Fig 10), with 79 to 99 % of particles removed from the water compared with the concentration in influent water, dependent on the design of the works. Three studies reported an increase in abundance of microplastics on passage through treatment works, and in all three cases these studies considered concentrations of microplastics in sedimented sludge. The influence of other pathways on the abundance of microplastics was more equivocal, with studies reporting an increase, decrease or no change (Fig 10).

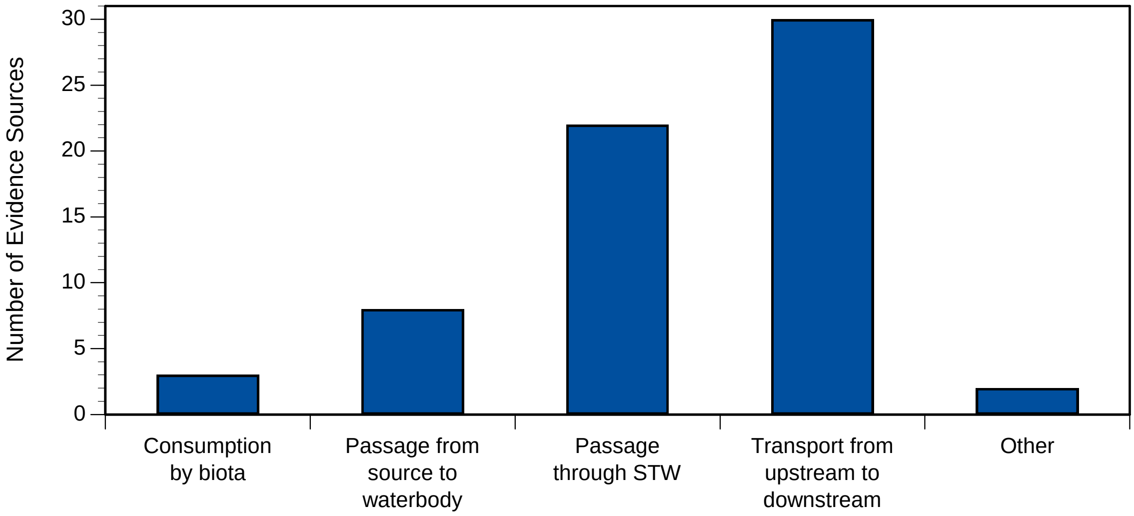

Fig 9. Volume of evidence regarding influence of transport pathways on microplastics in freshwaters and estuaries.

The influence of the pathways considered on the average size of the microplastic particles was equivocal, with studies reporting an increase, decrease or no change (Fig 10). When considering passage though treatment works, unlike change in total abundance, there was no influence of whether studies had considered water or sediment on the direction of change in average size of particles. However, it should be noted that the numbers of studies reporting on change in average size were low. Similarly, a low number of studies reported the influence of pathways on morphology and profile. Those studies that were available, appeared to indicate a change in morphology profile from upstream to downstream (Fig 10), and a change in polymer profile on passage through treatment works (Fig 10), but these findings cannot be considered conclusive as they are based on few studies.

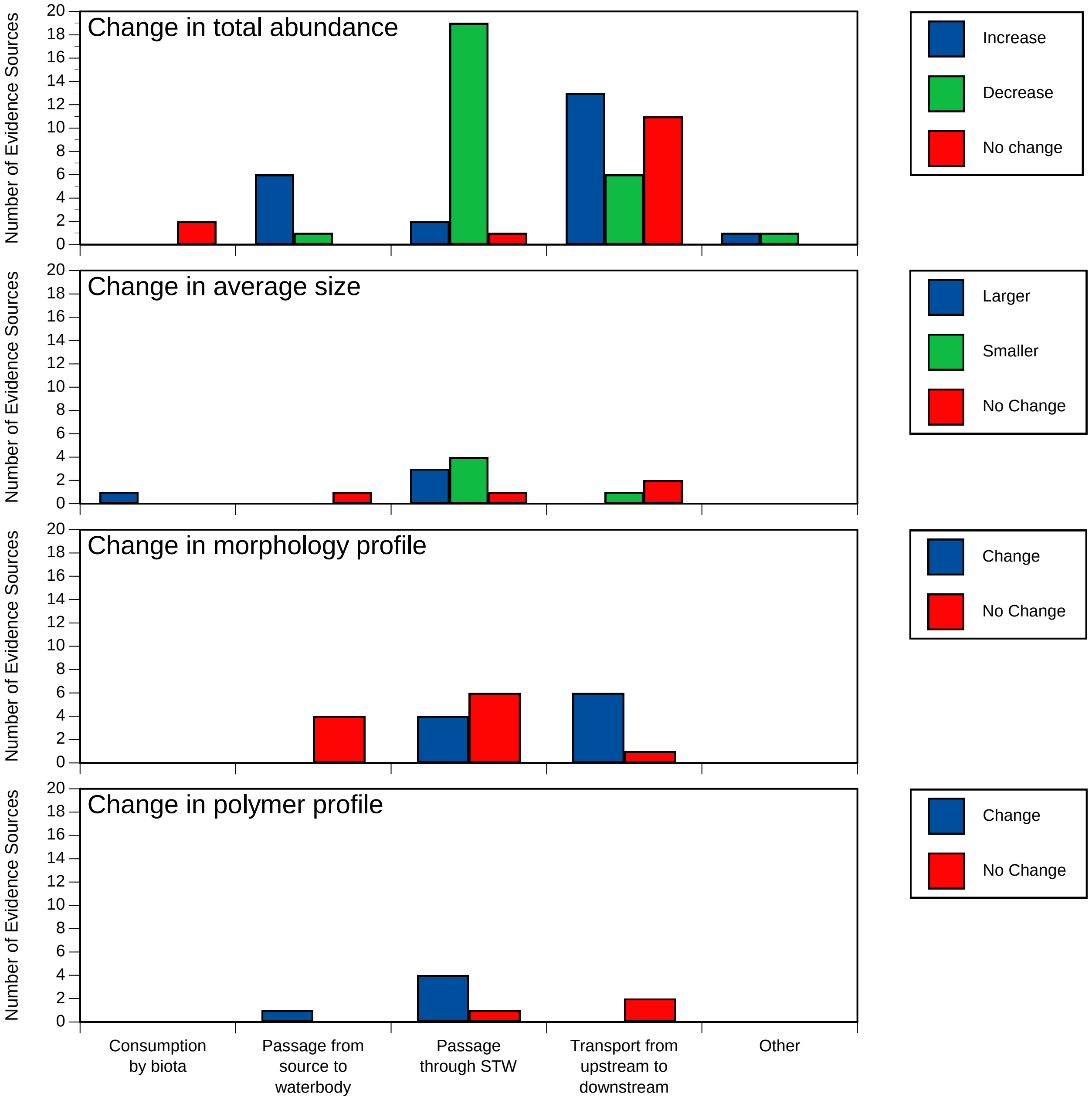

Fig 10. Influence of transport pathways on the profile of microplastics found in freshwaters and estuaries.

4.3.2 Processes

Only a small volume of evidence was available that considered the effect of transport processes on the profile of microplastics in freshwaters and estuaries. Most of these studies considered the effects of transport processes on total abundance. Unsurprisingly, deposition was associated with a decrease in abundance in water and an increase in sediment (Fig 11). The influence of other processes (resuspension, aggregation and degradation) on total abundance was equivocal, although the number of studies was too low to provide a conclusive assessment. Nevertheless, the work of Hoellein et al. (2019), involving careful experimental manipulation in experimental channels, indicated that the deposition velocity of microplastic particles in flowing waters (affected by deposition and resuspension) followed the patterns expected for natural organic particles of equivalent size and density, such that existing understanding of the movement of particles could be applied to microplastics and models of transport developed based on this assumption (Nizzetto et al. 2016b). Two studies reported an increase in the abundance of particles with degradation, whilst one reported a decrease: this difference appears to be one of scale, where the fragmentation of larger particles resulted in an increase in abundance (Song et al. 2018, Xiong et al. 2019), whilst the degradation of smaller particles resulted in the apparent loss of particles (da Silva Dutra et al. 2019).

