The sizes and shapes of plastics in rivers

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Abstract

Limited data exists on physical and geometric properties of river litter. To resolve this, we reveal the physical-structural relationships of river litter, using two of the most comprehensive datasets generated to date. First, we dissect the properties of river litter using a detailed dataset of over 14,000 riverbank items, for which their dimensions (longest L_1, intermediate L_2, shortest L_3) and physical characteristics (mass, volume, density) are determined. These properties were then mapped onto a dataset of nearly 240,000 River-OSPAR items collected from 22 river and riverbank sites across four continents. We then identify the most persistent River-OSPAR litter categories, together with kernel density estimations of their principal dimensions and geometries. Results show that only 25 River-OSPAR categories account for 80% of all river and riverbank litter, with soft plastic pieces/films and candy, snack, and crisps packaging being the most abundant. Flat, 2D shaped macrolitter are the most persistent litter items, with 48% of the top 25 items sharing similar geometric properties: L_1 between 1 - 10 cm, and a flatness ratio (L_3 / L_2) of < 0.4. In practice, these are flat objects with two larger dimensions and a third that is at least one order of magnitude smaller. This large, physically based dataset enables prioritisation of which shapes, sizes, and densities should be targeted by future plastic transport models, informing what plastics may be missing in current monitoring protocols, and the design of river clean-up technologies.

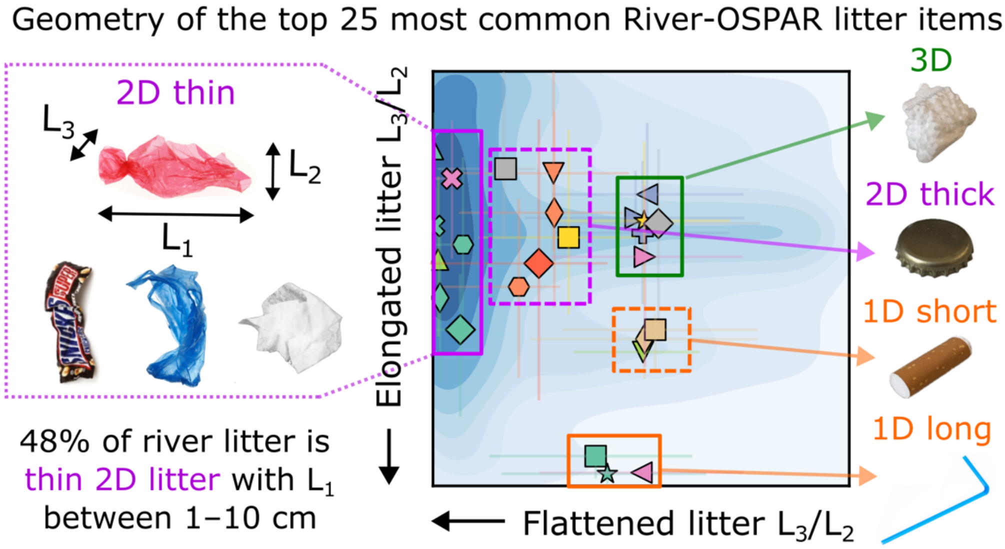
Keywords

Plastic pollution, Litter, Macroplastics, Microplastic, River plastic transport, Plastics Treaty, Plastic pollution modelling, OSPAR Commission.

Synopsis

This study demonstrates that just 25 River-OSPAR categories account for 80% of river litter, with 48% of items having the longest dimension of 1–10 cm and geometries that are flat 2D shapes.

Graphical abstract



1 Introduction

Plastic pollution is one component of the United Nations' triple planetary environmental crisis (UNFCC 2022), owing to its environmental persistence and detrimental impacts on biodiversity (MacLeod et al. 2021), human health (Krause et al. 2024), infrastructure (Tearfund 2023), and the economy (Beaumont et al. 2019). Governments and international organisations are drafting a legally binding resolution in response to plastic pollution, which includes the development of strategies to monitor, manage, and remediate existing plastic pollution in the environment (UNEP 2025). River systems are known conveyors and accumulation zones of litter originating from land-based sources and are increasingly recognised in monitoring and clean-up efforts (van Emmerik and Schwarz 2020; González-Fernández et al. 2023). A critical step toward developing such solutions in rivers is pinpointing the most persistent polluting litter items and quantifying the physical properties that govern their mobilisation, movement and fate. This, in turn, will assist on identifying which litter properties should be prioritised for the development of litter transport models, which litter items may be missed by current monitoring campaigns, or simply to inform the design of clean-up strategies in rivers.

One methodology currently adopted to characterise litter collected from rivers and riverbanks is the River-OSPAR (Oslo-Paris Convention) litter index, which is an adaptation of the OSPAR Guidelines originally developed for monitoring marine litter on beaches but modified to include categories common to riverine environments (van Emmerik et al. 2020c; OSPAR Commission 2020). The River-OSPAR index comprises 109 unique litter categories and provides a harmonised framework for data collection across different basins, enabling consistent recording of litter by volunteers, researchers, and stakeholders. While this approach has enhanced public awareness and, in some cases, influenced policy decisions, such as the European Union's directive on single-use plastics (European Commission 2019), the River-OSPAR classification system primarily provides qualitative information on the types of litter common in rivers, without their full properties.

