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Macroplastic pollution in freshwater environments: Focusing public and policy action

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HIGHLIGHTS

- Marine and freshwater plastic studies provide different priority plastic typologies.
- Priority items from litter rates do not correspond to priority plastic pollution items.
- The top three freshwater plastic pollution typologies result from short term food acquisitions.
- Inconsistent measurement approaches restricts the utility of macroplastic studies.

GRAPHICAL ABSTRACT

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ABSTRACT

Understanding and managing plastic pollution is an increasingly important environmental priority for policy makers, businesses and scientists. Awareness of the potential damage to the world's oceans has grown but there is less attention given to freshwater ecosystems. Yet, rivers are the dominant source of plastic pollution to the marine environment, as well as a potential sink, accumulating plastic from multiple sources. Actions to reduce the presence of macroplastics in rivers is fundamental to conserving both freshwater and marine environments, but there is limited understanding of potential pollution sources, vectors and storage. Importantly, there are only a handful of studies examining the typologies of freshwater macroplastic pollution, often using different categories and collection methods. This impedes setting priorities for scientific investigation and mitigation measures. The present study identifies the most prevalent macroplastic items in freshwater environments in Europe, with a focus on consumer plastic items, i.e. those that could potentially be reduced by targeted actions by the public, as well as industrial and government intervention. Our analysis addresses the differences between reported macroplastics in freshwater and marine environments as well as those estimated from litter rates. Our results identify a macroplastic "top ten", i.e. those dominant plastic typologies that require a more focused effort to reformulate their use and management, as well as setting a common baseline for a more consistent data gathering and reporting approach.

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1. Introduction

Plastic pollution is one of today's most prominent environmental challenges. Awareness of the potential damage to the world's oceans (Beaumont et al., 2019; Galgani and Loiselle, 2019) has grown. Governments, businesses and the general public are beginning to take action, often in a rather uncoordinated manner and based on limited information. The majority of plastics that end up in the world's oceans are carried there by rivers, with studies showing up to 80% (Schmidt et al., 2017; Schwarz et al., 2019). Significant research attention has focused on marine plastics, while only 13% of published studies have been dedicated to plastic pollution in freshwater environments (Blettler et al., 2018). Of these, the majority (76%) are on microplastics i.e. unidentifiable plastic pieces < 5 mm in size. The limited information on freshwater environments and the hydrological link between source and sink initially suggests that types and quantities of macroplastics (>5 mm in size) in freshwater ecosystems might be comparable to those found in the marine environment. However, no studies have compared these environments, even though such information is fundamental to addressing the freshwater pollution load through focused and distributed mitigation approaches.

Recent evidence indicates that freshwater environments act as both source of plastic pollution to the marine environment, as well as sink, potentially preventing a proportion from reaching the oceans (Horton et al., 2017; Lebreton et al., 2017; Schmidt et al., 2017). The presence of plastics in river and lake sediments (Corcoran et al., 2015; Wang et al., 2018; Schwarz et al., 2019) is evidence of this sink, as is the large discrepancy between the plastic waste present in the ocean (1%) and the estimates of total waste input (van Sebille et al., 2015). There are multiple mechanisms that influence the transport, sedimentation, degradation and permanence of macroplastics in freshwater environments. These include polymer type, biofilm formation, size, shape (influencing density) as well as the hydrological characteristics of the river or lake (Chen et al., 2019; Schwarz et al., 2019). There is a clear link between product type and many of these properties, as polymer type, litter size, shape and density provide specific properties that may influence its fate (Ryberg et al., 2019). Their presence in even the most remote freshwater environments is evidence of their permanence (Imhof et al., 2013; Free et al., 2014).

Marine studies place plastic bags, bottles, packaging straps and fishing lines in oceans as the most common plastic pollution items globally (Blettler et al., 2018). Beach studies identify cigarette butts, food wrappers, drinks bottles and straws/stirrers as the dominant items (www.coastalcleanupdata.org, accessed 9th July 2019). The limited freshwater studies conducted have also found these items in freshwater environments in the UK and Europe (e.g. Morritt et al., 2014; Joint Research Centre (European Commission), 2018).

