Sample size requirements for riverbank macrolitter characterization

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Abstract

Anthropogenic litter is omnipresent in terrestrial and freshwater systems, and can have major economic and ecological impacts. Monitoring and modelling of anthropogenic litter comes with large uncertainties due to the wide variety of litter characteristics, including size, mass, and item type. It is unclear as to what the effect of sample set size is on the reliability and representativeness of litter item statistics. Reliable item statistics are needed to (1) improve monitoring strategies, (2) parameterize litter in transport models, and (3) convert litter counts to mass for stock and flux calculations. In this paper we quantify sample set size requirement for riverbank litter characterization, using a database of more than 14,000 macrolitter items (>0.5 cm), sampled for one year at eight riverbank locations along the Dutch Rhine, IJssel and Meuse rivers. We use this database to perform a Monte Carlo based bootstrap analysis on the item statistics, to determine the relation between sample size and variability in the mean and median values. Based on this, we present sample set size requirements, corresponding to selected uncertainty and confidence levels. Optima between sampling effort and information gain is suggested (depending on the acceptable uncertainty level), which is a function of litter type heterogeneity. We found that the heterogeneity of the characteristics of litter items varies between different litter categories, and demonstrate that the minimum required sample set size depends on the heterogeneity of the litter category. More items of heterogeneous litter categories need to be sampled than of heterogeneous item categories to reach the same uncertainty level in item statistics. For example, to describe the mean mass the heterogeneous category soft fragments (>2.5cm) with 90% confidence, 990 items were needed, while only 39 items were needed for the uniform category metal bottle caps. Finally, we use the heterogeneity within litter categories to assess the sample size requirements for each river system. All data collected for this study are freely available, and may form the basis of an open access global database which can be used by scientists, practitioners, and policymakers to improve future monitoring strategies and modelling efforts.

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Abstract

Anthropogenic litter is omnipresent in terrestrial and freshwater systems, and can have major economic and ecological impacts. Monitoring and modelling of anthropogenic litter comes with large uncertainties due to the wide variety of litter characteristics, including size, mass, and item type. It is unclear as to what the effect of sample set size is on the reliability and representativeness of litter item statistics. Reliable item statistics are needed to (1) improve monitoring strategies, (2) parameterize litter in transport models, and (3) convert litter counts to mass for stock and flux calculations. In this paper we quantify sample set size requirement for riverbank litter characterization, using a database of more than 14,000 macrolitter items (>0.5 cm), sampled for one year at eight riverbank locations along the Dutch Rhine, IJssel and Meuse rivers. We use this database to perform a Monte Carlo based bootstrap analysis on the item statistics, to determine the relation between sample size and variability in the mean and median values. Based on this, we present sample set size requirements, corresponding to selected uncertainty and confidence levels. Optima between sampling effort and information gain is suggested (depending on the acceptable uncertainty level), which is a function of litter type heterogeneity. We found that the heterogeneity of the characteristics of litter items varies between different litter categories, and demonstrate that the minimum required sample set size depends on the heterogeneity of the litter category. More items of heterogeneous litter categories need to be sampled than of heterogeneous item categories to reach the same uncertainty level in item statistics. For example, to describe the mean mass the heterogeneous category soft fragments (>2.5cm) with 90% confidence, 990 items were needed, while only 39 items were needed for the uniform category metal bottle caps. Finally, we use the heterogeneity within litter categories to assess the sample size requirements for each river system. All data collected for this study are freely available, and may form the basis of an open access global database which can be used by scientists, practitioners, and policymakers to improve future monitoring strategies and modelling efforts.

1. Introduction

Anthropogenic litter (hereinafter called litter) is omnipresent in the natural environment and has major economic consequences such as damage to vessels, and ecological impacts including ingestion and entanglement (van Emmerik and Schwartz, 2020; Lau et al., 2020). Litter is defined as any solid manufactured waste item that enters the environment through intentional or unintentional improper disposal (McCormick and Hoellein, 2016). In response to these threats many efforts have been made to reduce the amount of litter in the natural environment. Understanding and quantifying litter sources, transport, and accumulation processes may increase the efficacy of prevention and reduction efforts. Previous studies have demonstrated that the transport and accumulation of litter in water, both in the vertical and horizontal dimension, strongly depends on the interaction between the fluid dynamics and the characteristics of the litter (Morales-Caselles et al., 2021; Kuizenga et al., 2022). For example, the settling rate and transport of litter in water is affected by the density, surface area and size of the litter (Kukulka et al., 2012; Chubarenko et al., 2016; Kowalski et al., 2016; Schwarz et al., 2019). Pedrotti et al. (2016) observed that in the Mediterranean Sea the abundance of high-density polymers decreased when moving away from the coast. Furthermore, wind driven transport of litter on land strongly depends on the density, shape, and size of litter items as well (Garello, et al., 2021; Mellink et al., 2022b). Finally, the retention of litter in (riparian) vegetation depends on the size and shape of the litter (Cesarini & Scalici, 2022). To improve our understanding of the behavior of litter in the natural environment, such as litter transport pathways and fate, and to improve litter monitoring and modelling, it is therefore essential to identify the variability litter characteristic and the corresponding statistics, and the implications of this variability for sampling efforts.

Litter is a heterogeneous entity (Roebroek et al., 2021), as it comes in many shapes (Ballerini et al., 2022), varying in size, mass, density, and the rate at which it degrades over time (Delorme et al., 2021). Uncertainty arises when a generalized value, such as an average, is used to represent a heterogeneous variable like litter (Schwarz et al., 2019). However, it is unclear what the relation is between sample set size and reliability and representativeness of the statistics. Reliable item statistics are needed to improve monitoring efficiency, when determining how many items need to be sampled to characterize a system. Furthermore, transport models should be parameterized with reliable item category statistics, since litter transport and retention dynamics strongly depend on the material characteristics. Roebroek et al. (2022) show that litter transport model uncertainty decreases with several orders of magnitude with increasing availability of litter data. Consequently, litter transport models that do not accurately capture litter heterogeneity, inevitably feature a greater level of uncertainty. Furthermore, litter heterogeneity introduces additional uncertainties in the conversion of litter amounts (and fluxes) to mass (per unit time), and vice versa (van Calcar & van Emmerik, 2019). Such conversions often rely on generalized litter masses to convert the observed number of items to a total mass (Vriend et al., 2020b). For specific rivers the uncertainty can be several orders of magnitude (Roebroek et al., 2022). Due to the heterogeneous nature of litter, a generalized conversion factor based on generalized litter masses, induces higher uncertainty, and consequently a representative value per litter type is ideally needed.

This study presents an approach to determine what sample size is needed for representative and reliable litter statistics. This analysis is based on a dataset containing the characteristics (item category, length, width and mass) of more than 14,000 riverbank litter items. We found that increasing the sample set size decreases the uncertainty in the sampled litter statistics. However, it was found that reducing uncertainty through increasing sample set size, levels off beyond a certain sample set size. We also found that the heterogeneity of the characteristics of litter items varies between different litter categories and demonstrate that the minimum required sample set size depends on the heterogeneity of the litter category. With the dataset and analysis presented in this study we aim to contribute to improving the efficiency of litter monitoring strategies, the accuracy of litter transport models, and the conversion of litter item counts to litter masses for stock and flux calculations.

2. Methods

2.1. Study area

The catchments of the studied rivers Rhine, IJssel and Meuse (Figure 1), are heavily industrialized and densely populated (~ 300 inhabitants/km^2) (van der Wal et al., 2013). The river Rhine (Bovenrijn) enters the Netherlands at Spijk, 161 km from the river mouth. At 147 km the Rhine bifurcates into the Waal (67% of the discharge), Nederrijn (22%) and IJssel (11%) (Schielen et al., 2007). The Waal and Nederrijn then converge at 42 km from the river mouth. The river Meuse enters the Netherlands at Eijsden, 250 km from the river mouth, and discharges 10% of the mean discharge of the Rhine-system (230 m^3/s and 2200 m^3/s respectively). Near the coast (~80 km from the sea), the branches of the Rhine and Meuse systems converge and intertwine. Ultimately, the Rhine-Meuse system drains into the North Sea, while the river IJssel drains into lake IJssel after 125 km.

Sampling locations were chosen to be at the upstream and downstream end of the Dutch section of the rivers Rhine (R), Meuse (M) and IJssel (IJ) (Figure 1). Supplementary Materials A provides a detailed description of the sampling areas. The sampling areas at Nijmegen (R1) and Rotterdam (R3) are located along the river Rhine, while Arnhem (R2) is located at the Nederrijn beyond the first major bifurcation of the Rhine. Arnhem (IJ1) and Kampen (IJ2) are situated on the river IJssel, while the river Meuse was sampled at locations in Maastricht (M1), Ravenstein (M2) and Moerdijk (M3). Location M3 is located beyond the point where the rivers Rhine and Meuse merge, and is therefore affected by both river systems. Location M3 and R3 are in the tidal zone, and can therefore be subject to bidirectional currents.