By employing the River-OSPAR framework, or through similar methodologies, previous studies have quantified and catalogued the different types of litter found in both the active channel (the river) (González-Fernández et al. 2021; Vriend et al. 2023; Oswald et al. 2025) and the adjacent low-lying floodplains (the riverbank) (Tramoy et al. 2019; van Emmerik et al. 2020b; Ballerini et al. 2022). The quantitative characteristics of these items – such as their dimensions, shape, flexibility and density – require intensive efforts and are typically overlooked by many monitoring campaigns. To the knowledge of the authors, there is no single real-world dataset of individual river litter items, which include their principal dimensions, as well as their volume, mass and density. These properties are nonetheless fundamental parameters for determining when litter is mobilised, how they are predominately transported and where they ultimately end up (Waldschläger et al. 2022; Russell et al. 2023). Furthermore, simplifying the diversity river litter into their statistical distributions provides useful information (Kooi and Koelmans 2019), for instance, inputs for population balance models (Shettigar et al. 2024) that can predict transport in fluvial environments of continuous distributions of litter.

This study conducts a meta-analysis compiling published research that have sampled and categorised litter items from rivers and riverbanks using the River-OSPAR litter index. This allows us to establish the top 25 most persistent litter items across global river systems, building on a dataset of 239,290 litter items from 22 study sites across four continents. Using multivariate statistics, we then map the physical properties from a more detailed dataset of 14,052 litter items collected from riverbanks (de Lange et al. 2023). Our statistical analysis allows us to characterise the complete geometric and physical properties of river litter – including their shortest dimension and volume, which are absent from the dataset of de Lange et al. (2023) and most other studies. This delivers a comprehensive description of the most persistent types of river litter and helps to prioritise which shapes and sizes should be targeted by future plastic transport models, monitoring protocols, and clean-up technologies.

2 Methods

2.1 Literature search and meta-analysis

First, we identified and compiled into a database the studies reporting and categorising litter collected from in-stream sampling of active channels (rivers) and litter collected from adjacent floodplains (riverbanks) using the River-OSPAR litter index. Using a Scopus-keyword search, a total of 14 research studies were suitable for meta-analysis: seven studies which focused on sampling litter in rivers and eight studies that sampled litter from riverbanks. These studies investigated 11 different rivers from

Europe, Central America, Africa and Asia. Table 1 shows the selected studies, the geographical locations of the river, the study area (river or riverbank) and the total number of River-OSPAR items categorised.

Table 1. Selected studies for meta-analysis, river location, study area (river or riverbank) and total number of plastics collected in the study.

Study	Rivers sampled	Location	Study area	Total number of categorised River-OSPAR items
van Emmerik et al. 2020b	Meuse, Waal and Rhine Rivers	The Netherlands	Riverbank	152,415
Ballerini et al. 2022	Durance River	France	Riverbank	25,423
Tramoy et al. 2019	Seine River	France	Riverbank	20,259
de Lange et al. 2023	Rhine, IJssel, and Meuse	The Netherlands	Riverbank	16,488
Oswald et al. 2023	Waal River	The Netherlands	River (surface, suspended and near-bed load)	12,832
Oswald et al. 2025	Rhine, Waal and IJssel Rivers	The Netherlands	River (surface, suspended and near-bed load)	11,153
Vriend et al. 2023	Rhine River	The Netherlands	River (surface, suspended and near-bed load)	6,684
Pinto et al. 2024	Odaw River	Ghana	River (surface) and riverbank	3,802
Tramoy et al. 2022	Huveaune River	France	River (surface load)	3,147
Silburn et al. 2023	Belize River	Belize	Riverbank	2,505
Tasseron et al. 2024	Rhine, IJssel, and Meuse Rivers	The Netherlands	Riverbank	1,865
Nguyen and Bui 2023	Saigon River	Vietnam	Riverbank	713
van Emmerik et al. 2018)	Saigon River	Vietnam	River (surface load)	614
Bardenas et al. 2023	Mahiga Creek	Philippines	River (suspended load)	124

2.2 Identifying prevalent litter items in rivers and on riverbanks

From the studies selected, we extracted data on either the total count or the percentage of each River-OSPAR item identified in the selected rivers or riverbanks and compiled into a database (see Lofty 2025)

Some investigations reported only the top 10 or 20 River-OSPAR litter items found in the sampled river, therefore the total amount of each litter items was sometimes not available, resulting in a total of 239,290 litter items from the selected studies. In order to remove bias towards studies with larger samples, we first compute the relative occurrence of each river-OSPAR litter category. We then calculate the average relative occurrence, considering the 14 studies selected (Table 1), allowing us to establish a global rank of most prevalent litter.

We classified each River-OSPAR category based on their material composition, as in van Emmerik et al. (2020a): soft polyolefin (PO soft), hard polyolefin (PO hard), polystyrene (PS), expanded polystyrene (EPS), polyethylene terephthalate (PET), multilayer, other plastic, glass, metal, paper, wood, rubber and textiles. Table 2 displays the materials assigned to each River-OSPAR item collected from rivers and on riverbank with their common usage and density (ρ) range. We further flag each River-OSPAR category by whether the item is flexible and will deform under typical river hydrodynamics or will remain rigid in structure (Table 2). This classification is of interest since the dimensions and geometry of flexible elements can change during river transport, which may influence how they are mobilised, deposited, or retained.