A comparison of the most prevalent macroplastic items in freshwater versus marine environments has not been conducted, nor has a thorough investigation of macroplastic prevalence in freshwaters. There are only a handful of studies examining the typologies of freshwater macroplastic pollution, often using different categories and inconsistent collection methods. This complicates public, corporate and personal decision making to address the challenge of reducing these ubiquitous macropollutants. Given the number of organisations conducting research and collecting data on the subject, the overall lack of accessible information creates large knowledge gaps that prevent priority setting.

Recent polls have found that a growing number of people rate plastic pollution as a priority environmental concern (IFAT, 2018; Ipsos MORI, 2018). There has been an increase in plastics-related policy change at international and national levels (Bourguignon, 2018; Defra, 2019), as well as industry reaction and campaigning by environmental advocacy groups. There is a clear need for focused research and effective action (by consumers, businesses and policy-makers) (Heidbreder et al., 2019).

The present study identifies and prioritises the most prevalent macroplastic items present in freshwater environments, with the purpose of informing public action to reduce plastic use, waste and pollution. We compare recent studies of freshwater plastics pollution with marine studies and available data on litter rates. Our focus is on consumer plastic items, i.e. those that could potentially be reduced by actions by the public, industry and government intervention. Our analysis focuses on knowledge gaps in current freshwater macroplastic pollution research and addresses potential strategies to fill these. We focus on one geographic region (Europe) with a method that could be extended to inform related studies that address this global challenge.

2. Methodology

2.1. Search strategy

In October 2018, relevant data from the published and grey literature were identified using a systematic search method, following the guidelines of CEBC Evidence Synthesis Guidelines (Collaboration for Environmental Evidence, 2018). To find the best search string, 14 test searches using Boolean search strings were run (see Supplementary Information Table 1). Relevant studies were identified using the final search string with Scopus, ISI Web of Science and Science Direct using classification based keywords. In addition, we took the first 100 hits of an advanced search performed using Google.co.uk, Google Scholar (patents excluded) and ResearchGate (including conference presentations and posters as well as reports, journal papers and datasets). Our search was restricted to English language search terms and to the years 2012–2018. To keep geographic consistency, the review was limited to European studies of consumer related macroplastics.

In total, 857 peer reviewed published studies were collated and primary information was extracted (year of publication and data collection, title, authors, country, publication) from each. To focus the analysis on the central aim of the study, inclusion and exclusion criteria were developed (see Supplementary Information Table 2). To assess observer bias in the application of these criteria, the titles and abstracts of a subset of 50 papers were vetted by two reviewers. The final Kappa score between reviewers showed near perfect agreement (0.92).

The review of 857 titles and abstracts identified 27 European freshwater litter studies as meeting the criteria. These were from studies in France, Germany, Italy, Poland, Switzerland, Republic of Ireland and the UK, or pan-European. Full texts of these 27 studies were reviewed and the following information collated: observational or experimental; sample size (total litter items); temporal and spatial scales; location; study environment (river/estuary/coast/riparian zones, wetlands, lakes and water column/surface of water/beach/riverbank/riverbed/etc.); survey method; total number of plastic item(s) identified; and proportion (or count) of each type of plastic item. Measures were taken to prevent the introduction of bias through language, publication status or reviewer.

After full texts had been reviewed, nine studies were found to provide sufficiently robust and numerous data to be included in the study:

- Five UK-specific studies – from the Thames (Morritt et al., 2014; Thames21, 2017), Crane (Friends of the River Crane, 2017) and Helford (Hirons, 2013) rivers, and estuaries in N. Ireland (Williams et al., 2017)

- Three country-specific studies – a river study from France (Bruge et al., 2018), lake study from Switzerland (Hammerdirt Association, 2016) and lake study from Poland (Czarkowski et al., 2016)
- One pan-European rivers study (Joint Research Centre (European Commission), 2018)

2.2. Data handling and analysis

Data from all nine studies were grouped in 15 categories of consumer plastic waste: food wrappers; cotton bud sticks; plastic bottles; plastic food containers, plastic lids, plastic cups, plastic carrier bags, plastic straws/cutlery; cigarette butts, smoking-related packaging, shoes, plastic toys, shotgun cartridges, balloons/balloon sticks. The categories were as specific as the available data would allow, and not all items were present in all studies. Variations in reporting methods between studies required that some data were aggregated; e.g. for sanitary items, some studies reported results for all sanitary items together, whilst others separated items out (e.g. wet wipes, nappies, sanitary protection). We did not include data on unidentified plastic pieces or items, or within any categories considered to be related to fishing, construction, industrial and agricultural activities.