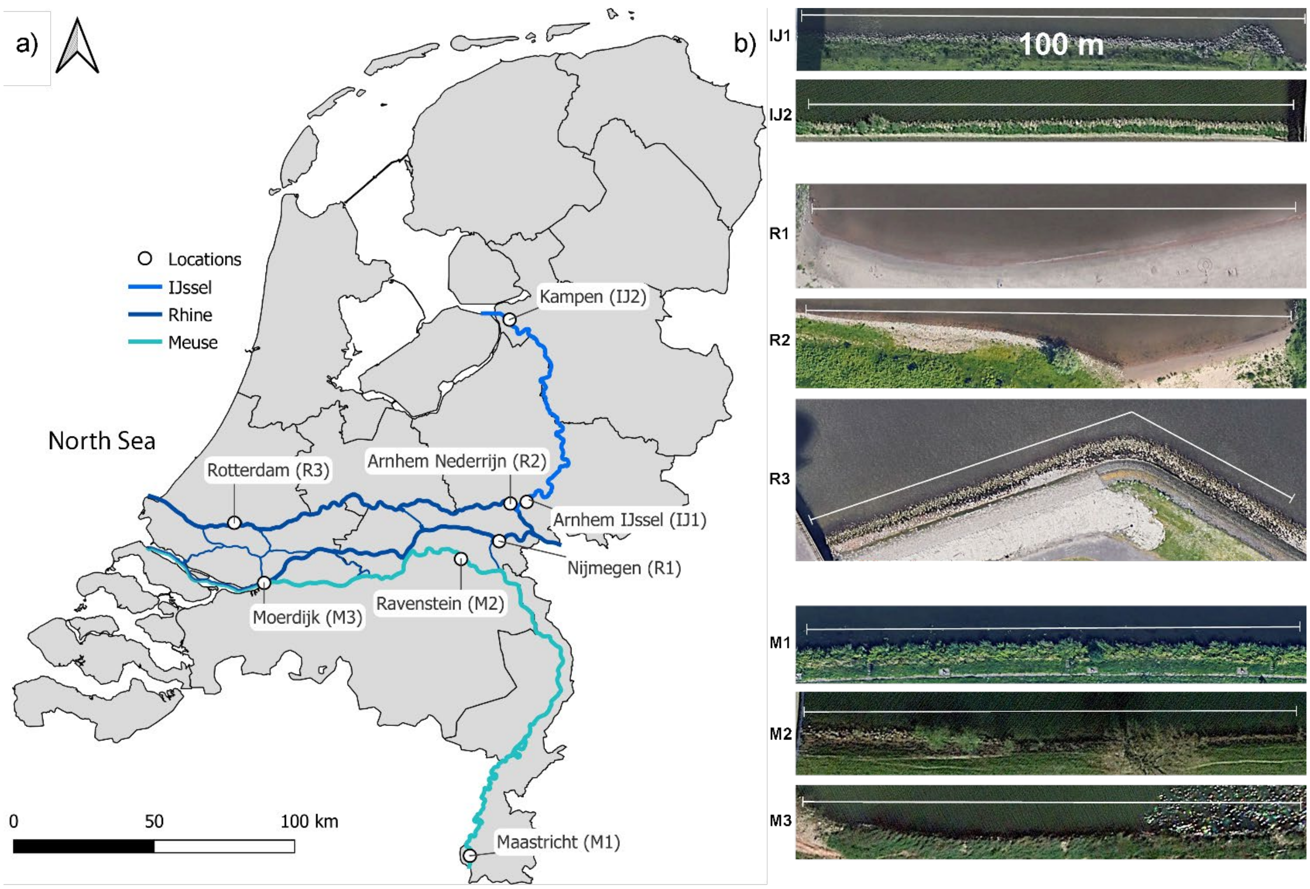

Figure 1. The study area (a) with the sample areas (Google Earth; Landsat and Copernicus) (b). b) The white line has a length of 100 m. Supplementary materials B provide more detailed information on the riverbanks. Sampling locations are chosen at the upstream and downstream end of the Dutch part of the river Rhine (R), Meuse (M) and IJssel (IJ). The river Meuse has an additional midpoint measurement, and the river Rhine has an additional sampling area beyond the first major bifurcation. The sampling areas at Nijmegen (R1; sandy; 130 km from the mouth), Arnhem (R2; sandy; 130 km from the mouth) and Rotterdam (R3; stones; 30 km from the mouth) characterize the river Rhine, Arnhem (IJ1; sandy; 125 km from the mouth) and Kampen (IJ2; vegetated; 16 km from the mouth) characterize the river IJssel, and the river Meuse was sampled at a location in Maastricht (M1; vegetated; 250 km from the mouth), Ravenstein (M2; vegetated; 138 km from the mouth) and Moerdijk (M3; vegetated; 56 km from the mouth).

2.2. Sample collection and processing

Riverbank macrolitter was collected once per month between January and December 2021 at eight riverbank sites. Location R2 was sampled only in January and December, and location M1 was not sampled in January due to limited sample collection and processing capacity. The width of the sampling area was defined as the distance from the waterline to the high waterline, having a maximum value of 25 m (van Emmerik et al., 2020). The waterline is defined here as the interface between the river and the riverbank. The high waterline can be identified in the field by the fact that a proportion of the organic matter floating at the river surface is deposited at this elevation along the water margin once the peak flow begins to recede. Sampling was carried out until one of the following criteria was met:

(1) coverage of 100 meters length, (2) collection of material equaling 80 liters, or (3) a sampling time exceeding 90 minutes. These limits were set based upon the availability of surveyors for the sample collection, the state of the riverbank (the required sampling time can be considerably higher if there is dense vegetation), and available capacity for subsequent laboratory analysis of the sampled material. The width of the sampled locations varied between 1 and 10 m and the length between 10 and 100 meters. It should be noted that riverbank sampling is biased towards larger items, since smaller items are more difficult to identify by eye (Hanke et al., 2019), hence statistics for the smaller macrolitter items (< 1 cm) should be taken with caution.

Collected samples were analyzed in the Laboratory for Water and Sediment Dynamics at Wageningen University. First, the items were manually and superficially cleaned of sediment and organic debris to preserve the state in which they were sampled. Superficial cleaning was performed to remove sediment and organic debris from the items. Items may have fragmented during transport, which may have led to more litter items being analyzed in the lab oratory than originally sampled. Second, the items were categorized using the River-OSPAR protocol (supplementary materials B), developed by the North Sea Foundation (van Emmerik et al., 2020). This protocol is based on the OSPAR guidelines for beach litter monitoring (OSPAR commission, 2010), with adjusted categories to better account for items frequently found in (Dutch) rivers. The protocol includes 111 specific item categories, divided over nine parent categories (i.e. plastic, rubber, textile, paper, wood, metal, glass, sanitary, and medical items). The River-OSPAR categorization system gives a detailed overview of the abundance of various types of litter. To facilitate direct comparison with other categorization methods in future research efforts, we included a 'conversion table' (Supplementary materials F) for rapid re-categorization in one of the other published categorization methods (Vriend et al., 2020a; Schwarz et al., 2019; Kiessling et al., 2019; Nally et al., 2017; Fleet et al., 2021).

Finally, we determined the mass, length and width of the 14,052 items sampled between January and May, and in the months of August and November. Due to limited resources, items were not analyzed in the other months. The mass was weighed on a scale (0.01 g accuracy). In case individual items did not reach the minimum detectable mass, multiple items of the same category were weighed collectively, and a mean value assigned to each. For item length and width, the two longest axes were measured with a 0.1 cm accuracy.

2.3. Data analysis

2.3.1. Determination of item category heterogeneity

Category heterogeneity ψ [-] was used to assess item category variability. This represents the normalized standard deviation (also known as coefficient of variation) and is defined as

$$\Psi = \frac{\sigma}{\mu} \qquad \text{(equation 1)}$$

in which σ is the standard deviation and μ is the mean of a certain category parameter, such as item length or mass.

2.3.2. Determination of sample set size requirements

The number of items needed to accurately represent category statistics depends on the category heterogeneity. We studied the relation between statistical uncertainty and sample size, which can be used to determine how many items are required for a representative and reliable value of the mean item mass across all riverbanks (sample set size requirement; SSR). A representative value means that the subset of the population accurately reflects the characteristics of the full population, while a reliable value means that the method to determine this value consistently has the same outcome. To this end, we randomly drew a subset from the total set and calculated the mean mass. The size of the subset ranged from one item to all items in the total set. Next, a Monte Carlo based bootstrap analysis was performed 10,000 times for each subset size to determine the deviation of the subset from the dataset mean. From these runs, we calculated the 50, 75, 90 and 95% confidence intervals. These simulations were run using all litter categories lumped together, and for each single item category with more than ten sampled items (59 out of 111 item categories, representing 89% of the total number of items). In this way, the number of items needed to give a representative estimate (within a certain confidence interval) of the mean mass of an item category could be determined. A deviation of 5, 10 or 20% of the actual mean value (the mean mass based on the whole category) is given. All subsequent analysis was performed for the 90% confidence interval with a 10% deviation from mean, and the results might change for different combinations of those. Finally, the same analysis was carried out to calculate the values for median mass and mean length for all items, and as an example for two item categories (soft fragments >2.5 cm and metal bottle caps). This analysis could be performed for other item variables (e.g. length, width) and statistics (median) as well, but was considered out of scope for the present study.

2.3.3. Determination of river system heterogeneity

The concept of litter heterogeneity and SSRs per item category can be upscaled to a riverbank location or even a whole river-system, to allow for characterization of heterogeneity at various scales. The heterogeneity of a location or a river system is based on the items found in this system, and the corresponding SSRs. Based on the SSR for a 90% confidence interval and a deviation of 10% from the mean, an item category is defined as homogeneous, heterogeneous or mixed based on the median SSR, the median SSR and mean SSR of all categories:

Homogeneous:	$SSR_i < \eta\ (SSR_{all})$
Mixed:	$\eta\ (SSR_{all}) \leq SSR_i \leq \mu\ (SSR_{all})$
Heterogeneous:	$\mu\ (SSR_{all}) < SSR_i$

in which μ is the mean and η the median of SSR_i. SSR_i is the sample set size requirement for item category i, while SSR_{all} represents the SSRs of the whole population.

Finally, if less than 10 items were collected, no SSR was calculated, and the item heterogeneity was left undefined. All items found within a system were classified this way, and subsequently the ratio between homogeneous, mixed, heterogeneous and undefined items were determined on multiple scales. This allowed for comparison between the riverbank locations, and between the Meuse, Rhine and IJssel river systems.