Table 2. Material classifications assigned to each River-OSPAR litter item, their typical polymer type, common usage, density range (from Kooi & Koelmans, (2019) and Russell et al., (2023)) and flexibility.

Material category	Common usage	Density range (ρ) (g/cm^3)	Rigid/flexible
Soft polyolefin (PO soft)	Plastic bags, films, foils, wrappings and flexible plastics	0.89 – 0.98	Flexible
Hard polyolefin (PO hard)	Bottle caps, lighters, hard containers and rigid plastics.	0.83 – 0.92	Rigid
Polystyrene (PS)	Plastic cutlery, food containers, straws and cups	1.04 – 1.10	Rigid
Expanded polystyrene (EPS)	Foams, packaging, takeaway containers	0.01 – 0.04	Rigid
Polyethylene terephthalate (PET)	Plastic bottles	1.35 – 1.45	Rigid
Multilayer	Cigarettes, crisp packets, candy bar wrapper, juice or milk cartons	0.89 – 1.45	Rigid/Flexible
Other plastics	Plastic items not described in the River-OSPAR litter index	0.89 – 1.45	Rigid/Flexible
Glass	Glass bottles and jars	2.20 – 2.80	Rigid
Metal	Beverage cans, glass bottle caps, scrap metal	2.70 – 8.00	Rigid
Rubber	Tyres, balloons and condoms	1.10 – 1.20	Rigid/Flexible

Paper	Cardboard packaging, toilet paper, newspaper and cups	0.60 – 1.20	Rigid/Flexible
Textiles	Clothing, carpets, fabrics	1.30 – 1.80	Flexible
Wood	Pallets, corks, ice cream sticks	0.30 – 1.00	Rigid

2.3 Shape and size statistical description

To characterise the dimensions and shapes of litter in rivers and on riverbanks, we start by dissecting the dataset of de Lange et al., (2023), which reports the mass (M), the two largest dimensions (L_1 and L_2), and the River-OSPAR ID for 14,052 litter items collected from riverbanks along the Dutch Rhine, IJssel, and Meuse rivers.

We first computed the Pearson coefficient for the de Lange et al. (2023) dataset (Figure S1), which showed positive correlations, indicating that larger values in one variable are generally associated with larger values in the others, which aligns with the expectations (i.e. larger dimensions typically contribute to a greater particle mass). Correlations were non-negligible, suggesting that the statistical dependence among mass and size variables must be explicitly accounted for in the statistical modelling process.

For each River-OSPAR category, we next model the joint probability distribution using empirical copulas (Salvadori and De Michele 2007), a tool which enables the separate modelling of the dependence (correlation) structure among multiple random variables.

We generated a synthetic dataset by aggregating item counts reported from each of the 14 investigations in Table 1. In these studies, the authors provide the total number of litter and River-OSPAR ID of each item. For each site, we created a dataset of $N = 10^4$; which is large enough to be statistically meaningful. Take Nguyen and Bui (2023) as an example: the study found that 12.34% of litter in the Saigon River consisted of Plastic bags (e.g., shopping bags) (River-OSPAR ID = 2). Accordingly, this study contributes 1,234 synthetic items with River-OSPAR ID = 2. For each of these 1,234 synthetic elements, we assign M, L_1 and L_2 by randomly drawing from the corresponding category from de Lange et al. (2023), following the observed distribution. For certain River-OSPAR categories, no objects were found in the de Lange dataset. In these cases, it was not possible to apply this category-based procedure. Then, we use the all-categories distribution.

2.4 Completing volume and shortest dimension

The mass of an object is related to the density and the volume by $M = \rho V(L_1, L_2, L_3)$. We nonetheless lack prior information on the density of individual plastic litter items from the original studies. To address this, we adopted a statistical modelling approach. We first treat density as a random variable by assigning a triangular symmetric distribution using the ranges of Table 2 for each River-OSPAR ID, based on Kooi & Koelmans, (2019) and Russell et al., (2023). This is transferred to the volume through $V = M/\rho$.

However, in some cases, the measured volume of the item does not correspond directly to the polymer material volume. A typical example is beverage bottles > 0.5 L (River-OSPAR ID = 4.1), where the PET polymer makes up only about 2% of the object's total volume. For such categories, the volume of the object would be incorrect. To address this, we instead calculated effective density ranges (defined as the mass of the item divided by its total measured volume, which includes voids). This adjustment was applied to categories where the polymer density does not represent the bulk density of the object, which included plastic bottles, metal beverage cans, glass bottles, plastic cups and straws.

We next modelled the volume term $V = kL_1L_2L_3$, as a random function where k is an unknown parameter, based on the shape. As litter items can be found in a large diversity of shapes, we assigned a shape selected at random from a set of common geometric approximation: cuboid ($k = 1$), ellipsoid ($k = \pi/6$), elliptical cylinder ($k = \pi/4$), triangular prism ($k = 1/2$), elliptical cone ($k = \pi/12$), tetrahedron ($k = 1/6$), rectangular pyramid ($k = 1/3$), elliptical pyramid ($k = \pi/12$), and wedge ($k = 1/2$). Under these assumptions, it is possible to estimate the unmeasured third dimension, $L_3 = V/kL_1L_2$.