Prevalence of each item was represented by percentage of total litter collected for each study. For Czarkowski et al., 2016, we used the mean values reported for proportion of litter items found across five study lakes. For Williams et al., 2017, only data from the three estuary sites were included, while marine sites were excluded. Due to limitations of the River Crane study (plastic bottles were the only macroplastic item recorded; Friends of the River Crane, 2017), this study was not included in the analysis to avoid over-representation of this plastic type.

2.3. Ranking the results

Two approaches were used to account for the varying dimensions of the selected studies and prevent the possibility of over-representation of results from studies with a smaller number of plastic items recorded (Fig. 1). The first approach was based on assigning a weighted score to each study, based on the total litter items recorded. In this approach, the mean number of items collected across all studies was used to calculate the proportional contribution of each study, relative to the mean. For example, a study that collected the same number of items as the mean had an assigned weight of 1; a study with half as many items as the mean had an assigned weight of 0.5. For each study, the prevalence of each litter item was corrected by the respective weight of that study. The second approach did not apply any weighting to correct prevalence of items, using the original percentages based on the reported number of litter items. The litter categories were then put into ranked lists, based on the mean presence for each litter category across the nine studies. The ranks and sensitivity between approaches was compared.

Bias created by any particular study was tested by comparing the relationship between ranking of an item and the number of studies that recorded that item. Spearman's rank correlation (ρ) was applied to compare ranks generated by different datasets and ranking approaches, considering 12 degrees of freedom and $\alpha = 0.01$.

Grubb's test was used to identify potential outliers (Grubbs, 1969). Potential outliers were identified and a comparison made of their Grubbs statistic ($(x_{out}-x_{avg})/s$) to a Grubbs critical value, which is based on the number of samples. For data points within each study that were identified as significant outliers, the effect of their removal on the final ranked list was examined and tested for significance (degrees of freedom = 12, $\alpha = 0.01$), to identify whether any resulting changes to the ranked list after removal of the anomalies were significant.

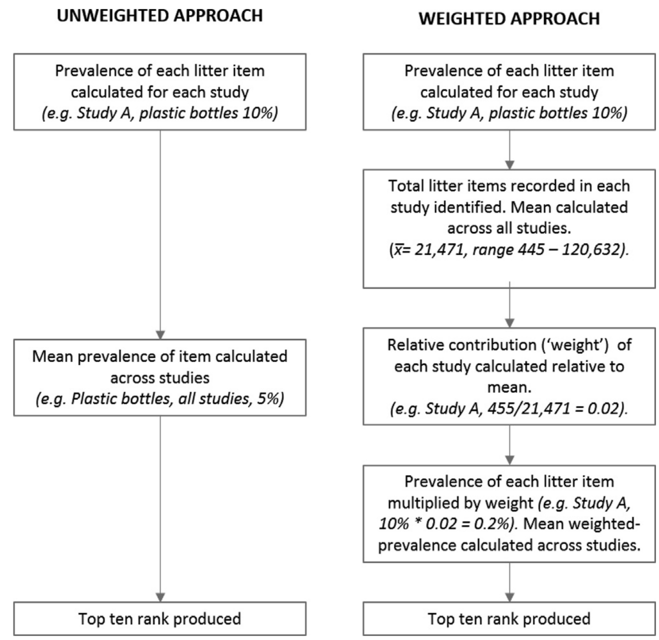

Fig. 1. Approach used to calculate weighted and un-weighted prevalence and top ten ranks for each litter item identified in the freshwater macroplastic studies identified.

2.4. Comparison with marine prevalence studies

To identify differences between data on European freshwater and marine macroplastic pollution, we compared the present study with three large scale marine studies, each representing different geographical dimensions: from the UK, Europe (European Environment Agency, 2019) and worldwide (Ocean Conservancy, 2018b http://discomap.eea.europa.eu/map/fme/MLWPivotExport.htm). Other studies were reviewed, but inconsistency in data reporting did not allow comparison. The ranked lists from each study were compared to the present freshwater study, based on the percentage of all litter for each item (degrees of freedom = 12, $\alpha = 0.01$). Outliers were identified and their effect on comparisons with the available marine studies was tested.

3. Results

3.1. Weighted vs unweighted data

For the study weighted approach, weightings ranging from 0.02 to 5.62. The aggregate ranking using all studies indicated that plastic bottles, food wrappers and cigarette butts were the dominant categories of freshwater plastic pollution (Table 1). The ranking of the unweighted approach showed a prevalence of plastic bottles, food wrappers and bags.