Studies of deposition and aggregation of microplastics only reported an increase in average size, in both cases from studies of sediment, whereas studies of degradation only reported a decrease in average size (Fig 11). Degradation does not just occur through physical abrasion; microbial degradation has been shown to result in the loss of mass of particles (Brunner et al. 2018, Park and Kim 2019) although the extent to which such biological degradation occurs is not known. Change in the profile of microplastic particle morphologies was only described by studies of deposition, and change in profile of polymers was described by studies of deposition and degradation. Difference among particles in terms of their size, morphology and the density of the polymer appears to influence their propensity to settle out of the water column (e.g. Di and Wang 2018, Hoellein et al. 2019, Watkins et al. 2019). Deposition reduces the concentration of microplastics in water, and affects the profile of size, morphology and polymers, with larger, denser particles more likely to partition to sediments. Particles composed of less resistant polymers are more likely to be degraded (Brunner et al. 2018, Park and Kim 2019).

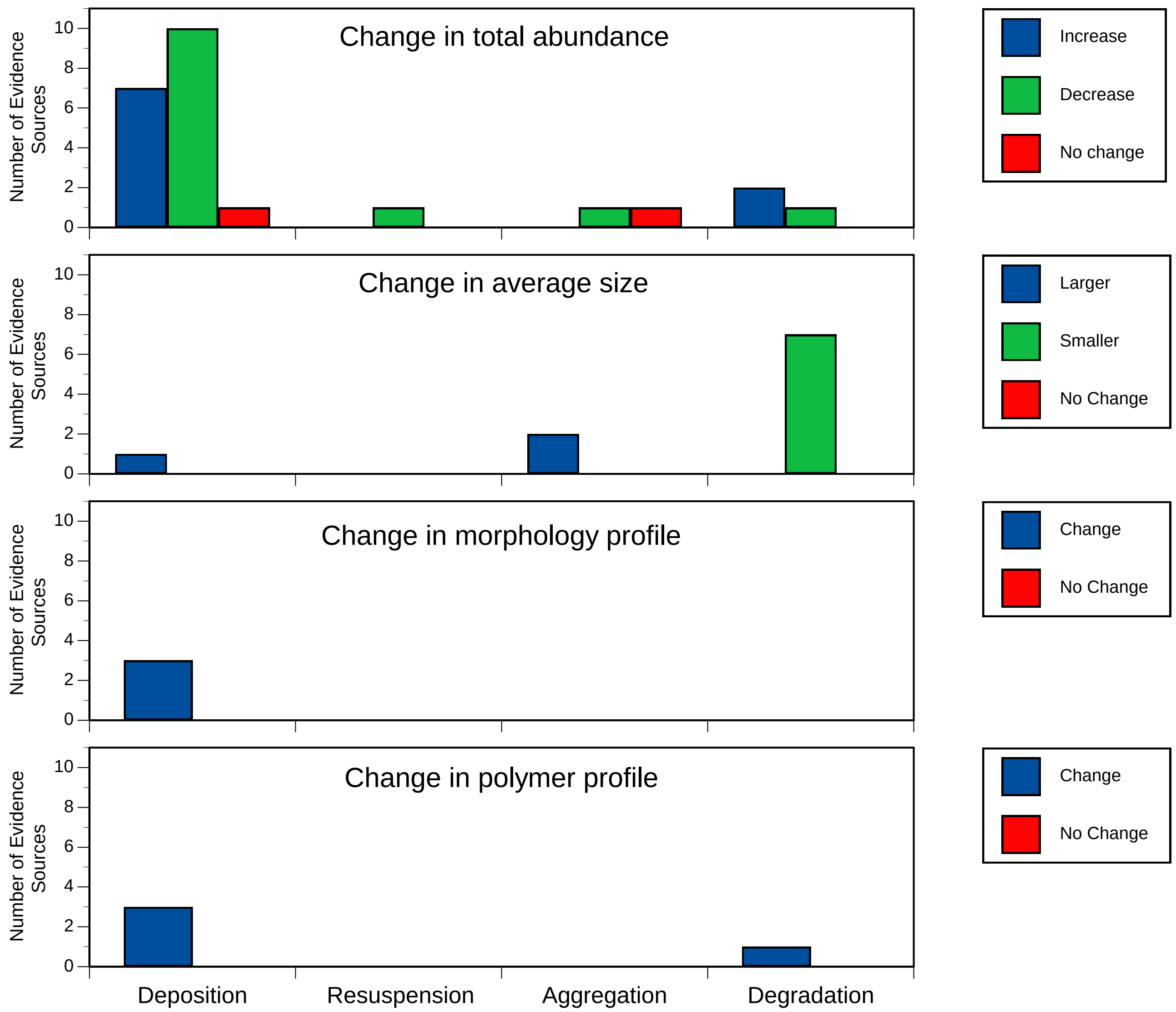

Fig 11. Effect of transport processes on the profile of microplastics in freshwaters and estuaries.

4.4 Secondary question: Within studies reporting the predominant types of microplastics found, is there a link identified to local land use or industry?

As detailed in section 4.1, very few studies provided clear evidence identifying the source(s) of the microplastics present in freshwater and estuarine environments. Where sources were identified, it was typically though upstream-downstream comparison focussing on point sources. Here, as detailed in section 4.3, the influence of upstream to downstream on the profile of microplastics such that a link to local land use or industry (e.g. urban areas: Klein et al. 2015, Mani et al. 2015, Miller et al. 2017) could be identified was equivocal (Fig 10). Where changes in the profile of microplastics were identified, it was typically through a spatially constrained sampling strategy focussed on a specific, pre-defined point source (e.g. Kay et al. 2018), although such a strategy did not always result in a link being identified (e.g. Barrows et al. 2018, Lin et al. 2018, Alam et al. 2019). As such, at this time it is not possible to conclude that there is a link between local land use or industry and the predominant microplastics found in freshwaters and estuaries.

Using the evidence available, it was not possible to conclude that there is a link between local land use or industry and the predominant microplastics found in freshwaters and estuaries.

4.5 Secondary question: Are microplastics from different sources prevalent in different matrices of the aquatic environment (biota, water, or sediment)?

Notwithstanding the caveats outlined in section 4.1, i.e. that there are considerable uncertainties concerning the attribution of the sources of the microplastics present in freshwater and estuarine environments, there did not appear to be considerable distinction among the matrices of the aquatic environment in terms of the sources attributed. Textiles, sewage, personal care products, industry and packaging were the more frequently identified sources of the microplastics in water, and industry, textiles and packaging the more frequently identified sources of the microplastics in sediment (Fig 12). However, the attribution of sources may reflect the design and aims of the studies in question rather than a robust assessment of the relative importance of different sources. Very few studies provided sufficient evidence to identify the sources of the microplastics within biota.