By estimating the shortest dimension (L_3) of each litter item, we can infer key shape parameters. For every litter item in the synthetic dataset, the elongation ($EL = L_2/L_1$) and flatness ($FL = L_3/L_2$) ratios were calculated, as well as Corey shape factor (Corey et al. 1949) ($CSF = L_3/\sqrt{L_1L_2}$). These shape descriptors enable a detailed characterisation of the size and shape of litter items based on their dimensions and geometric approximations and have been used previously to define sediment (Corey et al. 1949; Dietrich 1982; Cattapan et al. 2024) and plastic transport formulae (Waldschläger and Schüttrumpf 2019; Yu et al. 2022; Dittmar et al. 2024).

3 Results

3.1 The most persistent litter items in river environments

The meta-analysis covers a total of 34,296 and 204,994 litter items in rivers and riverbanks, respectively. Figure 1 shows the top 25 most persistent River-OSPAR items, separated by their study area (river or riverbank), and coloured by their material composition.

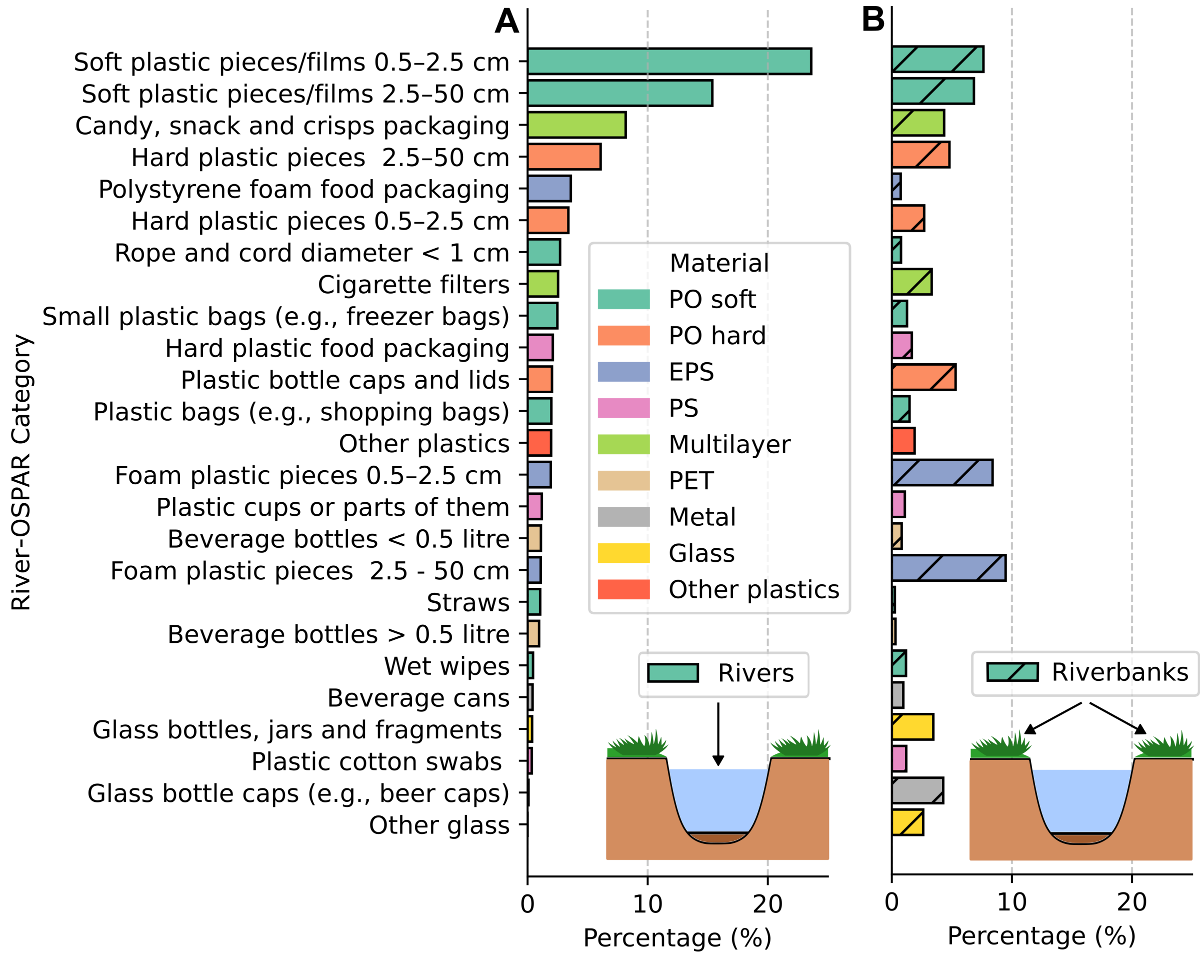


Figure 1. Top 25 most persistent River-OSPAR items in A) rivers (N = 34,296 items) and B) on riverbanks (N = 204,994 items), separated by their study area (river or riverbank) and coloured by their material composition.