The unweighted and weighted rankings showed a significant differences in the final prevalence rankings ($\rho = 0.79$) (Table 2). The most significant change that occurred was the movement of plastic bags from number 10 (0.69% of all litter) in the weighted approach, to number 4 (5.49% of all litter) with no weighting. This can be attributed to very high percentages of bags being recorded in two studies with very low sample numbers and therefore with a low overall weighting, with plastic bags counting for 23.7% and 9.86% (average all studies 5.49%). The other two most affected were takeaway containers (from rank 4 from 8) and cups (move from

Table 1
Distribution of macroplastic observed in eight studies, with respect to the litter categories used in the present study. NR = not recorded.

Study	Total number of litter items recorded	Percent of plastic items in all litter (%)	Percent of identifiable plastic items from plastic litter only (%)	Percent of total litter items recorded for individual plastic items (%)														
				Food wrappers	Cotton bud stick	Bottles and lids	Cup	Bag	Takeaway container	Straw and cutlery	Sanitary items	Cigarette butt	Cigarette packaging	Shoes	Toys	Shotgun/ injection gun cartridges	Balloons	TOTAL
River Thames, UK (Thames21, 2017)	22,316	97.50	88.27	17.00	13.00	10.00	8.00	0.36	7.00	2.00	1.80	1.00	1.00	0.18	0.48	NR	0.26	62.08
Helford Estuary, UK, (Hirons, 2013)	426	88.26	76.06	6.34	0.23	3.76	0.47	9.86	3.99	1.41	0.00	0.23	0.00	0.00	0.00	0.23	0.00	26.52
Lake Geneva (Hammerdirt Association, 2016)	27,790	76.40	83.77	6.10	4.50	3.50	0.00	0.00	0.00	1.10	0.00	20.70	0.00	0.00	0.00	1.50	0.00	37.40
Lakes of NE Poland (Czarkowski et al., 2016)	1634	Could not calculate	Could not calculate	NR	NR	8.69	NR	23.70	NR	NR	NR	NR	3.54	NR	NR	NR	NR	35.93
Adour River, France, (Bruge et al., 2018)	120,632	91.67	44.36	2.68	0.83	6.99	1.35	0.31	3.02	0.32	0.44	2.07	0.23	0.17	0.54	0.26	0.14	19.35
River Thames, UK (Morritt et al, 2014)	8490	99.96	76.35	25.30	0.00	0.50	5.10	1.50	0.00	0.80	21.50	0.10	19.00	0.00	0.00	0.00	0.40	74.20
Northern Ireland estuaries (Williams et al., 2017)	2326	59.75	76.62	5.03	1.07	16.86	NR	8.21	1.85	NR	2.32	NR	NR	NR	NR	NR	NR	35.34
RIMMEL Rivers Project (Europe) (JRC/EC, 2018)	8599	82.93	45.81	0.00	0.00	9.79	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.24	0.47	0.00	0.10	12.41
Total	192,213	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Average	24,027	70.93	59.27	8.92	2.80	7.51	2.49	5.49	2.52	0.94	3.72	4.02	3.40	0.10	0.25	0.40	8.92	37.90
Range	120,206	40.21	43.90	25.30	13.00	16.36	8.00	23.70	7.00	2.00	21.50	20.70	19.00	0.24	0.54	1.50	25.30	61.79
Standard Deviation	37,680	12.82	16.42	8.30	4.41	4.74	3.03	7.81	2.27	0.67	7.31	7.49	6.48	0.10	0.25	0.56	8.30	19.48
Confidence Interval	31,501	11.86	15.18	7.67	4.08	3.96	3.18	6.53	2.10	0.70	6.76	7.87	5.99	0.11	0.26	0.70	7.67	16.29

Table 2
Comparison of dominant litter categories (ranks) determined by weighted and unweighted approaches to account for the varying dimensions of the selected studies.