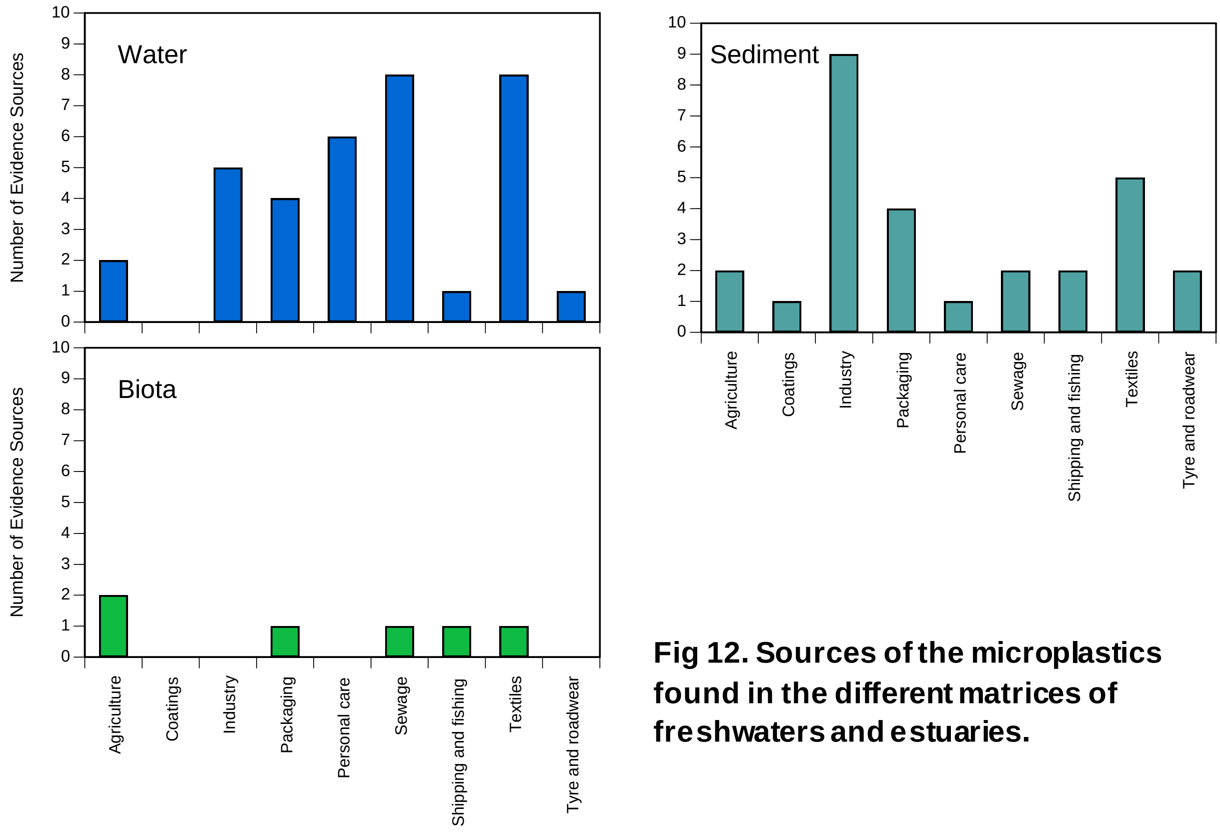

Fig 12. Sources of the microplastics found in the different matrices of freshwaters and estuaries.

Where the source of microplastics was identified, most studies ascribed the particles to either a mixture of primary and secondary microplastics or to secondary microplastics, irrespective of the matrix (Fig 13). This finding is in line with the findings of section 4.2, but is also covered by the same caveats, i.e. that confident attribution of the microplastic particles found in freshwaters and estuaries as either primary or secondary microplastics is not possible.

The most frequently reported release pathway of microplastics to water was via sewage, although studies also reported contributions via direct inputs, tributaries, surface run-off and direct inputs from fisheries and aquaculture (Fig 14). Studies of the microplastics in sediment identified the same release pathways as those in water, with wastewater also identified by the highest number of studies. Few studies identified the release pathways of the microplastics in biota, however, aerial deposition was identified as a release pathway which was not identified by any studies of microplastics in water or sediment. Nevertheless, it should be noted that caveats outlined in section 4.3.1 are applicable to these findings: the number of studies available does not necessarily reflect the relative importance of the different pathways, rather the design of those studies. No studies considered the relative importance of different release pathways for the microplastics present in the different matrices. Furthermore, the only modelling study to give estimates of emissions to freshwaters to date (Kawecki and Nowack 2019), did not provide any information on the fate of those microplastics once released and, thus, could not provide any indication of the relative importance of different sources and release pathways for the different matrices.

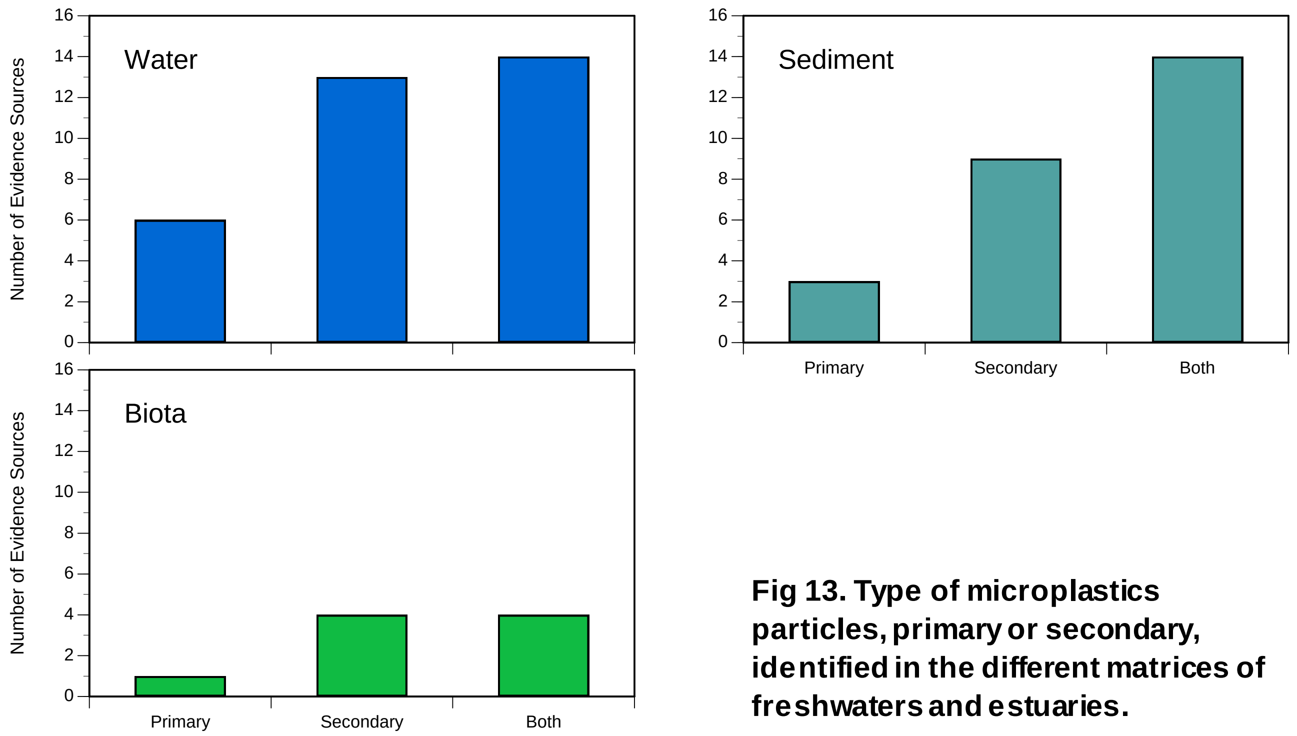

Fig 13. Type of microplastics particles, primary or secondary, identified in the different matrices of freshwaters and estuaries.