The top 25 items shown in Figure 1 represent 80% of the most persistent litter items found in riverine systems. The data reveals distinct differences in the composition of litter found between rivers and riverbanks. In rivers, soft plastic pieces/films 0.5–2.5 cm (River-OSPAR ID 117.2) (23%), soft plastic pieces/films 2.5–50 cm (River-OSPAR ID 46.2) (15%) and candy, snack and crisps packaging (River-OSPAR ID 19) (8%) were the most commonly identified items. Over half the litter items identified in rivers were composed of PO soft plastic (54%), with a material density close to that of water (ρ = 0.89 – 0.98 g/cm^3). In contrast, on riverbanks the most common items were foam plastic pieces 2.5–50 cm (River-OSPAR ID 46.3) (9%) and foam plastic pieces 0.5–2.5 cm (River-OSPAR ID 117.3) (8%). These materials are composed of highly-buoyant EPS (ρ = 0.01 – 0.04 g/cm^3) and were predominantly found on riverbanks and less frequently in water samples. Similarly, very dense litter such as glass and metal items (ρ > 2 g/cm^3), were commonly collected from riverbanks but almost absent from river water samples.

Differences in litter composition between river and riverbanks can be attributed to differences in hydrodynamic between river compartments. In rivers, litter is transported from upstream sources, while on riverbanks, litter is introduced either through direct human activity or via overbank flooding events that occur a few times each year. Unlike in rivers, where continuous transport likely occurs, litter deposited on a riverbank, typically remains stationary until it is re-mobilised by another high-flow event. The likelihood of different types of litter being deposited on riverbanks during high-flow events depends largely on their buoyancy. Highly buoyant items, such as EPS, which float on the water surface are more likely to be deposited on the banks and retained by vegetation as water levels recede. In contrast, litter with a density closer to that of water, such as PO soft litter, are more likely to be submerged and mix within the active channel, making them less likely to be deposited on riverbanks.

Alternatively, differences in litter composition can arise from the sampling methodology. Most in-stream river litter collections from the meta-analysis (Table 1) have focused on sampling the surface or suspended layers of the river. For instance, six studies sampling the surface layer, which hold a bias for buoyant items or items that are hydrophobic, stabilised by surface tension (Valero et al. 2022). Four studies sampled the suspended layer, capturing items whose transport is governed by turbulence, and only three studies targeted the near-bed region (5 – 10 cm above the riverbed). Notably, none of the studies in this meta-analysis employing the River-OSPAR litter categories conducted direct sampling of the riverbed or sediments, where dense materials such as glass and metal would be transported as bedload or deposited in the riverbed. Consequently, reported riverine litter compositions may be biased toward floating and suspended materials, underestimating the contribution of high-density items deposited in sediments or transported as bedload.

3.2 Size distributions of litter in rivers

Figure 2A-C presents Kernel Density Estimation (KDE) plots of the longest (L_1), intermediate (L_2), and shortest (L_3) dimensions, of the top 25 River-OSPAR items, ranked by their prevalence in rivers. Figure 2D shows the predicted transport modes of each litter item in rivers (bed, suspended and surface load) based on their intrinsic material density, presented in Table 2. Data presented in Figure 2 and from this point onwards, correspond to the dataset described in Section 2.3 and 2.4, which is available at Lofty (2025). KDE plots of each River-OSPAR litter category's volume, mass and density are available in Figure S2.