Litter category	Unweighted data	Weighted data	Change from unweighted to weighted				
	Mean % of all litter	Rank	Mean % of all litter	Rank	Movement in rankings (up=↑, down=↓)	Number of ranks moved	Change in mean % of all litter
Food wrappers	8.92%	1	7.33%	2	↑	1	−1.59%
Bottles and lids	7.51%	2	7.61%	1	↓	1	0.10%
Bags	5.49%	3	0.69%	10	↑	7*	−4.80%
Cigarette butts	4.02%	4	6.58%	3	↓	1	2.57%
Sanitary items	3.72%	5	1.87%	7	↑	2	−1.85%
Smoking-related packaging	3.40%	6	1.44%	8	↑	2	−1.95%
Cotton bud sticks	2.80%	7	3.45%	5	↓	2	0.64%
Takeaway containers	2.52%	8	3.61%	4	↓	4*	1.08%
Cups	2.49%	9	2.99%	6	↓	3*	0.50%
Straws, stirrers, cutlery	0.94%	10	0.94%	9	↓	1	0.00%
Gun cartridges	0.40%	11	0.68%	12	↑	1	0.28%
Toys	0.25%	12	0.62%	11	↓	1	0.37%
Balloons	0.15%	13	0.21%	14	↑	1	0.06%
Shoes	0.10%	14	0.21%	13	↓	1	0.11%
Total	42.71%		38.22%				

Table 3
Proportions of total litter, plastic litter and identifiable plastic litter for each of the 14 plastic categories. Identifiable plastic litter % is the percentage plastic items that could be associated to a particular litter category with respect to the total number of items that could be associated to specific litter categories.

Rank	Litter category	% of all litter	% of all plastic litter	% of all identifiable plastic litter	Number of studies in which item was recorded (out of 8)
1	Food wrappers	8.92%	10.05%	12.99%	7
2	Bottles and lids	7.51%	9.76%*	14.93%*	8
3	Bags	2.89%	3.87%*	5.11%*	8
4	Cigarette butts	4.02%	5.12%	6.51%	6
5	Sanitary items	3.72%	3.96%	5.20%	7
6	Smoking-related packaging	3.40%	3.55%*	4.66%*	7
7	Cotton bud sticks	2.80%	3.17%	3.84%	7
8	Takeaway containers	2.52%	2.90%	4.33%	7
9	Cups	2.49%	2.56%	3.35%	6
10	Straws, stirrers, cutlery	0.94%	1.04%	1.33%	6
11	Gun cartridges	0.40%	0.50%	0.67%	5
12	Toys	0.25%	0.27%	0.52%	6
13	Balloons	0.15%	0.16%	0.24%	6
14	Shoes	0.10%	0.11%	0.21%	6
	Total	42.71%	43.69%	59.50%	–

* Percentages calculated from only 8 of the 9 studies due to lack of available data in Czarkowski et al. (2016).

rank 6 to 9), which resulted from the low weight assigned to the Polish study (Czarkowski et al., 2016).

The use of weighted averages skewed the analysis of the variance of study data, making it impossible to report appropriate confidence intervals and standard deviations of the proportions of all litter, all plastic litter and all identifiable plastic litter. Given these inherent challenges, we accepted the possibility of a study size bias by using the unweighted data used for all further analysis. This is based on the assumption that the study size has a lower influence on the prominence of specific categories with respect to other factors including location (nation, ecosystem), transport mechanisms and source.

3.2. Top ten consumer-related macroplastic items

Of the 192,213 litter items counted, an average of 71% (±12%) were identified as plastic and 59% (±15%) were identifiable as consumer related macroplastic items. This identification was performed visually and followed a similar approach in all studies. It should be noted that visual identification of macroplastics type has inherent errors that should be considered. This has been shown in manual sorting of plastic waste in waste management (Shahbudin et al., 2010). The other recorded items were non-plastic pieces, unidentified items, or industrial, agricultural or fishing related.

The ranking of the plastic categories (Table 3) shows that the top three items – food wrappers, bottles and lids, and bags - made up 22% of all litter, 24% of all plastic and 33% of identifiable plastic. Five of the top ten were food related, two were sanitary/cosmetic, and two were smoking related. The total top ten make up 41.81% of all litter, or 43% of all plastic litter and 58% of identifiable plastic litter.

It should be noted that for the Polish study (Czarkowski et al., 2016), it was not possible to calculate proportions of plastic only items out of all litter collected. The percentage of plastic litter and the percentage of identifiable litter were calculated across seven of the eight studies. The resulting percentages (Table 3) for the three items recorded by that study (bottles, bags, cigarette packaging) were lower than percentage of all litter.