3. Results and Discussion

3.1. Riverbank macrolitter classification

In total 16,488 items (184 kg) were collected and categorized from eight riverbanks over 12 months, of which 14,052 (85%) were measured and weighed. For a detailed description of the length distribution of the items, see Supplementary Materials E. The majority of items were plastics (70% of item count, 33% of total mass) and mainly composed of unidentifiable plastic fragments (50% of all items) (Table 1). This result is in line with the findings of van Emmerik et al. (2020), who found 55.8% of riverbank litter items to be fragments along the Dutch Rhine-Meuse system. Although plastic dominates the collected item count (Table 1), local spatial variations exist (Figure 2). This can mainly be contributed to the type and use of riverbank (supplementary materials A), which play a role in which items are trapped and retained (Liro et al., 2022). For example, recreational areas, such as R1, show a lower percentage of plastic items (for example only 15% of item counts for R1) and are dominated by consumer items such as cigarette filters, metal bottle caps and glass bottles.

The average item mass was 11.1 g (6.1 g for plastics), and the median mass was 0.55 g (0.53 g for plastics) (Table 1). The summarizing statistics per item category can be found in Supplementary materials C. The difference between the mean and median mass indicated a highly positively skewed distribution with many light items and relatively few heavy outliers. The large number of fragments (for example soft fragments, hard fragments, foam fragments) are responsible for this skewedness (Figure 3a). Heavy outliers include items of scrap metal such as bikes, and metal pipes (Figure 3b). The skewed distribution may have far reaching consequences for setting up a mass-balance using only summarizing statistics. For example, estimates of floating plastic flux, based upon items per hour (which is subsequently converted to mass per year), can differ by an order of magnitude when using either the mean or the median mass for this conversion (van Emmerik et al, 2022).

The ten most frequently found items (Figure 3) represent 56% of the total amount of items and 65% of the total mass. The twenty most abundant items represent 66% of the total item count and 87% of the total mass, respectively. The top ten items vary strongly when considering the item count or mass as demonstrated in Figure 3. In terms of frequency, plastic fragments, food packaging, and items related to consumables and cigarette filters are the most abundant categories (Figure 3a). In terms of mass, the top ten items mainly consist of higher-density items such as metal (mean mass 41 g), wood (mean mass 176 g) and glass (mean mass 27 g) (Figure 3b). This discrepancy between abundance in count and mass emphasizes the importance of mass statistics for reliable estimates of litter mass balances. Although accumulated material on riverbanks is often expressed in item count per surface area, item mass per surface area is more relevant for closing the mass balance. Considering that items will likely increase over time due to fragmentation, we consider item mass per surface area a more appropriate indicator for riverbank litter accumulation.

*Table 1. Statistics of all the collected litter. *in parentheses: the number of months in which lab analysis was performed.*

Location	*Length of measurement periods**	*Most commonly found item (Supplementary materials D)*	*Total number of items*	*Total mass of items (kg)*	*Total number of plastic items*	*Total mass of plastic items (kg)*	*Median mass (g)*	*Mean mass (g)*	*Mean item density (items/m)*	*Mean mass density (g/m)*
All	*-*	*Soft fragment (>=2.5 cm) (14%)*	*16,488*	*184*	*11,596 (70%)*	*61 (33%)*	*0.55*	*11*	*8.13*	*38.5*
R1	*12 (7)*	*Cigarette filter (49%)*	*3,193*	*12*	*471 (15%)*	*2.7 (22%)*	*0.55*	*4.8*	*3.32*	*7.01*
R2	*2 (1)*	*Other metal (<50 cm) (26%)*	*378*	*1*	*231 (61%)*	*0.29 (27%)*	*0.55*	*3.1*	*2.55*	*6.79*
R3	*12 (7)*	*Soft fragment (>=2.5 cm) (23%)*	*1,141*	*47*	*702 (62%)*	*10 (22%)*	*3.30*	*49*	*2.52*	*41.0*
M1	*11 (9)*	*Hard fragment (>=2.5 cm) (9%)*	*4,983*	*20*	*4,540 (91%)*	*13 (66%)*	*0.53*	*4.3*	*15.1*	*54.4*
M2	*12 (7)*	*Soft fragment (>=2.5 cm) (27%)*	*1,286*	*33*	*1,130 (88%)*	*12 (38%)*	*0.70*	*28*	*3.27*	*23.3*
M3	*12 (7)*	*Soft fragment (>=2.5 cm) (24%)*	*3,429*	*25*	*3,119 (91%)*	*17 (69%)*	*0.49*	*9.3*	*32.7*	*154*
IJ1	*12 (7)*	*Wet tissue (19%)*	*422*	*35*	*231 (55%)*	*0.42 (1%)*	*0.67*	*90*	*0.346*	*4.44*
IJ2	*12 (7)*	*Soft fragment (>=2.5 cm) (27%)*	*1,656*	*11*	*1,172 (71%)*	*4.0 (36%)*	*0.30*	*8.4*	*5.29*	*17.12*

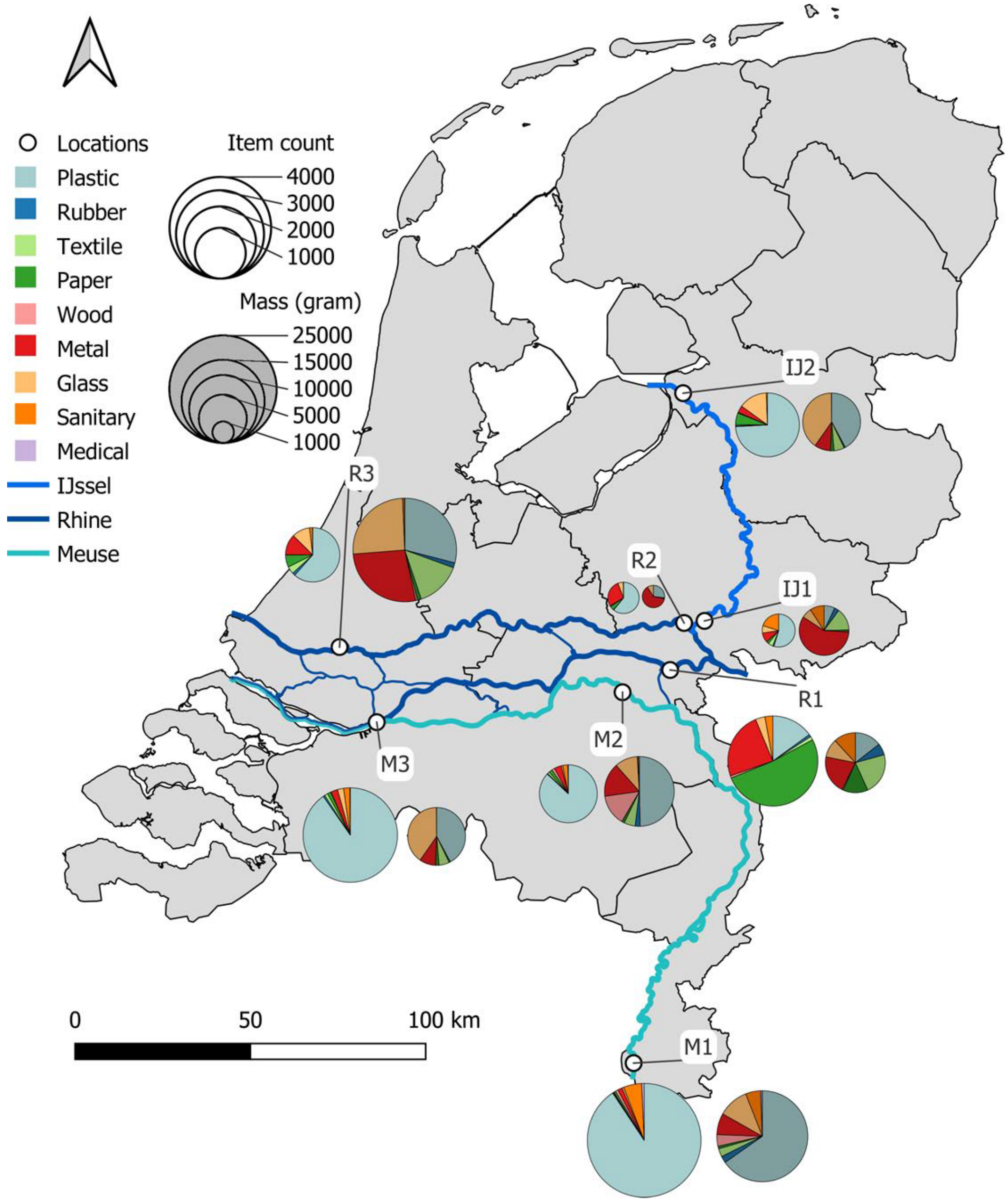

Figure 1. Map showing the eight riverbank locations along the Dutch Rhine (R1, R2, and R3), Meuse (M1 and M2), and IJssel (IJ1 and IJ2) rivers. For each location, the total number of litter items (left pie chart) and the total mass of litter items (right pie chart) found for the nine parent litter categories (plastic, rubber, textile, paper, wood, metal, glass, sanitary, and medical) is shown. The diameters of the pie charts indicate the total amount and mass of the items.