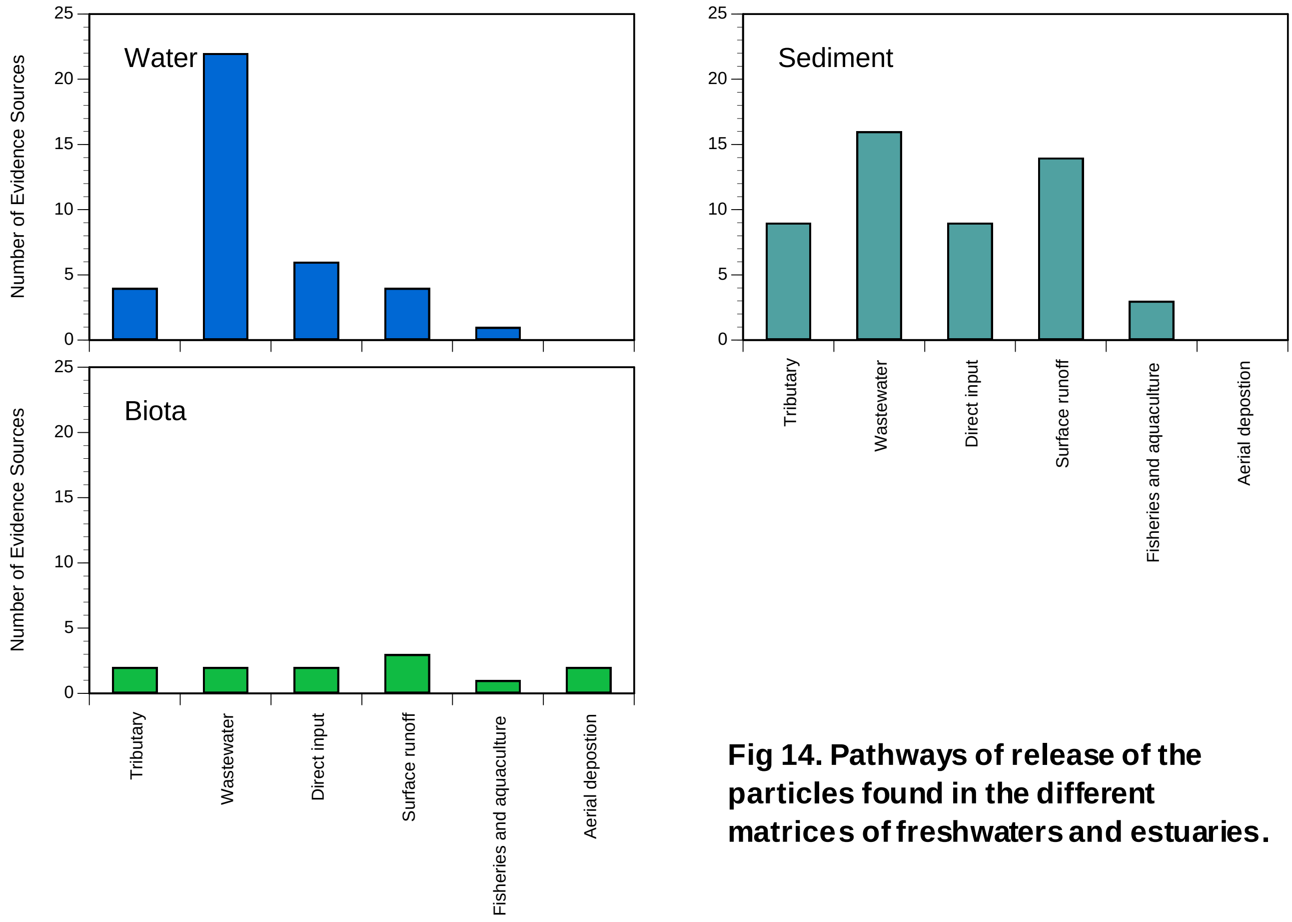

Fig 14. Pathways of release of the particles found in the different matrices of freshwaters and estuaries.

The evidence available is insufficient to conclude that the microplastics prevalent in different matrices of the aquatic environment (biota, water, or sediment) are from different sources.

4.6 Reliability

Cumulative reliability scores ranged from 0 to 17 (Fig. 15), with an average of cumulative score of 8.38, a score that was less than half of the points available (total possible score = 18 for studies of water and/or sediment, 20 for studies of biota). The number of reliability categories that scored zero ranged from the maximum possible 9 to 0 per study (Fig. 15). A zero score in any criterion indicated it was evaluated as “not reliable”: the average was 3.66 zeros per study, which indicates that most studies were based on methods that were unreliable in over a third of the aspects considered. Using a more punitive measure of reliability, the product of the scores in all categories, only 8 studies did not score 0. Overall, the majority of studies regarding the sources and transport of microplastics in freshwaters and estuaries are based on methods that are in many aspects not reliable. It should be noted that it was not possible to score 25 of the studies considered, largely experimental studies, as they did not use methods that fitted to the reliability categories considered.

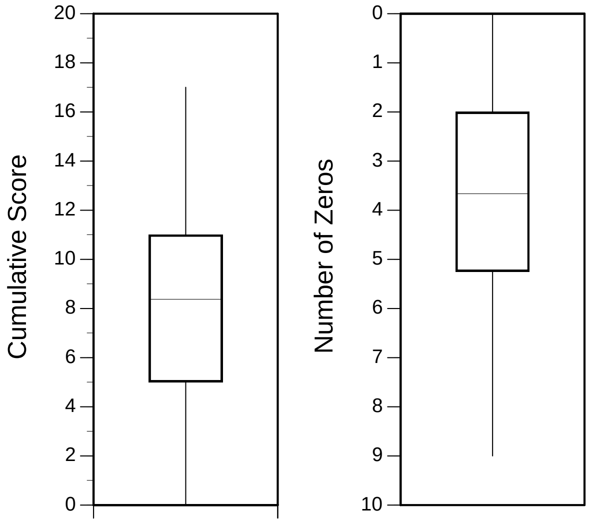

Fig 15. Range, 25%ile, 75%ile, and mean for cumulative score and number of zero reliability scores.

The majority of studies regarding the sources and transport of microplastics in freshwaters and estuaries are based on methods that are in some aspects not reliable.

5. Limitations

Key limitations of this review are outlined below; these stem primarily from the fact that this is a relatively new and developing scientific field.

There are inconsistencies in the way methods and results are reported in different studies.

The design of the field based studies considered, and the preconceptions underlying these designs, are likely to have influenced the results obtained by those studies.

Methods are developing rapidly. To date, no formal linking of sources to particles in the environment, using tracers or source apportionment, has been undertaken.

The findings presented are summaries of the evidence available and, therefore, are infuenced by the reliability of the primary literature, including grey literature, on which this report is based. An assessment of the reliability of the 125 studies included in this review was undertaken (see section 4.6). However, this assessment of reliability was not used to exclude studies from the review, which was based on all 125 evidence sources.

6. Conclusions

The aim of this evidence review was to address the question "What are the sources of microplastics reported to have been found in freshwater and estuarine environments?" using the evidence available from studies of microplastics in freshwaters and estuaries. It was clear from this evidence that considerable uncertainties remain concerning the main sources responsible for the microplastics present in freshwater and estuarine environments. The experts interviewed were also of the opinion that there is considerable uncertainty regarding the sources of the microplastic particles found in freshwater and estuarine environments. There is evidence that microplastics from certain sources (e.g. industry, waste water treatment works, tyre wear) are present in freshwaters and estuaries, but a robust assessment of the relative importance of different sources contributing to the microplastics found in freshwaters and estuaries is not possible with the evidence currently available. Most models of release of microplastics into the environment do not specify the receiving environment, and none include the processes that affect the transport and fate of microplastic (and macroplastic) particles after emission, so it is not possible to relate modelled emissions to concentrations of microplastics in freshwaters and estuaries. Achieving robust conclusions was further hindered as the reliability of the evidence on microplastics based on field studies was poor: only 8 studies did not score at least one zero, indicating that most studies were unreliable in at least one aspect.