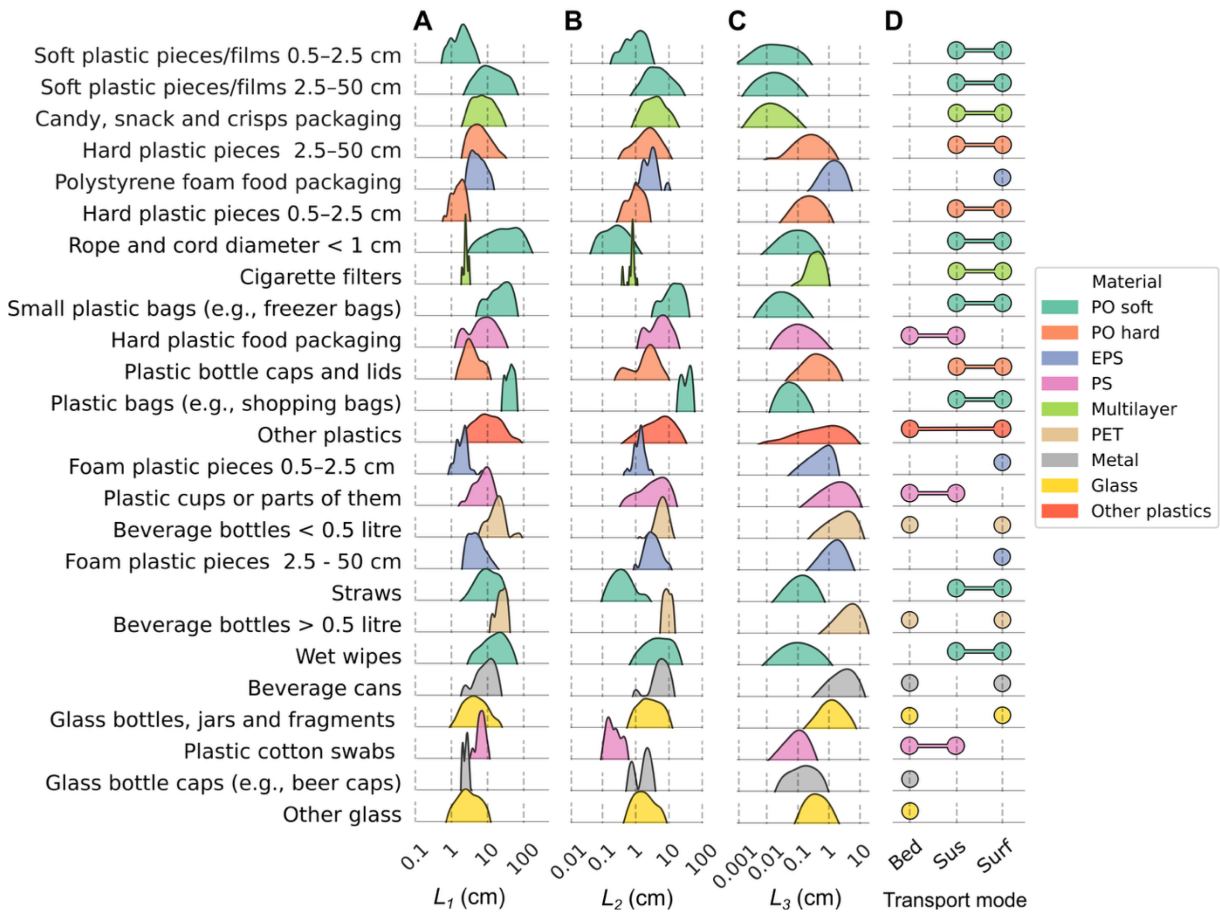


Figure 2. KDE plots for the top 25 most common River-OSPAR litter A) longest (L_1), B) intermediate (L_2) and C) shortest (L_3) dimensions, as well as each item's predicted transport modes in rivers - bed load (bed), suspended load (sus) or surface load ($surf$) - based on their intrinsic density (Table 2). Litter items are ranked by their prevalence in rivers (Figure 1) and coloured by their material composition.

We begin with a qualitative inspection of the results obtained from the built dataset to support the validity of the proposed approach. Consider, for example, a River-OSPAR category with which we are familiar — candy, snack, and crisp packaging. The median values of L_1 and L_2 are on the order of 10 cm, while L_3 is on the order of 0.01 mm, aligning with our expectations of such category and consistent with the typical thickness of food wrapping materials (approximately 0.05 - 0.12 mm). For completeness, CDF's and statistical comparisons of the L_1 dimensions of the top 25 litter items between the full dataset and measured litter items reported by de Lange et al., (2023) are available in Figure S3.

Across the top 25 River-OSPAR litter categories, the longest dimension (L_1) typically ranges from 1 to 50 cm, with 60 % of all items measuring between 1 and 5 cm. The intermediate dimension (L_2) is generally one order of magnitude smaller, ranging from approximately 0.1 to 10 cm, with exceptions observed for small and large plastic bags. While the long and intermediate dimensions generally span two orders of magnitude, the shortest dimension exhibits the greatest variability—spanning up to three orders of magnitude and typically ranging from 0.01 to 10 cm. 98% of top 25 River-OSPAR litter items have longest dimension > 1 cm suggesting that the majority can be classed as macrolitter, as defined by Hartmann et al. (2019).

The variability in object sizes differs significantly across River-OSPAR categories. Litter items with a highly standardized geometry and size, such as cigarette filters and plastic bottles, exhibit a very narrow size distribution, while litter items with a consistent geometry, but a range of possible sizes, such as plastic cups, present a broader distribution with a clear peak around the median value. On the other hand, some categories group together less well-defined items—such as those labelled "other plastics." In these cases, the variability is much higher, and the resulting distribution is considerably broader, reflecting the heterogeneity of the objects within the category.

3.3 Shape distribution of litter in rivers

Figure 3 plots the average elongation (EL) and flatness (FL) ratios of the top 25 litter items found in rivers and on riverbanks. Figure 3 represents the bivariate KDE map for the plastic frequency based on elongation and flatness across the synthetic dataset, while marginal KDE plots for elongation and flatness are shown above and to the right of the main plot. Dashed lines in Figure 3 delineate the boundaries between different shape categories: *spheres* (EL > 0.66, FL > 0.66), *rods* (EL < 0.66, FL > 0.66), *disks* (EL > 0.66, FL < 0.66), and *blades* (EL < 0.66, FL < 0.66) - following the shape classifications proposed by Zingg (1935) and adapted by Russell et al. (2025) for litter items. Spherically shaped particles have all three axes of similar length (i.e. $L_1 = L_2 = L_3$). Disk-shaped particles have two equal longer axes and one shorter axis (i.e. $L_1 = L_2 \neq L_3$). Rod-shaped particles have one longer axis with the other two equal shorter axes (i.e. $L_1 \neq L_2 = L_3$). Blade-shaped particles have all three axes of different lengths (i.e. $L_1 \neq L_2 \neq L_3$). KDE distributions for EL, FL and the CSF each River-OSPAR category is available in Figure S4, while bivariate KDE maps each River-OSPAR category are available in Figure S5.