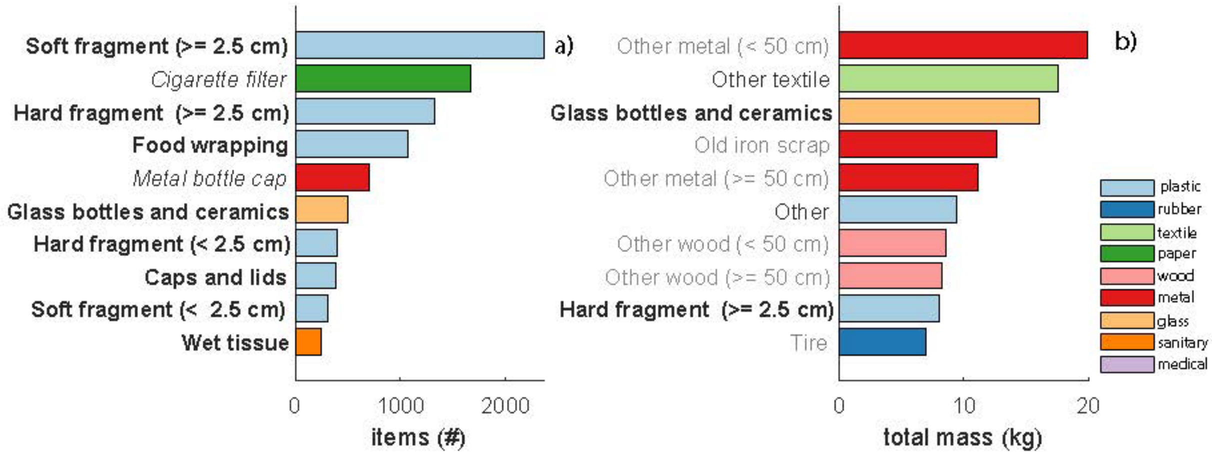

Figure 2. List of the top 10 most frequently found items based upon (a) item amount and (b) mass. Item categories are defined as homogeneous (italic), ***heterogeneous*** *(bold),* mixed *(normal) or undefined (grey) based on the analysis below.*

3.2. Item category heterogeneity

Item characteristics in the dataset can vary significantly within and between litter categories. To be able to give an accurate measure of mean, median and standard deviation of litter item categories (Supplementary material C), the sample size must be large enough to capture the mass and length variability within a category. The number of items needed to accurately represent category statistics (within a certain uncertainty level), depends on the heterogeneity of the category. Aggregated categories in the River-OSPAR system (e.g. soft fragments larger than 2.5 cm), may have large variability in item mass and size. For categories consisting of relatively uniform items (e.g. cigarette filters) this may be the opposite. The variability within a category can be characterized by a category heterogeneity Ψ (Equation 1) and is presented as histograms of length and mass (Figure 4). Wider distributions, such as that of soft and hard fragments, belong to more heterogeneous item categories, which is reflected in Ψ (1.03 and 0.92 for item length, respectively). Note the axis scale break in the x-axes of subfigures 4f through 4j, which indicate a wider histogram than inferred from the visible histogram. Narrower distributions, such as cigarette filters and metal bottle caps are described by a lower category heterogeneity ($\Psi = 0.08$ and $\Psi = 0.14$ for item length, respectively). Item heterogeneity is one of the most important factors that determines how many items should be sampled to obtain representative item statistics and these SSRs are discussed below.

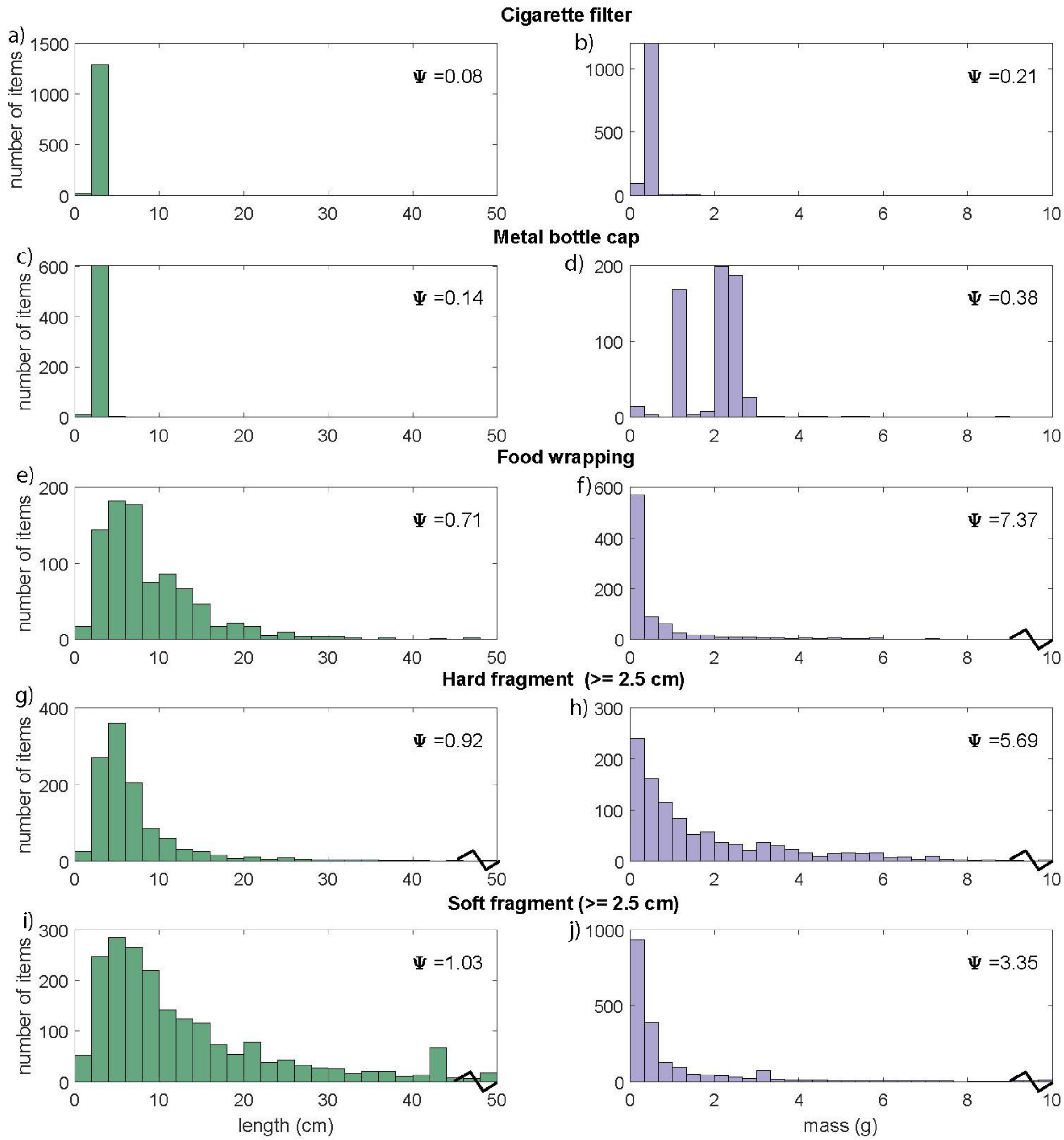

Figure 4. Length and mass distribution of the five most commonly found items, and their corresponding category heterogeneity Ψ. The scale break in the x-axis of subfigures f through j indicate a wider histogram than inferred from the visible histogram.

3.3. Sample set size requirements

By collecting more litter items, the item statistics (such as median and mean mass or length for example) become less uncertain, and this is especially relevant for heterogeneous litter categories. The amount of statistical uncertainty decreases with increasing sample size, meaning that the possible range of outcomes of the mean or median from the subset, differs increasingly less from the total population. However, uncertainty shows an inverse exponential decrease with sample size. Larger sample sizes only reduce statical uncertainty to a minor extent after a certain threshold. This threshold represents the minimum number of item samples that is required in order to obtain a representative number (within certain confidence bounds) of mass and length statistics.

To describe the mean mass of all litter at the sample locations with a maximum deviation of 10% of the mean based upon the total population with 90% confidence, at least 8,900 items need to be sampled and measured (63% of the total amount of weighed items). To capture the representative mean length 1,200 items (9%) need to be collected, while only 173 items (1%) are needed to describe the median mass (Figures 5a through 5d). The more heterogeneous an item category, the more samples need to be collected to obtain representative mass and length statistics. An example for the SSR of a homogeneous and a heterogeneous subclass is presented for the heterogeneous category "soft fragments larger than 2.5 cm", 990 items (42% of full sample) are needed to find a mean mass (within 10% of the mean mass based on the full population) with 90% confidence (Figure 5e through 5h). When determining the mean mass of homogeneous item categories such as "metal bottle caps" (Figure 5i through 5l), only 38 (6% of full sample) items suffice.

The number of samples to be collected and measured depends on the acceptable confidence boundary and a maximum level of deviation from the mean of the total population. In the aforementioned examples, a maximum deviation of 10% was allowed and estimated with 90% confidence. With these conditions, an accurate representation of the mean mass of food packaging is reached when 150 items are measured. However, if a deviation of +/- 20% is permitted, only 110 items are needed to reach the uncertainty required. Similarly, if a confidence boundary of 50% is permitted, only 95 items are required to represent the mean mass (+/- 10%). The level of confidence and maximum level of deviation allowed therefore impact the SSR.

We show the SSR of 59 item categories with more than 10 items in Table 2, which may be used in to find a balance between statistical uncertainty and sampling effort in future monitoring efforts. These 59 item categories make up 89% of total amount of collected items. The mean SSR equals 158 items, while the median equals 40 items. Our dataset does not include sufficient samples for all categories to provide an estimate of the mean mass within the selected confidence boundaries and deviations of the mean in this study. When the number of items needed to represent the mean mass is equal to the total number of items collected (indicated by the red shade in Table 2), or when a level of uncertainty (confidence boundary and deviation from the mean) is never reached (represented by N/A in Table 2), it is not possible to provide a SSR. For the highest confidence boundary (95%) and lowest deviation from mean (5%), this is the case for 37 items categories. Table 2 also shows the category heterogeneity for each item category, calculated based upon the available dataset, even if it was not sufficiently large enough to determine SSRs. As demonstrated in the aforementioned examples, to obtain the same uncertainty levels in the mass-size statistics of riverbank litter, the SSRs of heterogeneous item categories are higher than of homogeneous item categories. This is underlined by the correlation (R-squared) between SSR and category heterogeneity for these 59 item categories, which is on average 0.45, but varies between 0.12 and 0.60.