Confident attribution of the sources of the microplastic particles found in freshwaters and estuaries as either primary (i.e. manufactured) or secondary (i.e. degradation products) is not possible. Nevertheless, the available evidence indicated that the majority of microplastics released are from secondary sources, and it appears that secondary microplastic particles are more abundant in freshwaters and estuaries than primary particles.

The experts interviewed were of the opinion that the main sources of microplastics in freshwaters and estuaries are likely to vary spatially, dependent on the types of activities undertaken in the catchment of the waterbody. However, using the evidence available, it was not possible to conclude that there is a link between local land use or industry and the predominant microplastics found in freshwaters and estuaries. Models can estimate the rate of emission of particles, but little is known about the fate of microplastics once they are released. The experts were of the opinion that the evidence linking the microplastics found in freshwaters and estuaries to specific sources is weak and only applicable to point sources: most inputs are likely to be diffuse.

Transport processes affect the profile of microplastics in freshwaters and estuaries, which may confound identification of the sources of microplastics. Deposition reduces the concentration of microplastics in water, and affects the profile of size, morphology and polymers. There is evidence that particles degrade through the action of physical and biological processes, affecting the concentration and profile of microplastics, although little is known about the process and rate of degradation under environmental conditions. Passage through sewage treatment works results in a substantial decrease in the concentration of microplastics in effluent compared with influent water and an increase in the concentration of microplastics in sedimented sludge. The influence of other transport pathways on the profile of microplastics appears equivocal. However, the movement of microplastics through the environment appears to follow the patterns expected for natural organic particles of equivalent size and density, opening up the possibility of using existing knowledge to model the movement of microplastics though the environment.

Although differences in the profile of microplastics are expected to occur among the different matrices, the evidence available is insufficient to conclude that the microplastics prevalent in different matrices of the aquatic environment (biota, water, or sediment) are from different sources. This finding corroborated the opinion of the external experts, who indicated that there is insufficient evidence to confidently define any differences among the matrices, or the mechanisms that lead to such differences.

7. Recommendations

Based on the findings of this evidence review, it is recommended that a more robust approach to identifying the sources of microplastic particles found in freshwaters and estuaries is adopted. To date, the identification of the source of particles found has been subjective and putative. It is suggested that the approaches used to identify sources of fine sediment, such as tracers and source apportionment, may provide a fruitful line of investigation.

Although models have been developed to estimate the release of microplastics into the environment, the fate and transport processes that occur after release have not been included within these models. It is recommended that such fate and transport processes are included in release models in order to predict environmental concentrations of microplastics in freshwaters and estuaries. Similarly, it is recommended that such models should be polymer specific, as in the release models developed by Kawecki and Nowack (2019). In this way it may be possible to compare estimates with data describing field concentrations. A more robust approach to quantifying and characterising the microplastic particles found in freshwaters and estuaries is required also, in order to provide data of sufficient quality that can be used to verify release models.

To enable such models, more research effort is required to determine the influence of processes and pathways on the fate of microplastics once they are released. Here, the understanding developed through studies of the movement of sediments could be adopted as the available evidence indicates that microplastics follow the patterns expected for natural organic particles of equivalent size and density.

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Song, Y. K., S. H. Hong, M. Jang, G. M. Han, S. W. Jung, and W. J. Shim. 2018. Combined Effects of UV Exposure Duration and Mechanical Abrasion on Microplastic Fragmentation by Polymer Type. Environmental Science & Technology **52**:3831-3832.

Sundt, P., P.-E. Schulze, and F. Syversen. 2014. Sources of Microplastic Pollution to the Marine Environment;. Norwegian Environment Agency https://www.miljodirektoratet.no/globalassets/publikasjoner/M321/M321.pdf.

Thompson, R. C., Y. Olsen, R. P. Mitchell, A. Davis, S. J. Rowland, A. W. G. John, D. McGonigle, and A. E. Russell. 2004. Lost at sea: Where is all the plastic? Science **304**:838-838.

Watkins, L., S. McGrattan, P. J. Sullivan, and M. T. Walter. 2019. The effect of dams on river transport of microplastic pollution. Science of the Total Environment **664**:834-840.

Xiong, X., C. Wu, J. J. Elser, Z. Mei, and Y. Hao. 2019. Occurrence and fate of microplastic debris in middle and lower reaches of the Yangtze River – From inland to the sea. Science of the Total Environment **659**:66-73.

Appendix A ER2_Capture.xls

See Excel spreadsheet ER2_Capture.xls. Column headers reproduced here for convenience

Evidence							
Ref No	Reference	Year	Title	Journal	Vol	Pages	URL
free	free	free	free	free	free	free	free

Waterbody Type	Study Type	Matrix		Smallest size particles considered (in µm)	Influence of Pathways?
			Other detail	µm	
menu	menu	menu	free	free	Y/N

Influence of Pathway/Transport on Total Abundance			
Effect of pathway	Pathway/transport	Details of pathway	Change in total abundance
Y/N	menu	free	menu

Influence of Pathway/Transport on Size Distribution			
Effect of pathway	Pathway/transport	Details of pathway	Change in size distribution
Y/N	menu	free	menu

Influence of Pathway/Transport on Relative Abundance of Morphologies			
Effect of pathway	Pathway/transport	Details of pathway	Change in morphology profile
Y/N	menu	free	menu

Influence of Pathway/Transport on Relative Abundance of Polymers			
Effect of pathway	Pathway/transport	Details of pathway	Change in polymer profile
Y/N	menu	free	menu

Influence of Process?	Influence of Process on Total Abundance			
	Effect of process	Process	Details of process	Change in total abundance
Y/N	Y/N	menu	free	menu

Influence of Process on Size Distribution			
Effect of Process	Process	Details of Process	Change in size distribution
Y/N	menu	free	menu

Influence of Process on Relative Abundance of Morphologies			
Effect of Process	Process	Details of Process	Change in morphology profile
Y/N	menu	free	menu

Influence of Process on Relative Abundance of Polymers			
Effect of Process	Process	Details of Process	Change in polymer profile
Y/N	menu	free	menu

Sources	Products			Sources/pathways				Character
	Product 1	Product 2	Other	Source 1	Source 2	Other		Primary/secondary
Y/N	menu	menu	free	menu	menu	free	free	menu

Plastic			Polymer				
Macro-	Micro-	Nano-	Polymer 1	Polymer 2	Polymer 3	Polymer 4	Other
Y/N	Y/N	Y/N	menu	menu	menu	menu	free

Quantities						
Quantified?	Load	Units	Time	Per capita	Units	Time
Y/N	free	menu	menu	Y/N	menu	menu

Continent	UK Location			
	UK	Lat	Long	Comments
menu	Y/N	free	free	free

menu = choice of options from pull down menu

Y/N = choice of Yes or No from pull down menu

free = any information can be entered into the field

Appendix B. Evidence Sources Used

Reference	Year	Title	Publication	Vol	Pages
Alam, FC, Sembiring E, Muntalif BS and Suendo V	2019	Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia)	Chemosphere	224	637-645
Amamiya, K, Saido K, Chung SY, Hiaki T, Lee DS and Kwon BG	2019	Evidence of transport of styrene oligomers originated from polystyrene plastic to oceans by runoff	Science of the Total Environment	667	57-63
Anderson, AG, Grose J, Pahl S, Thompson RC and Wyles KJ	2016	Microplastics in personal care products: Exploring perceptions of environmentalists, beauticians and students	Marine Pollution Bulletin	113	454-460
Baldwin, AK, Corsi SR and Mason SA	2016	Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology	Environ Sci Technol	50	10377-10385
Ball, H, Cross R, Grove E, Horton A, Johnson A, Jürgens M, Read D and Svendsen C	2019	Sink to River - River to TapA review of potential risks from nanoparticles and microplastics.	UK Water Industry Research Limited	EQ01A231	
Barrows, APW, Christiansen KS, Bode ET and Hoellein TJ	2018	A watershed-scale, citizen science approach to quantifying microplastic concentration in a mixed land-use river	Water Res	147	382-392
Bayo, J, Olmos S and López-Castellanos J	2018	Non-polymeric chemicals or additives associated with microplastic particulate fraction in a treated urban effluent	WIT Transactions on The Built Environment	179	303-314
Blaskovic, A, Guerranti C, Fastelli P, Anselmi S and Renzi M	2018	Plastic levels in sediments closed to Cecina river estuary (Tuscany, Italy)	Mar Pollut Bull	135	105-109