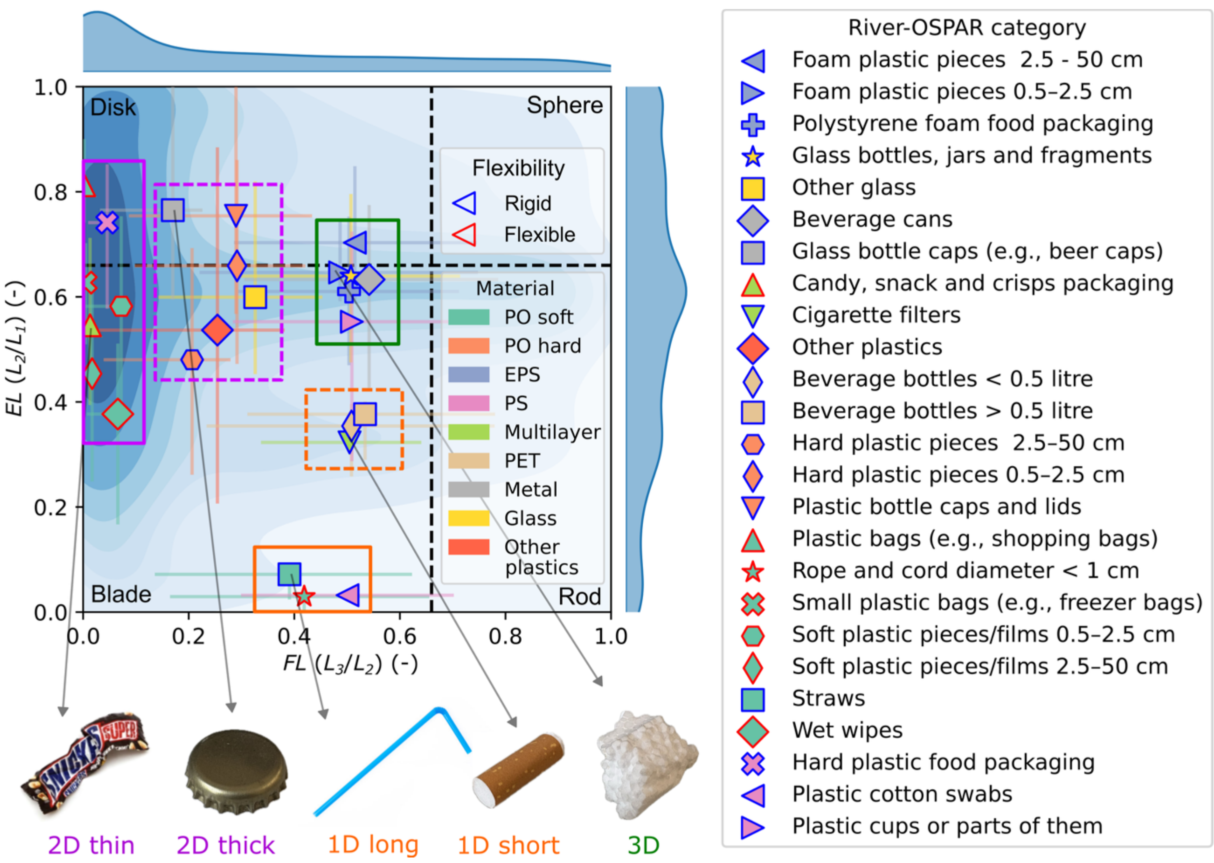


Figure 3. Geometric elongation (EL) and flatness (FL) ratio for the top 25 litter items found in rivers and on riverbanks. Markers indicate the average geometrical parameter, with horizontal and vertical lines representing the interquartile range (25^{th} – 75^{th} percentiles). The face colour of each marker indicates the material composition (Table 2), while the edge colour indicates whether the item is flexible (red) or rigid (blue). The colormap shows the bivariate KDE map for the synthetic dataset, with colour intensity indicating low (light) to high (dark) occurrences. Marginal KDE are also included for El and Fl ratios

From Figure 3, it is evident that the majority of litter items found in rivers and on riverbanks are flat 2D objects, with a longest dimension (L_1) that is approximately double the size of the intermediate dimension (L_2), with significantly smaller third dimension (L_3). This is indicated by a high-density region at FL < 0.2, and at EL between 0.4 – 0.8. Specifically, 50% of the top 25 River-OSPAR items have a FL value of < 0.2. The marginal FL KDE peaks at $FL \approx 0.05$, while the KDE of EL appears approximately uniform, suggesting that the ratio between the L_2 and L_1 is distributed evenly. 70% of litter items appear to be rigid, while the majority of flexible litter items tend to be flat in shape with a FL value < 0.1.

Most OSPAR items can be classified as either blade- (EL < 0.66, FL < 0.66) or disk-shaped items (EL > 0.66, FL < 0.66). Notably, no River-OSPAR items within the top 25 have geometries that are spherical- (EL > 0.66, FL > 0.66) or rod- shaped (EL < 0.66, FL > 0.66). Five distinct regions can be identified in Figure 3 (delineated as boxes), in which litter items cluster in similar geometries. Some items exhibit a more three-dimensional rigid geometry (3D), with $EL \approx 0.6$ and $FL \approx 0.5$, meaning that the intermediate dimension is half the length of the longest, and the shortest is half of the intermediate. Within this category includes polystyrene foam pieces, polystyrene food packaging, metal beverage cans, and plastic cups.