3.3. Robustness of final rank of freshwater plastic pollution

The final ranking was tested with respect to total occurrence of each item in the selected studies by comparing the rank for each

Table 4
Table of items that were identified as significant outliers, based on Grubbs test statistic for N = 11 ($G_{critical}$ = 2.09).

Study	Grubb's test statistic				
	Cotton bud stick	Plastic bag	Sanitary items	Cigarette butts	Cigarette packaging
River Thames, UK (Thames21), 2017	2.3	–	–	–	–
Lake Geneva, 2016	–	–	–	2.2	–
Lakes of NE Poland, 2016	–	4.3	–	–	–
River Thames, UK (Morritt et al, 2014)	–	–	2.4	–	2.2

Table 5
Comparisons of litter prevalence between the present European freshwater study, and marine studies in the UK, Europe and globally. SD = standard deviation.

	Present study			OC UK		OC Global		MLW Europe	
	% of all litter	SD	Rank	% of all litter	Rank	% of all litter	Rank	% of all litter	Rank
Food wrappers	9.02%	8.27%	1	8.81%	2	4.71%	4	3.78%	5
Cotton bud sticks	2.80%	4.41%	7	–	–	–	–	3.78%	4
Bottles and lids	7.60%	4.98%	2	10.34%	1	8.34%	2	10.61%	2
Cups	2.49%	3.02%	9	0.97%	8	1.75%	7	1.34%	8
Bags	5.64%	4.24%	3	2.73%	5	3.25%	5	4.82%	3
Takeaway containers	2.53%	2.27%	8	1.30%	6	2.13%	6	1.52%	7
Straws, stirrers, cutlery	0.87%	0.63%	10	3.09%	4	5.44%*	3	2.65%	6
Sanitary items	3.72%	7.31%	5	0.64%	10	0.52%	8	0.38%	11
Cigarette butts	4.02%	7.50%	4	8.28%	3	8.52%	1	20.75%	1
Smoking-related packaging	3.40%	7.00%	6	0.36%	11	0.29%	9	0.31%	12
Shoes	0.10%	0.10%	14	–	–	–	–	0.28%	13
Toys	0.25%	0.25%	12	0.68%	9	0.11%	11	0.40%	10
Gun cartridges	0.40%	0.56%	11	–	–	–	–	0.59%	9
Balloons	0.15%	0.14%	13	1.09%	7	0.15%	10	0.28%	14

item against the number of studies that recorded that item. There was a significant relationship indicating that the final ranking represented the aggregate information from the original studies.

Five data points were identified as potential outliers across four studies, (Table 4). The most notable was the prevalence of cigarette butts recorded in the Lake Geneva study, which was significantly higher than in the others. Cotton bud sticks were significantly more prevalent in the Thames 21 study than the other eight studies, plastic bags were significantly more prevalent in the Poland study, and sanitary items and cigarette packaging were significantly more prevalent in the deeper water column of the River Thames (Morritt et al., 2014).

Individual removal of each outlier changed the overall ranks of plastic items, but not their presence in the top ten. When all the potential outliers were removed, the top ten changed significantly (ρ = 0.78), although once again the same items remained the top ten. The top ten represented 43% of all plastic litter with outliers removed.

3.4. Comparison with marine macroplastic prevalence data

Comparisons were made with data from three marine studies (Table 5):

- Present study vs. Marine Litter Watch (MLW) data for Europe (European Environment Agency, 2019)
- Present study vs. UK data from the Ocean Conservancy (OC) Coastal Cleanup TIDES database (Ocean Conservancy, 2019)
- Present study vs. global data from the OC Coastal Cleanup TIDES database (Ocean Conservancy, 2019)
- MLW data for Europe vs. UK data from the OC Coastal Cleanup TIDES database

Comparisons of the ranks of plastic pollution items between marine and freshwater studies indicated a poor correlation between items identified in the freshwater studies compared to marine studies (Table 6). On the other hand, the ranks between individual marine studies were highly correlated.

Prevalence of specific plastic items influenced these comparisons. The removal of the category "straws/stirrers/cutlery" from the comparison increased the correlation ($p < 0.01$) between the freshwater ranking and the OC UK and OC Global rankings. The removal of "sanitary items" from the comparison led to a weak correlation between the freshwater study and the OC UK marine studies. Sanitary items were found to be much higher in freshwater with respect to marine, while "straws/stirrers/cutlery" were found to be much more prevalent in marine studies.