The SSRs can be the baseline for monitoring protocol design and serve as a rule of thumb or indication when making an initial design. If required, the SSR analysis can be expanded to calculate SSR based on median mass, mean or median length and mean or median width, based on this dataset. Since the SSR analysis depends on the used item categorization method, we included a 'conversion table' (Supplementary materials F) for rapid re-categorization in one of the other published litter categorization methods (Vriend et al., 2020a; Schwarz et al., 2019; Kiessling et al., 2019; Nally et al., 2017; Fleet et al., 2021).

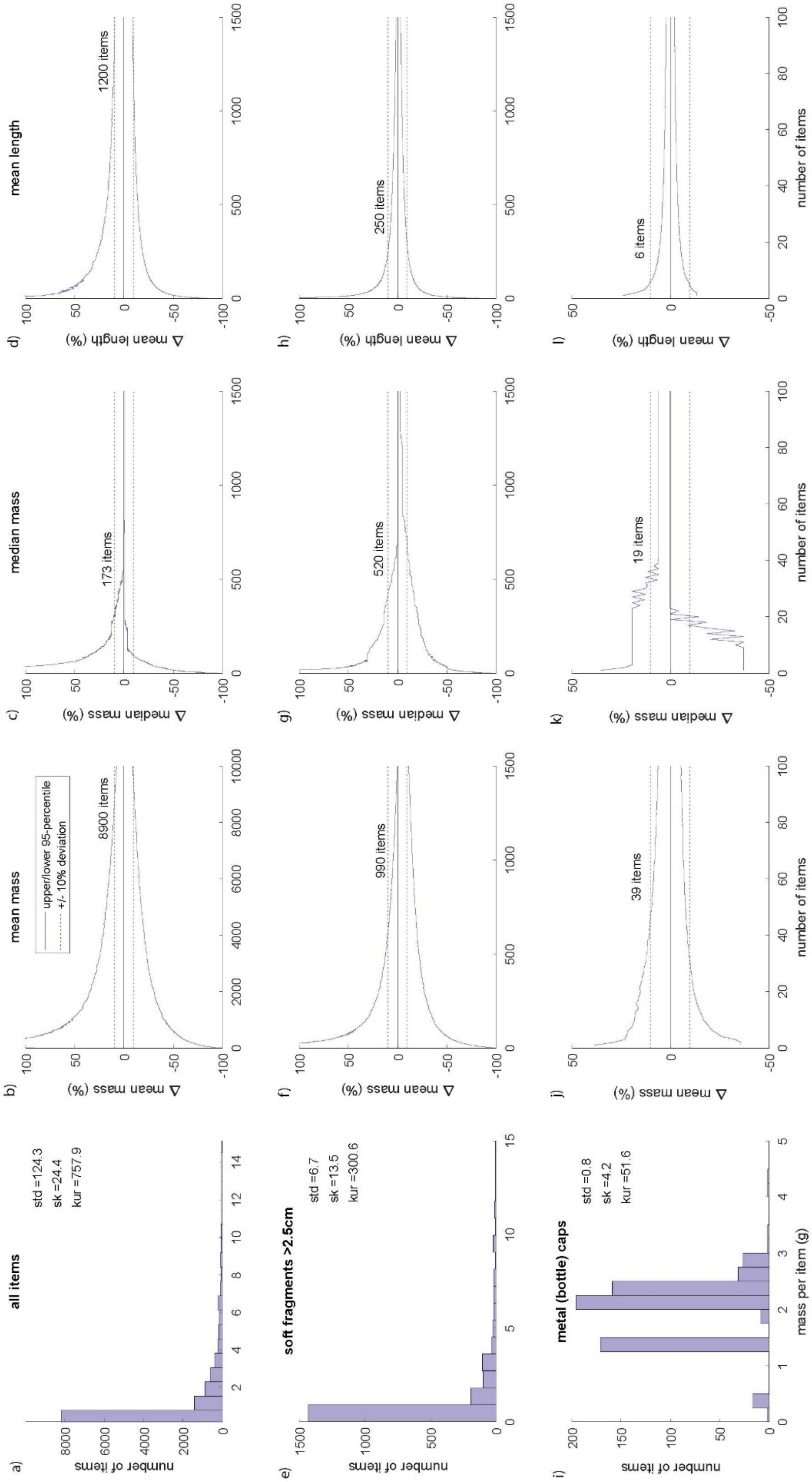
a)
all items
std =124.3
sk =24.4
kur =757.9
number of items
b)
mean mass
upper/lower 95-percentile
+/- 10% deviation
8900 items
Δ mean mass (%)
c)
median mass
173 items
Δ median mass (%)
d)
mean length
1200 items
Δ mean length (%)
e)
soft fragments >2.5cm
std =6.7
sk =13.5
kur =300.6
number of items
f)
990 items
Δ mean mass (%)
g)
520 items
Δ median mass (%)
h)
250 items
Δ mean length (%)
i)
metal (bottle) caps
std =0.8
sk =4.2
kur =51.6
number of items
mass per item (g)
j)
39 items
Δ mean mass (%)
number of items
k)
19 items
Δ median mass (%)
number of items
l)
6 items
Δ mean length (%)
number of items

Figure 3. Examples of the sampling size requirement based on all items (a-d), soft fragments >2.5 cm (e-h), and bottle caps (i-l). The sampling size requirement is shown for an accurate representation of mean mass, median mass and mean length, based on a 95% confidence interval, represented as a deviation from the value based on the complete dataset. The dashed horizontal lines indicate +/- 10%. In figure A, E and I the standard deviation (std), skewness (sk) and kurtosis (kur) of the distribution is shown, indicating item class homogeneity.

Table 2. Sample set size requirements based on mean mass for a selection of categories in the study database with more than 10 items. Full table can be accessed in Supplementary Materials G. Requirements are given for various confidence boundaries and deviations from the mean. Red numbers indicate that the number of items needed to represent the mean mass is equal to the total number of items collected. N/A means that this level of uncertainty (confidence boundary and deviation from the mean) is never reached, and more items need to be collected.

						Deviation from mean 20%				10%				5%			
OSPAR-ID	Name	Total number of items	μ_{mass} (g)	σ_{mass} (g)	Ψ (-)	Confidence boundary 0.5	0.75	0.9	0.95	0.5	0.75	0.9	0.95	0.5	0.75	0.9	0.95
3	Small bag	44	12.5	26.4	2.1	30	36	39	40	34	39	42	43	38	41	43	44
4.1	Bottle (>= 0.5 L)	34	80.0	176.7	2.2	1	1	29	30	1	32	34	34	30	32	34	34
4.2	Bottle (< 0.5 L)	127	40.4	75.1	1.9	34	63	82	90	74	110	120	120	110	120	N/A	N/A
4.3	Bottle label	23	4.6	9.4	2.1	18	21	22	23	21	22	23	23	22	23	23	23
6	Food packaging	170	9.1	18.6	2.0	42	79	110	120	95	140	150	160	150	160	170	170
7	Cosmetics packaging	19	17.0	16.7	1.0	8	13	15	16	14	17	18	18	18	19	19	19
15	Caps and lids	300	3.2	7.5	2.4	50	130	170	190	160	220	250	260	240	270	290	300
16	Lighter	38	11.7	3.5	0.3	1	3	6	8	4	10	16	18	12	22	28	30
20	Toy	18	52.3	111.2	2.1	14	16	18	18	15	17	18	18	17	18	18	18
21	Cup	116	3.2	7.7	2.5	51	77	90	95	88	110	110	N/A	110	110	N/A	N/A

3.4. River system heterogeneity

The SSRs of the litter items can be used to assess the heterogeneity of specific locations or entire rivers. This application is shown in Figure 6, which displays the litter heterogeneity based upon item count in the Rhine (R1, R2, R3), Meuse (M1, M2, M3) and IJssel (IJ1, IJ2) rivers, assuming a 90% confidence interval with maximum deviation of 10%. The litter on the riverbanks of the river Meuse and IJssel belong mainly to heterogeneous categories such as the large amount of hard and soft plastic fragments >2.5 cm (SSR 1300 and 1000, respectively). Contrastingly the river Rhine riverbanks encompass mostly homogeneous categories. When zooming to location-level heterogeneity (Table 3), it is clear that location R1 accounts for this. Location R1 can largely be described as a homogeneous sampling location, which contributes to the large number of homogeneous items in location R1 (Table 3), such as cigarette filters (SSR 11) and metal bottle caps (SSR 38) (Supplementary materials D). The heterogeneity of each sampling location (assuming a 90% confidence interval with maximum deviation of 10%) as shown in Table 3 strongly corresponds to the heterogeneity of its top 10 items (Supplementary Materials D).

Heterogeneity and SSRs vary considerably within and between rivers, which emphasizes the need for river and site-specific data collection. For example, more data should be collected for heterogeneous systems. Therefore, identifying litter heterogeneity per system can give an indication as to the resource investment required to accurately capture the systems' riverbank litter. When performing a Monte Carlo bootstrap analysis on all items found within a river system, with a 90% confidence boundary and a deviation of 10%, the river Rhine can be sampled by measuring 3,000 items (78% of all items found along the river Rhine). Similarly, 6900 items (71%) are needed for the river Meuse, and 2000 (96%) for the river IJssel. These items would give enough data to derive representative mean mass statistics, but it does not provide any spatiotemporal information. The SSR of river IJssel comprise of almost all items in our database, and more items should be collected to confirm the calculated SSR. The smaller SSR for river Rhine indicates its homogeneous character, while the larger SSR for river Meuse again confirms its more heterogeneous character. Furthermore, due to the intrinsic uncertainty within heterogeneous items, the uncertainty in litter statistics will always be larger for heterogeneous systems than for more homogeneous systems.