Other items exhibit a more two-dimensional geometry – where their long and intermediate axes are approximately half the size as each other ($EL \approx 0.6$), while the shortest axis is significantly smaller. These items can be further subdivided into two groups: thick two-dimensional rigid objects (2D thick), such as plastic bottle caps, with FL ratio between 0.1 – 0.4, and thin, flexible, two-dimensional objects (2D thin) with $FL < 0.1$, such as candy, snack and crisp packaging.

Finally, some litter items present a one-dimensional geometry, where the shortest dimension is about half the size as the intermediate dimension ($FL \approx 0.6$), while the long dimension is significantly larger. Similarly, these objects can be subdivided into two groups: short, rigid one-dimensional items (1D short), with $EL \approx 0.4$, such as cigarette filters and long one-dimensional items (1D long), with $EL < 0.1$, such as plastic straws. Other examples for 1D short items include beverage bottles, while examples for 1D long items include ropes, chord and cotton swabs.

4 Discussion

The identification of the top 25 most persistent River-OSPAR litter items, along with their dimensions and geometry distributions, offers a clear and empirically grounded basis for prioritising what litter items needs to be monitored effectively. The dominance of flat, 2D shaped macrolitter, highlights the need for protocols that are capable of effectively quantifying these plastics in rivers. Current, visual based monitoring of surface litter items using volunteers counting from bridges (González-Fernández and Hanke 2017; van Emmerik et al. 2018), UAVs (Geraeds et al. 2019) or cameras (Kataoka and Nihei 2020; Pinson and Vollering 2025) state they have a reliable detection limit for items between 2.5 and 5 cm. Based on this analysis, 34 % of litter items have an L_1 < 2.5 cm, meaning that potentially more than a third of litter may go undetected using these visual-based protocols. Therefore, water column monitoring methods capable of detecting small plastics (< 2.5 cm) such as net-based sampling (Liedermann et al. 2018; Oswald et al. 2023; Vriend et al. 2023; Oswald et al. 2025) or emerging techniques such as sonar (Flores et al., 2022) and echo sounding (Broere et al. 2021), may be more favoured for quantifying the litter items identified in this study.

The new completed dataset presented in this study (Lofty 2025) may also be used as an input for the numerical modelling of plastic transport in aquatic environments, for instance, into population balance models introduced by (Shettigar et al. 2024). The results indicate that plastic transport models should largely prioritise the dynamics of flat-shaped litter items, rather than adapting traditional sediment transport frameworks, which are typically calibrated for near-spherical particles. For such plastics, their drag coefficient may vary significantly even at equivalent Reynolds numbers (Kramer et al. 2021).

To date, many laboratory and field experiments have focused on litter items represented by 3D geometries—such cups (Valero et al. 2022; Lofty et al. 2024a), bottles (Liro et al. 2024; Liro et al. 2025) and rigid items (Russell et al. 2023; Lofty et al. 2024b; Przyborowski et al. 2024). However, these geometries are not commonly observed in river systems (Figure 4). Therefore, future experimental work should refocus on realistic particle geometries, which is essential for the development of representative transport processes and for the calibration and validation of hydrodynamic models.

Finally, knowledge of the physical characteristics of dominant litter items should also inform the design and optimisation of clean-up technologies, such as floating booms (Blettler et al. 2023), barriers (Pinson and Vollering 2025), interceptors (The Ocean Cleanup 2025; Toe et al. 2025), racks (Honingh et al. 2020) and traps (Gasperi et al. 2014). These technologies should be designed with suitable grid or mesh sizes or positioned in the river to target these most frequently observed items.

5 Conclusions

In this work, we present the top 25 most persistent River-OSPAR indexed litter items found in river and on riverbanks and generate distributions of their principal dimensions and geometries. This is conducted by employing a meta-analysis of the relative occurrence of 239,290 litter items from rivers and riverbanks across Europe, Central America, Africa and Asia, as well as a dataset from de Lange et al., (2023), which provides mass, and longest and intermediate dimensions for 14,052 litter items collected from riverbanks. Applying copula-based statistical modelling, we are able to complete a large dataset with key physical properties capturing the joint distribution of mass and principal dimensions for each River-OSPAR item. This approach enabled us to estimate the unmeasured third dimension of each item and derive shape descriptors, such as elongation, flatness and CSF, enabling insight into the geometries of the most common river litter.

The results reveal that only 25 River-OSPAR litter categories cover 80% of all litter items in rivers and riverbanks, with the most prominent being soft plastic pieces/films (River-OSPAR ID 117.2 & 46.2) and candy, snack and crisps packaging (River-OSPAR ID 19). Buoyant, flat-shaped macrolitter items dominate the physical properties of the top 25 litter items. Specifically, 48% of the top 25 litter items share similar geometric properties; they have a longest dimension of between 1 and 10 cm, a flatness ratio of < 0.4 and an elongation ratio of any value between 0 and 1. In practice, these are flat objects with two larger dimensions and a third that is at least one order of magnitude smaller. These shapes are distinct from those of natural sediments or microplastics and may have significant implications for their transport and fate in rivers. The generated dataset provides a physically realistic and statistically robust foundation for prioritising litter types, geometries, and dimensions that should be targeted to improve plastic monitoring strategies, enhance physics-based transport models, and guide the design of clean-up technologies – shifting the focus towards more realistic geometries and materials to better replicate real-world river litter

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