Reference	Year	Title	Publication	Vol	Pages
Bordos, G, Urbanyi B, Micsinai A, Kriszt B, Palotai Z, Szabo I, Hantosi Z and Szoboszlay S	2019	Identification of microplastics in fish ponds and natural freshwater environments of the Carpathian basin, Europe	Chemosphere	216	110-116
Boucher, J, Faure F, Pompini O, Plummer Z, Wieser O and Felippe de Alencastro L	2019	(Micro) plastic fluxes and stocks in Lake Geneva basin	TrAC, Trends Anal Chem	112	66-74
Brunner, I, Fischer M, Rüthi J, Stierli B and Frey B	2018	Ability of fungi isolated from plastic debris floating in the shoreline of a lake to degrade plastics	PLoS ONE	13	
Campbell, SH, Williamson PR and Hall BD	2017	Microplastics in the gastrointestinal tracts of fish and the water from an urban prairie creek	Facets	2	395-409
Carr, SA, Liu J and Tesoro AG	2016	Transport and fate of microplastic particles in wastewater treatment plants	Water Res	91	174-182
Castaneda, RA, Avlijas S, Simard MA and Ricciardi A	2014	Microplastic pollution in St. Lawrence River sediments	Can J Fish Aquat Sci	71	1767-1771
Chauhan, D, Agrawal G, Deshmukh S, Roy SS and Priyadarshini R	2018	Biofilm formation by Exiguobacterium sp. DR11 and DR14 alter polystyrene surface properties and initiate biodegradation	RSC Advances	8	37590-37599
Chen, X, Xiong X, Jiang X, Shi H and Wu C	2019	Sinking of floating plastic debris caused by biofilm development in a freshwater lake	Chemosphere		856-864
Cheung, PK and Fok L	2017	Characterisation of plastic microbeads in facial scrubs and their estimated emissions in Mainland China	Water Res	122	53-61

Reference	Year	Title	Publication	Vol	Pages
Cheung, PK, Fok L, Hung PL and Cheung LTO	2018	Spatio-temporal comparison of neustonic microplastic density in Hong Kong waters under the influence of the Pearl River Estuary	Sci Total Environ	628-629	731-739
Corcoran, PL, Norris T, Ceccanese T, Walzak MJ, Helm PA and Marvin CH	2015	Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record	Environ Pollut (Oxford, U K)	204	17-25
Cox, K	2018	Distribution, Abundance, and Spatial Variability of Microplastic Pollution in Surface Waters of Lake Superior	University of Waterloo	MSc Thesis	
da Silva Dutra, L, de Souza Belan Costa T, Lobo VTV, Paiva TF, de Souza Nele M and Pinto JC	2019	Preparation of Polymer Microparticles Through Non-aqueous Suspension Polycondensations: Part III—Degradation of PBS Microparticles in Different Aqueous Environments	Journal of Polymers and the Environment	27	176-188
Dantas, DV, Barletta M and da Costa MF	2012	The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae)	Environmental Science and Pollution Research	19	600-606
Di, M and Wang J	2018	Microplastics in surface waters and sediments of the Three Gorges Reservoir, China	Sci Total Environ	616-617	1620-1627
Dris, R, Gasperi J, Rocher V and Tassin B	2018	Synthetic and non-synthetic anthropogenic fibers in a river under the impact of Paris Megacity: Sampling methodological aspects and flux estimations	Sci Total Environ	618	157-164
Dris, R, Gasperi J, Rocher V, Saad M, Renault N and Tassin B	2015	Microplastic contamination in an urban area: a case study in Greater Paris	Environ Chem	12	592-599

Reference	Year	Title	Publication	Vol	Pages
Dubaish, F and Liebezeit G	2013	Suspended Microplastics and Black Carbon Particles in the Jade System, Southern North Sea	Water, Air, Soil Pollut	224	1-8
Elsaker, S, Parrish K and Fahrenfeld N	2018	Role of bed sediments as a sink for microplastics	Abstracts of Papers of the American Chemical Society	256	ENVR -243
Estahbanati, S and Fahrenfeld NL	2016	Influence of wastewater treatment plant discharges on microplastic concentrations in surface water	Chemosphere	162	277-284
Faure, F, Demars C, Wieser O, Kunz M and de Alencastro LF	2015	Plastic pollution in Swiss surface waters: nature and concentrations, interaction with pollutants	Environ Chem	12	582-591
Free, CM, Jensen OP, Mason SA, Eriksen M, Williamson NJ and Boldgiv B	2014	High-levels of microplastic pollution in a large, remote, mountain lake	Mar Pollut Bull	85	156-163
Frere, L, Jaffre J, Bihannic I, Soudant P, Lambert C, Paul-Pont I, Rinnert E, Petton S and Huvet A	2017	Influence of environmental and anthropogenic factors on the composition, concentration and spatial distribution of microplastics: A case study of the Bay of Brest (Brittany, France)	Environ Pollut	225	211-222
Frere, L, Paul-Pont I, Rinnert E, Petton S, Jaffre J, Bihannic I, Soudant P, Lambert C and Huvet A	2017	Influence of environmental and anthropogenic factors on the composition, concentration and spatial distribution of microplastics: A case study of the Bay of Brest (Brittany, France)	Environ Pollut	225	211-222

Reference	Year	Title	Publication	Vol	Pages
Gallagher, A, Rees A, Rowe R, Stevens J and Wright P	2016	Microplastics in the Solent estuarine complex, UK: An initial assessment	Mar Pollut Bull	102	243-249
Gies, EA, LeNoble JL, Noel M, Etemadifar A, Bishay F, Hall ER and Ross PS	2018	Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada	Mar Pollut Bull	133	553-561
Gil-Delgado, JA, Guijarro D, Gosalvez RU, Lopez-Iborra GM, Ponz A and Velasco A	2017	Presence of plastic particles in waterbirds faeces collected in Spanish lakes	Environmental Pollution	220	732-736
Gundogdu, S, Cevik C, Ayat B, Aydogan B and Karaca S	2018	How microplastics quantities increase with flood events? An example from Mersin Bay NE Levantine coast of Turkey	Environmental Pollution	239	342-350
Hendrickson, E, Minor EC and Schreiner K	2018	Microplastic Abundance and Composition in Western Lake Superior As Determined via Microscopy, Pyr-GC/MS, and FTIR	Environ Sci Technol	52	1787-1796
Hernandez, E, Nowack B and Mitrano DM	2017	Polyester Textiles as a Source of Microplastics from Households: A Mechanistic Study to Understand Microfiber Release During Washing	Environmental Science & Technology	51	7036-7046
Hoellein, TJ, McCormick AR, Hittie J, London MG, Scott JW and Kelly JJ	2017	Longitudinal patterns of microplastic concentration and bacterial assemblages in surface and benthic habitats of an urban river	Freshwater Science	36	491-507
Hoellein, TJ, Shogren AJ, Tank JL, Risteca P and Kelly JJ	2019	Microplastic deposition velocity in streams follows patterns for naturally occurring allochthonous particles	Scientific Reports	9	