Table 3. Litter heterogeneity per sample site, based on mean mass with a 90% confidence boundary and 10% deviation from the mean, in the river Rhine (R1, R2, R3), Meuse (M1, M2, M3) and IJssel (IJ1, IJ2).

Location	*Homogeneous (%)*	*Mixed (%)*	*Heterogeneous (%)*	*Undefined (%)*
All	*16*	*13*	*64*	*7*
R1	*73*	*9*	*16*	*2*
R2	*7*	*5*	*62*	*26*
R3	*12*	*25*	*57*	*5*
M1	*8*	*10*	*81*	*1*
M2	*9*	*13*	*75*	*4*
M3	*7*	*13*	*78*	*2*
IJ1	*8*	*12*	*73*	*8*
IJ2	*6*	*17*	*72*	*4*

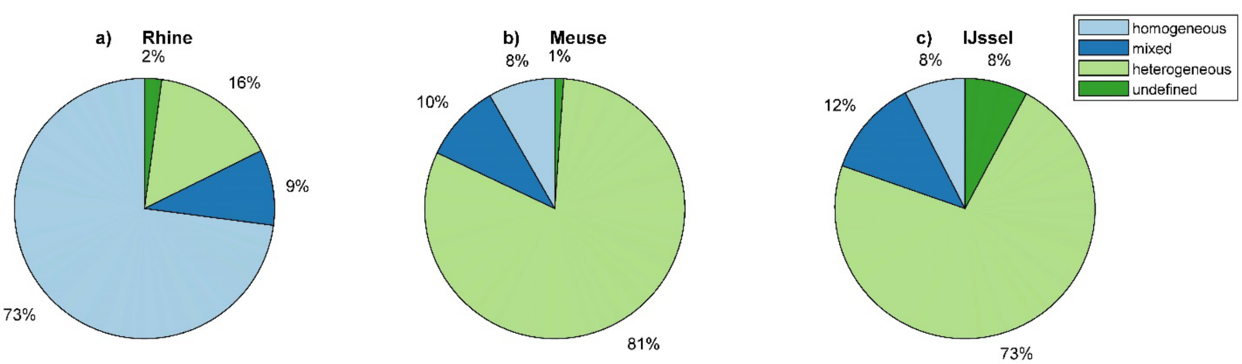

Figure 4. River system heterogeneity based on a 90% confidence boundary and 10% deviation from the mean, in the river Rhine (R1, R2, R3), Meuse (M1, M2, M3) and IJssel (IJ1, IJ2). Homogeneous: $SSR_{category} \leq$ median SSR_{all} (40 items). Heterogeneous; $SSR_{category} \geq$ mean SSR_{all} (158 items). Mixed: median $SSR_{all} < SSR_{category} <$ mean SSR_{all}. Undefined: SSR could not be determined.

4. Synthesis and outlook

This study quantifies the sample size requirements of anthropogenic litter items and assesses their heterogeneity, based upon more than 14,000 riverbank items. Our results show that statistical uncertainties decrease with increasing sample set size, as might be expected, but the amount information gain gradually diminishes when increasing the sample size. Therefore, determining the appropriate sample size requires finding an optimum between the acceptable uncertainty and the requisite sampling effort. In addition, the results demonstrate that heterogeneous litter item categories require larger sample set sizes than homogeneous categories in order to obtain similar uncertainty levels in the size and mass statistics.

The determination of litter heterogeneity and the derived required sample set sizes are crucial for optimizing the efficiency of litter monitoring protocols. SSRs can make data collection more efficient, as it is known for what item categories more and less items need to be collected and analyzed. The SSR can serve as a limit on data collection to avoid wasting resources on collecting data with uncertainty levels beyond the scope of the research question for which the data are used. This study provides a method to estimate SSR, and gives a first indication of the order of magnitude of the number of items that should be sampled for certain uncertainty levels for specific litter items. The approach taken in this research can be transferred to other systems, and the findings can be used as a starting point for studies in other river systems. For example, collecting homogeneous item categories can be performed in less detail than measuring heterogeneous categories in future monitoring campaigns. Furthermore, the analysis needed to optimize monitoring in these different systems can be adopted from this study. By starting with collecting very detailed data, subsequent sample collection can be downscaled to ensure more efficient monitoring. This can take the form of an iterative process, during which, at any point in the study, the data needs can be reassessed by performing a Monte Carlo based bootstrap analysis.

Litter transport and fate models can benefit from including litter statistics generated in this study. For example, models used to study the transport behavior of litter could include the mass and size of specific item categories. These parameters affect litter behavior associated with buoyancy or wind sensitivity (Kuizenga et al., 2022; Mellink et al., 2022). Including such parameters will therefore help to account for the fundamental transport and retention behavior of different litter categories in river systems, and potentially improve model results.

Similarly, the data presented in this study can be used to improve models used to estimate the mass transport of litter in rivers (see for example Meijer et al., 2021). Recent insights gained by Roebroek et al. (2022) indicate that item-mass conversion is a significant contributor to model uncertainty in this type of model. Our dataset on items-specific mass-statistics can thus be used to more accurately perform this conversion, decreasing uncertainty in model results. The mass statistics of litter categories can further be used to improve item count-to-mass conversion in studies that currently do not include mass. Including mass in these datasets allows for data on environmental litter pollution to be compared with litter production, leakage and transport, since all data are then expressed in the same units (mass per unit time). This allows for the study of the relation between these fluxes. For example, our litter-statistics can be used to include mass in datasets that were previously collected in item-count based studies (e.g. Morales-Caselles et al., 2021; Crosti et al., 2018; Gonzalez-Fernandez et al., 2021). This can now be directly compared with data from mass-based studies on, for example waste production and plastic transport (e.g. Lebreton & Andrady, 2019, Meijer et al., 2021; Borrelle et al., 2020). Including the mass statistics from our study may also reduce the uncertainty in studies that perform item-to-mass conversion using limited data (e.g. Vriend et al., 2020b; van Emmerik et al., 2019).

Several steps can be taken to assess and improve the applicability of the data presented in this study. First, it should be explored as to whether the SSR determined from the current data are river-system specific or whether relevant parameters such as item-specific mass of SSRs are transferable between river systems. Our findings will most likely be applicable to riverine systems with similar climatological characteristics and similar industrial and consumption patterns. Differences in consumption, activities (Nelms et al., 2021), waste management, riverbank morphologies and vegetation (Liro et al., 2022) might lead to other types of litter being present and different size and mass statistics in other river environments. By applying our methodology to existing litter datasets (e.g. Tramoy et al., 2019) or by collecting a new dataset in a different type of river system, the universality of our SSRs can be assessed. If the results are comparable between different types of river system, the sample size requirements presented in this study could act as guidelines for future research thus guiding the scale of future sampling efforts.

Second, the dataset presented in this study could form the basis for an open-access global database. This is essential for improving litter monitoring and modelling efforts. Although global modelling studies are extremely relevant to understand litter fluxes, litter data varies locally (Schwarz et al., 2019), and local data are necessary to reduce the uncertainty in results. This local data can in turn be upscaled to regional or global domains. The suggested open-access database can be used by scientists, policymakers and stakeholders a to improve future monitoring, policymaking and solution designs.

5. Concluding remarks

We present a method to determine the sample size requirements for specific item categories and for river systems. These may be used to optimize data collection efforts, by prioritizing the collection and analysis of items that have a larger heterogeneity. The same size requirements vary considerably between item categories and river systems. For a heterogeneous item class such as soft fragments larger than 2.5 cm, 990 items were needed to describe the mean mass with 90% confidence, and when determining the mean mass of uniform items, such as metal bottle caps, only 39 items were necessary. At least 8,900 items had to be sampled in order to describe the mean mass of all litter items on all locations with a confidence level of 90% and a maximum of 10% deviation from the mean. For representative aggregated statistics on the river basin scale, 1645, 2065, 2033 items have to be sampled for the Rhine, Meuse and IJssel, respectively. All collected data are openly available, and can be used to optimize future monitoring efforts, and constrain model parameters. With this paper we aim to contribute to reducing uncertainties in litter monitoring and modelling, to better understand and quantify litter abundance, transport, fate, and impacts.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Conceptualization: TvE, SdL
Methodology: TvE, SdL
Formal Analysis: SdL
Investigation: SdL
Visualization: SdL, PT
Data collection: all authors
Writing–original draft: SdL, YM, PV

Writing-reviewing and editing: SdL, YM, PV, PT, TvE, FB, RH, VV, EH, NJ, LS
Project administration: TvE
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Data Availability Statement

All data are openly available through the 4TU repository DOI 10.4121/19188131

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Supplementary Material

Supplementary material to Sample size requirements for riverbank macrolitter characterization

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1 A: Riverbank characteristic

Table 1. Overview of riverbank characteristic. The length and width of the collection area each month is available in the repository 4.TU DOI 10.4121/19188131

Location	coordinates	River	Nearby city	Location along river	Distance to mouth (km)	Bank type	Number of measurements (incl dimensions and weight)
R1	51.85359, 5.85864	Rhine (Waal)	Nijmegen	Upstream	130	Sand floodplain, recreational	12 (7)
R2	51.95984, 5.93776	Rhine (Nederrijn)	Arnhem	Midpoint	130	Sandy floodplain, light vegetation	2 (1)
R3	51.8981, 4.4674	Rhine	Rotterdam	Downstream	30	Embanked, stones and lightly vegetated	12 (7)
M1	50.85363, 5.6976	Meuse	Maastricht	Upstream	250	Vegetated	11 (9)
M2	51.79533, 5.66357	Meuse	Ravenstein	Midpoint	138	Vegetated	12 (7)
M3	51.71166, 4.63603	Meuse	Moerdijk	Downstream	56	Vegetated, stones	12 (7)
IJ1	51.96666, 5.95598	IJssel	Arnhem	Upstream	125	Sandy floodplain, light vegetation.	12 (7)
IJ2	52.5603, 5.91998	IJssel	Kampen	Downstream	16	Embanked, stones and reed vegetation	12 (7)

2 B: Riverbank tally form

Table 2. Field tally form using an OSPAR-ID to identify 111 item categories.