3.5. Comparison with litter rates

Comparing litter rates with litter presence was performed using national studies (UK). A ranking of the items with the highest litter rates (Table 7) (Elliott and Elliott, 2018) showed no correlation with the most prevalent plastic items in freshwater environments in Europe (ρ = 0.27) or with the ranking of plastic items found in UK freshwater environments (ρ = 0.04). The top three most littered items were sanitary items, cigarette butts and cotton bud sticks, all of which are known to enter freshwater environments through drainage systems, with sanitary items and cotton buds in particu-

Table 6
Spearman's correlation between rankings of litter items between the present European freshwater study and marine studies from the UK, Europe and globally. Significant correlations at (α < 0.01) are in **BOLD**.

Studies compared	ρ
Present vs OC UK	0.51
Present vs OC Global	0.64
Present vs MLW	0.71
OC UK vs OC Global	**0.85**
OC UK vs MLW	**0.82**
OC Global vs MLW	**0.91**

Table 7
Ranks of UK litter rates in the UK of the top ten freshwater plastic litter categories and comparison to their presence in freshwater ecosystems.

Present study top ten	Litter rate in the UK (Elliott and Elliott, 2018)	Litter rate ranking
1) Food wrappers	Variable (e.g. crisp packets 3.7%; sweet wrappers 3.1%)	5
2) Bottles and lids	6.9%	6
3) Bags	Unknown	–
4) Cigarette butts	31.9%	2
5) Sanitary items	Variable (e.g. wet wipes 31.3%; Sanitary towels 21.3%)	1
6) Smoking-related packaging	Unknown	–
7) Cotton bud sticks	13.5% littered	3
8) Takeaway containers	5.1%	7
9) Cups	13.1%	4
10) Straws, stirrers, cutlery	Variable (e.g. Straws 3.1%, Cutlery 0.5%; stirrers 0.2%)	8

lar being commonly reported (Gouda, 2014; Resource Futures, 2018).

4. Discussion

4.1. Plastics top ten

Of the 14 categories of plastic litter items, the top ten most prevalent ranked were:

1) Food wrappers
2) Bottles and lids
3) Bags
4) Cigarette butts
5) Sanitary items
6) Smoking-related packaging
7) Cotton bud sticks
8) Takeaway containers
9) Cups
10) Straws, stirrers, cutlery

The percentage prevalence for each category after number nine (Cups) dropped to less than 1%, indicating that the last five categories were low contributors to freshwater plastic pollution in Europe. Considering the top ten, these items made up 43% of all the plastic litter recorded. A focused effort to reduce these item poses a significant opportunity for targeted action to reduce pollution. In particular, the top three most prevalent items, food wrappers, bottles and lids, and bags together made up 22% of all plastic litter recorded. This present clear targets for government, business, NGOs and other stakeholders in their plastic reduction efforts. However, it should be noted that the reduction of plastic use and management at its source has been shown to be more effective than policy (Willis et al., 2018). A secondary opportunity remains the interception and removal of macroplastics within the river environment (Blettler et al., 2018).

In the present study, focused on Europe, there were a limited number of outliers and inconsistencies across the eight studies. While the rank order was sensitive to the inclusion of individual studies, the final top ten remained consistent. Likewise, some items did not appear in all studies, with the lowest number of studies in which any single item appears was five. The fact that some items were more consistently recorded than others indicates the need for a common global approach to recording plastic pollution items in freshwater environments.

The comparison between plastic pollution in freshwater environments and that identified in marine studies showed that marine and freshwater environments have significantly different macroplastic compositions. This limits the utility of marine studies to address freshwater pollution challenges. Given that the most sensitive items to this comparison, sanitary items and "straws/stirrers/cutlery" showed opposite tendencies in freshwater and marine studies, there are likely to be differences in residence time and degradability that influence their persistence in one or the other environment, as well as different entrance mechanisms to the aquatic environment (Lambert and Wagner, 2018). Other differences are also present in the transport mechanism between river and marine conditions (Kooi et al., 2018) and the possibility of removal by riparian vegetation and flow restrictions. The clear difference between freshwater and marine rankings, and the consistency of marine rankings across different geographical areas highlight the need for a better understanding of the fates of these items in these two environments.