Reference	Year	Title	Publication	Vol	Pages
Hoffman, MJ and Hittinger E	2017	Inventory and transport of plastic debris in the Laurentian Great Lakes	Mar Pollut Bull	115	273-281
Horton, AA, Svendsen C, Williams RJ, Spurgeon DJ and 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	218-226
Hu, L, Chernick M, Hinton DE and Shi H	2018	Microplastics in Small Waterbodies and Tadpoles from Yangtze River Delta, China	Environ Sci Technol	52	8885-8893
Hurley, R, Woodward J and Rothwell JJ	2018	Microplastic contamination of river beds significantly reduced by catchment-wide flooding	Nat Geosci	11	251-257
Imhof, HK, Ivleva NP, Schmid J, Niessner R and Laforsch C	2013	Contamination of beach sediments of a subalpine lake with microplastic particles	Current biology : CB	23	R867-868
Imhof, HK, Laforsch C, Wiesheu AC, Schmid J, Anger PM, Niessner R and Ivleva NP	2016	Pigments and plastic in limnetic ecosystems: A qualitative and quantitative study on microparticles of different size classes	Water Res	98	64-74
Imhof, HK, Wiesheu AC, Anger PM, Niessner R, Ivleva NP and Laforsch C	2018	Variation in plastic abundance at different lake beach zones - A case study	Sci Total Environ	613-614	530-537
Kalcikova, G, Alic B, Skalar T, Bundschuh M and Gotvajn AZ	2017	Wastewater treatment plant effluents as source of cosmetic polyethylene microbeads to freshwater	Chemosphere	188	25-31
Karlsson, TM, Arneborg L, Broström G, Almroth BC, Gipperth L and Hassellöv M	2018	The unaccountability case of plastic pellet pollution	Marine Pollution Bulletin	129	52-60

Reference	Year	Title	Publication	Vol	Pages
Kataoka, T, Nihei Y, Kudou K and Hinata H	2019	Assessment of the sources and inflow processes of microplastics in the river environments of Japan	Environ Pollut	244	958-965
Kay, P, Hiscoe R, Moberley I, Bajic L and McKenna N	2018	Wastewater treatment plants as a source of microplastics in river catchments	Environ Sci Pollut Res	25	20264-20267
Klein, S	2015	Microplastics in Freshwater Systems			
Klein, S, Worch E and Knepper TP	2015	Occurrence and Spatial Distribution of Microplastics in River Shore Sediments of the Rhine-Main Area in Germany	Environ Sci Technol	49	6070-6076
Lahens, L, Strady E, Kieu-Le TC, Dris R, Boukerma K, Rinnert E, Gasperi J and Tassin B	2018	Macroplastic and microplastic contamination assessment of a tropical river (Saigon River, Vietnam) transversed by a developing megacity	Environ Pollut	236	661-671
Lares, M, Ncibi MC, Sillanpaa M and Sillanpaa M	2018	Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology	Water Res	133	236-246
Lechner, A, Keckeis H, Lumesberger-Loisl F, Zens B, Krusch R, Tritthart M, Glas M and Schludermann E	2014	The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river	Environmental Pollution	188	177-181
Lee, H and Kim Y	2018	Treatment characteristics of microplastics at biological sewage treatment facilities in Korea	Mar Pollut Bull	137	1-8

Reference	Year	Title	Publication	Vol	Pages
Lehtiniemi, M, Hartikainen S, Näkki P, Engström-Öst J, Koistinen A and Setälä O	2018	Size matters more than shape: Ingestion of primary and secondary microplastics by small predators	Food Webs	17	
Lepot, L, Vanden Driessche T, Lunstroot K, Barret A, Gason F and De Wael K	2017	Extraneous fibre traces brought by river water — A case study	Science and Justice	57	53-57
Lin, L, Zuo LZ, Peng JP, Cai LQ, Fok L, Yan Y, Li HX and Xu XR	2018	Occurrence and distribution of microplastics in an urban river: A case study in the Pearl River along Guangzhou City, China	Sci Total Environ	644	375-381
Liu, P, Qian L, Wang H, Zhan X, Lu K, Gu C and Gao S	2019	New Insights into the Aging Behavior of Microplastics Accelerated by Advanced Oxidation Processes	Environmental Science and Technology	53	3579-3588
Long, Z, Pan Z, Wang W, Ren J, Yu X, Lin L, Lin H, Chen H and Jin X	2019	Microplastic abundance, characteristics, and removal in wastewater treatment plants in a coastal city of China	Water Research		255-265
Lourenco, PM, Serra-Goncalves C, Ferreira JL, Catry T and Granadeiro JP	2017	Plastic and other microfibers in sediments, macroinvertebrates and shorebirds from three intertidal wetlands of southern Europe and west Africa	Environ Pollut	231	123-133
Lu, S, Zhu K, Song W, Song G, Chen D, Hayat T, Alharbi NS, Chen C and Sun Y	2018	Impact of water chemistry on surface charge and aggregation of polystyrene microspheres suspensions	Science of the Total Environment	630	951-959
Luo, W, Su L, Craig NJ, Du F, Wu C and Shi H	2019	Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters	Environ Pollut (Oxford, U K)	246	174-182

Reference	Year	Title	Publication	Vol	Pages
Lv, W, Zhou W, Lu S, Huang W, Yuan Q, Tian M, Lv W and He D	2019	Microplastic pollution in rice-fish co-culture system: A report of three farmland stations in Shanghai, China	Science of the Total Environment	652	1209-1218
Magni, S, Binelli A, Pittura L, Avio CG, Della Torre C, Parenti CC, Gorbi S and Regoli F	2018	The fate of microplastics in an Italian Wastewater Treatment Plant	Sci Total Environ	652	602-610
Mani, T, Blarer P, Storck FR, Pittroff M, Wernicke T and Burkhardt-Holm P	2019	Repeated detection of polystyrene microbeads in the Lower Rhine River	Environ Pollut	245	634-641
Mani, T, Hauk A, Walter U and Burkhardt-Holm P	2015	Microplastics profile along the Rhine River	Sci Rep	5	17988
McCormick, A, Hoellein TJ, Mason SA, Schluep J and Kelly JJ	2014	Microplastic is an abundant and distinct microbial habitat in an urban river	Environ Sci Technol	48	11863-11871
McCormick, AR, Hoellein TJ, London MG, Hittie J, Scott JW and Kelly JJ	2016	Microplastic in surface waters of urban rivers: concentration, sources, and associated bacterial assemblages	Ecosphere	7	
McIlwraith, HK, Lin J, Erdle LM, Mallos N, Diamond ML and Rochman CM	2019	Capturing microfibers - marketed technologies reduce microfiber emissions from washing machines	Mar Pollut Bull	139	40-45
Michielssen, MR, Michielssen ER, Ni J and Duhaime MB	2016	Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed	Environ Sci: Water Res Technol	2	1064-1073