Name river	
Province	
Area ID	
Date riverbank sampling	
Name Researcher #1	
Name Researcher #2	
Name Researcher #3	

Riverbank side	Left / Right
Sampling executed?	Yes / No
⟶ if not, why?	
Length sampled area (m)	
Width sampled area (m)	

OSPAR ID	Plastic and foam	Count
15	Caps and lids	
4.2	Bottles (<0.5 litre)	
4.1	Bottles (>0.5 litre)	
40	Industrial packages	
3	Small bags	
117.1	Hard fragments (<2.5 cm)	
46.1	Hard fragments (2.5 – 50 cm)	
47.2	Hard fragments (>50 cm)	
1172	Foams (<2.5 cm)	
462	Foams (2.5 – 50 cm)	
472	Foams (>50 cm)	
6.1	Foam food packages (e.g. hamburgers)	
212	Foam cups	
21	Drinking cups	
117.2	Soft fragments (i.e. foils) (<2.5 cm)	
46.2	Soft fragments (i.e. foils) (2.5 – 50 cm)	
47.1	Soft fragments (i.e. foils) (>50 cm)	
22.1	Plates & straws	
22.2	Mixing sticks (e.g. to stir your coffee)	
19	Food wrappers (multilayer) (e.g. chips)	
6	Food packages (e.g. snackbar fries box)	
4.3	Labels that were wrapped around bottles	
5	Packages from cleaning products	
1	Six-pack rings	
16	Lighters	
14	Parts from cars	
22	Cutlery	
481	Biofilm water filters	
36	Glow in the dark sticks	
38	Buckets	
38.1	Plant pots or trays	
43	Gun rounds	
25	Cleaning gloves (bit softer plastic)	
113	Professional gloves (bit harder plastic)	
42	Helmets	
10	Jerrycans	
11	Tubes of caulking (Dutch: *kitspuiten*)	
13	Crates	
39	Bands & tie wraps	
39.1	Tape (Dutch: *plakband*) & duct tape	
19.1	Lolly sticks	
8	Motor oil packages (<50 cm)	
9	Motor oil package (>50 cm)	
24	Net bags (e.g. nets for onions or fruit)	
2.1	Garbage bags	
17	Writing instruments (e.g. pens)	
20	Toys	
35	Fishing gear	
2	Big plastic bags	
31	Pieces of rope (diameter >1 cm)	
32	Pieces of rope (diameter <1 cm)	
35.1	Pieces of fishing line (nylon)	
43.1	Fireworks	
48	Other unidentifiable plastic items	
OSPAR ID	**Rubber**	**Count**
49	Balloons & ribbons	
52	Tires (e.g. from bikes or cars)	
53	Other unidentifiable rubber items	
OSPAR ID	**Textile**	**Count**
54	Clothes	
57/44	Shoes, boots & flipflops	
55	Pieces of carpet	
59	Other unidentifiable textile items	

OSPAR ID	Paper	Count
62.1	Carton drinking packages (e.g. milk)	
67.1	Other unidentifiable paper items	
64	Cigarette filters ("cigarette butts")	
63	Cigarette packages	
61	Carton	
65	Carton drinking cups	
66	Newspapers	
60	Bags	
67	Other unidentifiable paper items	
OSPAR ID	**Wood**	**Count**
72	Ice cream sticks	
68	Corks	
73	Paint brushes	
69	Pallets	
74	Other unidentifiable wood items (<50 cm)	
75	Other unidentifiable wood items (>50 cm)	
OSPAR ID	**Metal**	**Count**
81	Aluminium foils	
81.1	Capsules (e.g. coffee or coffee-milk)	
78	Soda cans	
79	Electrical wires	
83	Old metal (iron) (e.g. pipes)	
77	Caps (Dutch: *kroonkurken*) & beer caps	
84	Oil drums (Dutch: *olie vaten*)	
88	Barbed wires (Dutch: *prikkeldraad*)	
76	Spray cans	
86	Paint cans	
80	Fish lead	
82	Food cans	
120	Single use BBQ's/grills	
89	Other unidentifiable metal items (<50 cm)	
90	Other unidentifiable metal items (>50 cm)	
OSPAR ID	**Glass**	**Count**
91	Bottles (e.g. wine) & pots	
92	Light bulbs & (fluorescent) tube TL lamps	
93	Other unidentifiable glass items	
OSPAR ID	**Sanitary**	**Count**
7	Cosmetic packages (e.g. shampoo, deo)	
98	Plastic cotton swabs	
982	Wooden cotton swabs	
102.2	Wet tissues	
97	Condoms	
99	Sanitary towels & packages thereof	
18	Plastic hairbrush or hair comb	
100	Tampons & tampon applicators	
102.3	Pieces of toilet paper	
101	Toilet refreshers	
102	Other unidentifiable sanitary items	
OSPAR ID	**Medical**	**Count**
103	Packages (e.g. pills, contacts)	
104	Injection needles / syringes	
105	Other unidentifiable medical items	
OSPAR ID	**Nurdles**	**Count**
	Nurdles (per area of 50 by 50 cm)	

Notes ....

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3 C: Summarizing statistics

Table 3. summarizing statistics of each litter category. The dataset consists of 16,488 items and their river-OSPAR category (see supplementary materials B). For 14,052 items the length, width and mass are documented. Std indicates standard deviation.

catagory	Name	ospar ID	amount	mean mass (g)	std mass (g)	mean length (cm)	std length (cm)	mean width (cm)	std width (cm)
plastic	Caps and lids	15	385	3.56	5.67	4.06	2.25	3.48	2.42
	Bottle (< 0.5 L)	4.2	169	51.34	53.77	16.77	7.45	10.65	3.21
	Bottle (>= 0.5 L)	4.1	49	142.97	32.51	25.74	2.52	10.45	2.18
	Industrial packaging	40	49	54.42	67.96	66.28	56.53	24.79	12.45
	Small bag	3	74	20.55	15.55	25.55	9.58	18.64	9.10
	Hard fragment (< 2.5 cm)	117.1	393	0.27	0.30	1.70	0.80	1.12	0.49
	Hard fragment (>= 2.5 cm)	46.1	1329	10.24	32.05	7.02	6.43	3.82	4.95
	Hard fragment (>50 cm)	47.2	25	378.57	9.65	74.93	23.10	25.00	1.59
	Foam fragment (< 2.5 cm)	1172	1178	0.11	0.13	1.88	0.75	1.58	0.70
	Foam fragment (>=2.5 cm)	462	2615	2.49	13.01	5.09	3.80	4.06	4.43
	Foam (> 50 cm)	472	8	14.79	9.52	77.49	23.32	7.80	3.89
	Foam food packaging	6.1	55	3.66	2.94	10.75	3.27	9.01	1.46
	Foam cup	212	2	5.63	2.72	5.00	0.00	5.00	0.00
	Cup	21	130	3.07	4.97	8.40	2.51	6.02	3.75
	Soft fragment (< 2.5 cm)	117.2	302	0.08	0.12	2.17	0.96	1.30	0.65
	Soft fragment (>= 2.5 cm)	46.2	2359	1.88	5.03	14.39	14.47	7.52	8.10
	Soft fragment (>50 cm)	47.1	75	35.75	45.89	63.33	25.22	29.24	19.69
	Straw	22.1	89	1.60	1.24	15.68	3.23	1.25	1.13
	Swizzle stick	22.2	4	0.38	0.12	8.70	2.90	0.80	0.28
	Food wrapping	19	1065	2.48	7.16	9.61	6.44	5.55	4.72
	Food packaging	6	228	14.31	18.61	10.06	5.27	7.72	3.61
	Bottle label	4.3	30	4.15	6.80	14.46	8.05	10.76	7.86
	Cleaning product packaging	5	6	28.10	25.23	20.33	5.16	9.83	1.75
	Six pack ring	1	4	3.57	0.43	19.50	1.12	11.42	3.33
	Lighter	16	41	11.11	1.96	7.47	1.23	3.93	0.89
	Car part	14	7	110.87	45.66	13.48	4.22	5.88	2.85
	Cutlery	22	10	1.53	0.57	7.08	1.01	3.78	0.13
	Straw	22.1	89	1.60	1.24	15.68	3.23	1.25	1.13
	Water filter	481	0	NaN	NaN	NaN	NaN	NaN	NaN
	Glowstick	36	5	2.72	1.57	14.70	8.06	0.40	0.00
	Bucket	38	4	101.85	79.76	19.55	1.30	14.78	1.30
	Plastic plant pot	38.1	10	52.31	49.64	15.15	6.31	11.70	4.30
	Rifle cartridge case	43	6	2.82	0.20	4.40	0.92	2.20	0.28
	Cleaning glove	25	3	6.47	2.87	12.30	2.33	11.40	6.93
	Glove	113	0	NaN	NaN	NaN	NaN	NaN	NaN
	Helmet	42	0	NaN	NaN	NaN	NaN	NaN	NaN
	Jerrycan	10	2	201.19	0.00	31.00	0.00	19.75	0.00
	Caulking nozzle	11	1	84.50	0.00	21.50	0.00	6.00	0.00
	Plastic crate	13	0	NaN	NaN	NaN	NaN	NaN	NaN
	Cable tie	39	44	2.61	2.56	44.12	41.56	16.18	24.59
	Tape	39.1	30	2.98	3.41	9.37	5.35	7.80	3.52
	Lollipop stick	19.1	126	0.35	0.21	6.18	1.68	1.39	0.94
	Motor oil packaging (< 50 cr	8	0	NaN	NaN	NaN	NaN	NaN	NaN
	Motor oil packaging (>= 50 c	9	0	NaN	NaN	NaN	NaN	NaN	NaN
	Net bag	24	6	3.63	0.23	25.10	1.06	5.70	0.00
	Garbage bag	2.1	86	27.90	24.00	42.74	26.80	29.93	20.08
	Pen	17	10	4.69	1.58	7.43	2.48	4.43	0.18
	Toy	20	20	65.90	97.03	7.74	5.96	6.32	6.45
	Fishing gear	35	33	6.74	3.83	7.67	6.31	6.67	4.27
	Plastic bag	2	11	72.74	17.09	51.96	3.57	41.26	4.88
	Rope D>1cm	31	38	143.09	123.53	141.45	73.32	3.12	4.65
	Rope D<1cm	32	190	15.47	44.59	39.07	44.26	3.77	8.74
	Fishing wire	35.1	93	0.98	1.97	33.41	14.81	1.46	2.61
	Firework	43.1	10	7.12	3.39	7.33	2.18	1.71	0.80
	Nurdles	0	140	0.02	0.01	0.34	0.02	0.31	0.03
	Other	48	103	113.07	248.02	23.71	37.71	13.98	26.83