The discrepancy between the rank of macroplastic items that are most littered (in the UK) and the rank of macroplastic items present in the freshwater environment indicates that there is a notable knowledge gap regarding how these materials move through the environment. In particular, more information regarding transport mechanisms (horizontal transport) and potential deposition dynamics (vertical transport) is needed, both in the water (Battisti et al., 2017) as well as around freshwater ecosystems. Studies indicate that low density polymers, used in thin walled larger plastic are more likely to be transported through the river system (Schwarz et al., 2019). Regarding the littered macroplastic data, the highest ranked macroplastics were largely related to sanitary items (Table 7), which are often released into the public sewer system. Compared to their lower presence in the freshwater environment, it is likely that the relatively higher density of these waterlogged plastic items may reduce their presence in freshwater studies. Other possible explanations may be the increased difficulty in their identification as well as the variable efficiencies of wastewater treatment systems (Lahens et al., 2018). This discrepancy points to the need for further study of the fate of individual plastic items.

4.2. Knowledge gaps

The present study demonstrated the top ten macroplastic items related to freshwater plastic pollution in the study region (Europe). While targeting the reduction of the emission of these items into the environment, further efforts should be made to understand the potential influence of the following on their presence and permanence:

1) Differences in waste management and littering behaviour between countries
2) Differences in plastic items found in lakes, estuaries/tidal rivers and non-tidal rivers in relation to transport mechanisms
3) Depth specific residence time, comparing the presence of specific items on the water surface to those found in deeper waters or sediment.

All three of these challenges were highlighted in the discrepancy between marine and freshwater studies, as well as differences between studies. For example, in the Lake Geneva study, prevalence of cigarette butts was greater than 20% of the total macroplastics, compared to values below 2% in other studies. This could be associated to differences in littering behaviour and wastewater treatment, but also be related to the hydrological conditions of a closed waterbody or the characteristics of cigarette related materials in freshwater. The prolonged hydrophobicity and low density of many cigarette filters as well as their slow decomposition rate would increase their accumulation in closed waterbodies (Araújo and Costa, 2019). Another possible cause may be an increased load in of cigarette butts to Lake Geneva, with respect to other freshwater ecosystems examined in the present study. However, the incidence of smoking in Switzerland is one of the lowest in Europe (WHO/EURO, 2019). Additional studies should address these knowledge gaps to better inform targeted actions to reduce macroplastics in freshwater environments. Consistent and large scale information would help to support policy and business actions for each litter category, such as sanitary items, as suggested by Morritt (Morritt et al., 2014).

4.3. Towards more consistent macroplastic sampling and identification methods

The present study highlighted several major shortcomings in the identification of the macroplastic pollution in freshwater environments. There is a clear lack of consistency in identification categories and approaches. Inconsistent recording of macroplastics reduces the utility of this growing number of studies. Furthermore, data are not collected in a standardised manner. For example, while there are numerous litter collection schemes in riverine environments, there is no single agreed-upon method, common database or coordinating institution. An internationally consistent methodology, including a consistent categorisation is required. The Ocean Conservancy TIDES database is a good example of where this has been achieved in marine litter recording (Ocean Conservancy, 2019). Collaboration to merge these data sources regionally or internationally would provide more detailed basis for action to reduce freshwater plastic litter.

5. Conclusions

As a result of the high profile of plastic pollution issues, there have been a bewildering array of recommendations provided, most of which are based on a limited understanding of the problem (Pahl et al., 2017). A reduction on the plastic pollution load to freshwater environments would benefit from a prioritised action by government (waste management and policy), businesses (producers and distributors) and the public. Many businesses are taking action as a response of internal mechanisms and public pressure. However, an informed member of the public has very limited guidance on which brands and companies to support, which 'environmentally-friendly' products to choose or actions to follow. A consistent public campaign focused on the proper management across actors of the top ten priority macroplastics would lead to an important reduction of their presence in the environment (Blettler and Wantzen, 2019).

The present study shows that the three top items are directly related to single use short term food acquisitions. As these account for 22% percent of the overall litter, the impact of new programmes to address these items, by distribution chains and local recycling, could be significant. Rates of recycling in Europe reach 30%. It should be noted that these rates are far lower in developing countries, which have an increasing plastic use (Wu et al., 2018). Smoke related packaging and cigarette butts made up 7%. As these items are more easily associated to a single group of manufacturers and end users, differences in taxing and consumption characteristics between nations would allow for a more precise determination of the deterrent capacity of policy based approaches.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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