Reference	Year	Title	Publication	Vol	Pages
Miller, RZ, Watts AJR, Winslow BO, Galloway TS and Barrows APW	2017	Mountains to the sea: River study of plastic and non-plastic microfiber pollution in the northeast USA	Mar Pollut Bull	124	245-251
Mintenig, SM, Int-Veen I, Loder MGJ, Primpke S and Gerdts G	2017	Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-Fourier-transform infrared imaging	Water Res	108	365-372
Mintenig, SM, Loder MGJ, Primpke S and Gerdts G	2019	Low numbers of microplastics detected in drinking water from ground water sources	Sci Total Environ	648	631-635
Mitrano, DM, Beltzung A, Frehland S, Schmiedgruber M, Cingolani A and Schmidt F	2019	Synthesis of metal-doped nanoplastics and their utility to investigate fate and behaviour in complex environmental systems	Nature nanotechnology		
Moehlenkamp, P, Purser A and Thomsen L	2018	Plastic microbeads from cosmetic products: an experimental study of their hydrodynamic behaviour, vertical transport and resuspension in phytoplankton and sediment aggregates	Elementa-Science of the Anthropocene	6	
Mourgkogiannis, N, Kalavrouziotis IK and Karapanagioti HK	2018	Questionnaire-based survey to managers of 101 wastewater treatment plants in Greece confirms their potential as plastic marine litter sources	Mar Pollut Bull	133	822-827
Murphy, F, Ewins C, Carbonnier F and Quinn B	2016	Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment	Environ Sci Technol	50	5800-5808

Reference	Year	Title	Publication	Vol	Pages
Napper, IE and Thompson RC	2016	Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions	Mar Pollut Bull	112	39-45
Nel, HA, Dalu T and Wasserman RJ	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
Nizzetto, L, Bussi G, Futter MN, Butterfield D and Whitehead PG	2016	A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments	Environmental science Processes & impacts	18	1050-1059
Oriekhova, O and Stoll S	2018	Heteroaggregation of nanoplastic particles in the presence of inorganic colloids and natural organic matter	Environmental Science-Nano	5	792-799
Park, SY and Kim CG	2019	Biodegradation of micro-polyethylene particles by bacterial colonization of a mixed microbial consortium isolated from a landfill site	Chemosphere		527-533
Peng, G, Zhu B, Yang D, Su L, Shi H and Li D	2017	Microplastics in sediments of the Changjiang Estuary, China	Environ Pollut	225	283-290
Peters, CA and Bratton SP	2016	Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA	Environ Pollut	210	380-387
Phillips, MB and Bonner TH	2015	Occurrence and amount of microplastic ingested by fishes in watersheds of the Gulf of Mexico	Mar Pollut Bull	100	264-269
Pivokonsky, M, Cermakova L, Novotna K, Peer P, Cajthaml T and Janda V	2018	Occurrence of microplastics in raw and treated drinking water	Sci Total Environ	643	1644-1651

Reference	Year	Title	Publication	Vol	Pages
Primpke, S, Imhof H, Piehl S, Lorenz C, Loeder M, Laforsch C and Gerdts G	2017	Microplastics in the environment: environmental chemistry	Chem Unserer Zeit	51	402-412
Rodrigues, MO, Abrantes N, Goncalves FJM, Nogueira H, Marques JC and Goncalves AMM	2018	Spatial and temporal distribution of microplastics in water and sediments of a freshwater system (Antua~ River, Portugal)	Sci Total Environ	633	1549-1559
Schmidt, C, Krauth T and Wagner S	2017	Export of Plastic Debris by Rivers into the Sea	Environ Sci Technol	51	12246-12253
Schmidt, LK, Bochow M, Imhof HK and Oswald SE	2018	Multi-temporal surveys for microplastic particles enabled by a novel and fast application of SWIR imaging spectroscopy - Study of an urban watercourse traversing the city of Berlin, Germany	Environ Pollut	239	579-589
Shruti, VC, Jonathan MP, Rodriguez-Espinosa PF and Rodriguez-Gonzalez F	2019	Microplastics in freshwater sediments of Atoyac River basin, Puebla City, Mexico	Sci Total Environ	654	154-163
Sighicelli, M, Pietrelli L, Lecce F, Iannilli V, Falconieri M, Coscia L, Di Vito S, Nuglio S and Zampetti G	2018	Microplastic pollution in the surface waters of Italian Subalpine Lakes	Environ Pollut	236	645-651
Song, YK, Hong SH, Jang M, Han GM, Jung SW and Shim WJ	2017	Combined Effects of UV Exposure Duration and Mechanical Abrasion on Microplastic Fragmentation by Polymer Type	Environmental Science & Technology	51	4368-4376

Reference	Year	Title	Publication	Vol	Pages
Song, Z, Yang X, Chen F, Zhao F, Zhao Y, Ruan L, Wang Y and Yang Y	2019	Fate and transport of nanoplastics in complex natural aquifer media: Effect of particle size and surface functionalization	Science of the Total Environment	669	120-128
Stanton, T, Johnson M, Nathanail P, MacNaughtan W and Gomes RL	2019	Freshwater and airborne textile fibre populations are dominated by 'natural', not microplastic, fibres	Science of the Total Environment	666	377-389
Stolte, A, Forster S, Gerdts G and Schubert H	2015	Microplastic concentrations in beach sediments along the German Baltic coast	Mar Pollut Bull	99	216-229
Sturm, B, Bagchi S, Hiripitiyage Y, Mayo T and Handley J	2018	Environmental loading estimates and fate of microplastics from municipal wastewater treatment	Abstracts of Papers of the American Chemical Society, 256th ACS National Meeting & Exposition Boston, MA		ENVR-241
Talvitie, J, Heinonen M, Paakkonen JP, Vahtera E, Mikola A, Setala O and Vahala R	2015	Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea	Water Sci Technol	72	1495-1504
Talvitie, J, Mikola A, Setala O, Heinonen M and Koistinen A	2017	How well is microlitter purified from wastewater? A detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant	Water Research	109	164-172
Tan, X, Yu X, Cai L, Wang J and Peng J	2019	Microplastics and associated PAHs in surface water from the Feilaixia Reservoir in the Beijiang River, China	Chemosphere	221	834-840

Reference	Year	Title	Publication	Vol	Pages
Tsang, YY, Mak CW, Liebich C, Lam SW, Sze ETP and Chan KM	2017	Microplastic pollution in the marine waters and sediments of Hong Kong	Marine Pollution Bulletin	115	20-28
Turner, S, Horton AA, Rose NL and Hall C	2019	A temporal sediment record of microplastics in an urban lake, London, UK	Journal of Paleolimnology		
Unice, KM, Weeber MP, Abramson MM, Reid RCD, van Gils JAG, Markus AA, Vethaak AD and Panko JM	2019	Characterizing export of land-based microplastics to the estuary - Part I: Application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed	Sci Total Environ	646	1639-1649
Vaughan, R, Turner SD and Rose NL	2017	Microplastics in the sediments of a UK urban lake	Environ Pollut	229	10-18
Vermaire, JC, Pomeroy C, Herczegh SM, Haggart O and Murphy M	2017	Microplastic abundance and distribution in the open water and sediment of the Ottawa River, Canada, and its tributaries	Facets	2	301-314
Vianello, A, Boldrin A, Guerriero P, Moschino V, Rella R, Sturaro A and Da Ros L	2013	Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification	Estuarine, Coastal Shelf Sci	130	54-61
Wang, W, Ndungu AW, Li Z and Wang J	2017	Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China	Sci Total Environ	575	1369-1374
Wang, W, Yuan W, Chen Y and Wang J	2018	Microplastics in surface waters of Dongting Lake and Hong Lake, China	Sci Total Environ	633	539-545
Watkins, L, McGrattan S, Sullivan PJ and Walter MT	2019	The effect of dams on river transport of microplastic pollution	Science of the Total Environment	664	834-840

Reference	Year	Title	Publication	Vol	Pages
Wen, X, Du C, Xu P, Zeng G, Huang D, Yin L, Yin Q, Hu L, Wan J, Zhang J, Tan S and Deng R	2018	Microplastic pollution in surface sediments of urban water areas in Changsha, China: Abundance, composition, surface textures	Mar Pollut Bull	136	414-423
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