rubber	Balloon	49	35	2.42	0.43	8.67	1.55	4.94	1.00
	Tire	52	11	646.79	315.76	46.11	14.81	17.41	11.15
	Other rubber	53	51	36.33	57.50	14.21	9.28	4.03	3.43
textile	Clothes	54	40	117.60	60.95	25.04	7.30	19.36	9.89
	Shoes, boots, flipflops	57	3	116.38	0.00	21.70	0.00	7.50	0.00
	Pieces of carpet	55	1	220.00	0.00	96.00	0.00	34.00	0.00
	Other unidentifiable textile	59	141	124.23	295.43	47.25	58.47	16.62	19.72
paper	Drink carton	62.1	14	46.29	11.86	17.07	4.59	10.54	2.84
	Other paper	67.1	93	1.59	1.63	6.79	5.14	4.30	3.39
	Cigarette filter	64	1665	0.50	0.19	2.36	0.38	0.91	0.29
	Cigarette pack	63	15	7.60	1.64	12.73	1.93	8.47	0.47
	Cartboard	61	19	30.68	5.32	15.60	1.36	9.00	3.41
	Cartboard cup	65	9	21.57	3.28	11.18	2.01	10.31	1.00
	Newspaper	66	3	NaN	NaN	NaN	NaN	NaN	NaN
	Paper bag	60	3	NaN	NaN	NaN	NaN	NaN	NaN
	Other paper	67	96	5.00	4.70	9.92	3.89	12.70	6.29
wood	Popsicle stick	72	2	2.03	0.40	11.00	1.41	1.00	0.00
	Cork	68	35	7.52	4.88	3.75	0.99	2.53	1.16
	Paintbrush	73	0	NaN	NaN	NaN	NaN	NaN	NaN
	Pellet	69	0	NaN	NaN	NaN	NaN	NaN	NaN
	Other wood (< 50 cm)	74	50	479.62	123.41	15.12	5.38	9.70	3.32
	Other wood (>= 50 cm)	75	10	986.94	501.02	45.45	5.35	4.88	0.75
metal	Aluminium foil	81	109	5.14	6.44	4.91	3.15	3.04	1.50
	Metal capsule	81.1	5	10.21	0.00	4.47	0.00	4.93	0.00
	Drink can	78	243	42.55	43.47	9.71	3.36	7.14	2.35
	Electrical wire	79	6	4.79	0.16	14.12	0.52	0.96	0.40
	Old iron scrap	83	25	597.34	623.46	59.06	45.15	24.50	21.82
	Metal bottle cap	77	700	4.09	1.03	2.73	0.34	2.42	0.64
	Oil drum	84	0	NaN	NaN	NaN	NaN	NaN	NaN
	Barbed wire	88	2	3.46	1.84	37.75	42.78	0.15	0.07
	Spray can	76	12	137.42	69.88	17.22	3.47	8.39	3.15
	Paint can	86	0	NaN	NaN	NaN	NaN	NaN	NaN
	Fish lead	80	2	38.83	0.00	14.10	0.00	2.30	0.00
	Food can	82	7	22.19	6.08	7.07	1.60	8.95	2.05
	Single use grill	120	0	NaN	NaN	NaN	NaN	NaN	NaN
	Other metal (< 50 cm)	89	177	150.69	199.11	13.43	10.00	4.87	3.50
	Other metal (>= 50 cm)	90	15	882.52	566.82	58.68	29.70	20.69	12.00
glass	Glass bottles and ceramics	91	501	42.77	67.28	6.11	4.50	3.86	3.09
	Tube lamp	92	0	NaN	NaN	NaN	NaN	NaN	NaN
	Other glass	93	119	62.70	76.61	5.14	2.80	3.53	2.10
sanitary	Cosmetics	7	21	20.65	14.98	10.07	2.84	4.34	1.77
	Cotton swab	98	220	0.65	4.23	6.44	1.50	0.24	0.06
	Carton cotton swab	982	4	NaN	NaN	NaN	NaN	NaN	NaN
	Wet tissue	102.2	247	6.87	7.09	18.99	8.88	7.21	5.10
	Condom	97	1	0.21	0.00	4.50	0.00	4.50	0.00
	Sanitary towel	99	42	2.47	1.74	18.06	8.36	7.02	3.68
	Hair brush	18	0	NaN	NaN	NaN	NaN	NaN	NaN
	Tampon (applicator)	100	14	1.22	0.05	5.51	0.32	1.79	0.19
	Toilet paper	102.3	6	3.83	1.85	12.67	4.04	4.17	1.04
	Toilet refresher	101	1	9.86	0.00	11.50	0.00	10.30	0.00
	Other sanitary	102	18	9.07	9.70	15.21	5.87	8.36	6.28
medical	Medical packaging	103	10	4.90	9.38	5.96	2.15	2.49	1.07
	Syringe	104	8	10.65	10.34	9.35	1.75	2.45	0.28
	Other medical	105	25	8.86	0.42	8.29	3.25	10.09	0.99

4 D: Top 10 per location and per month

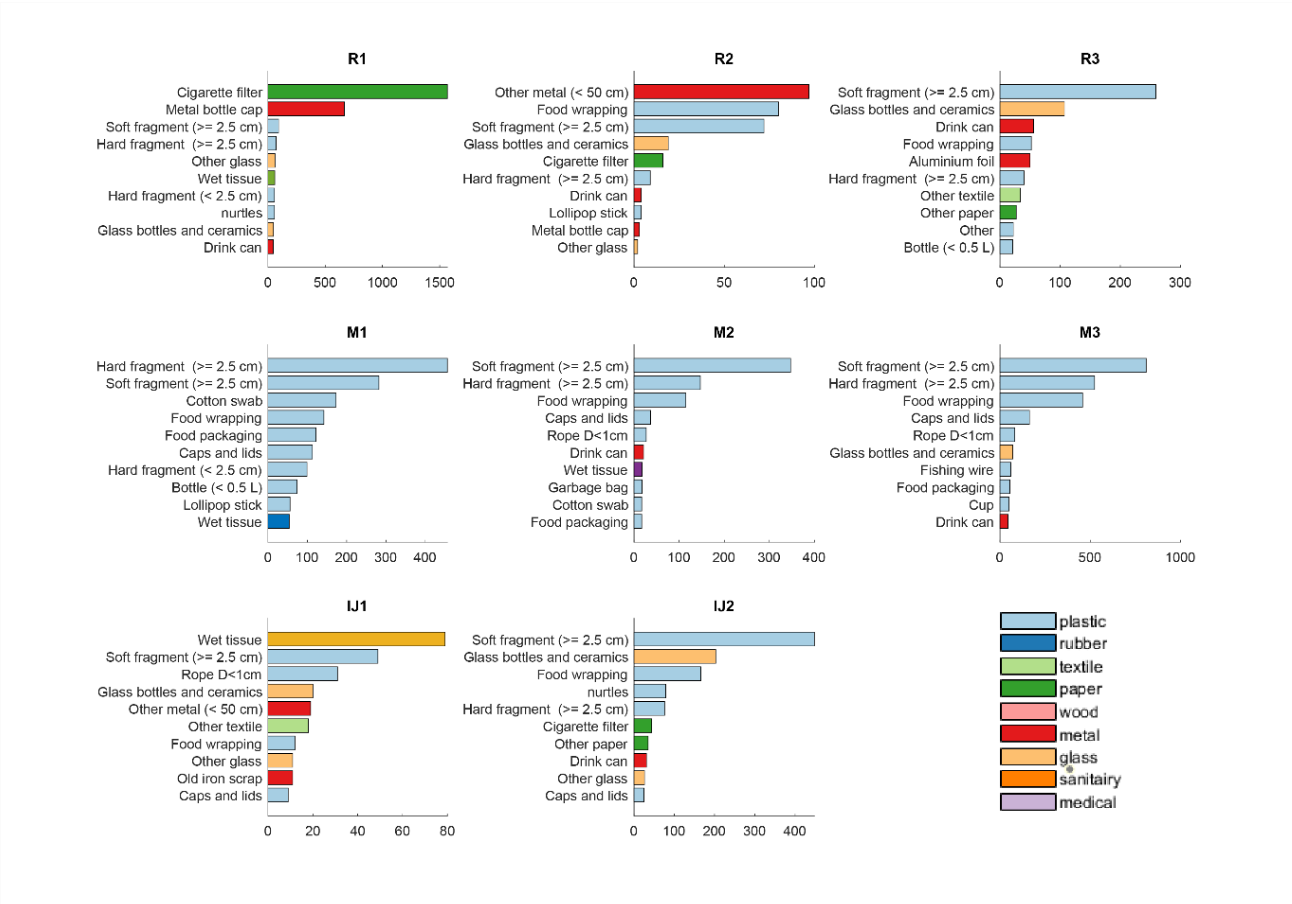

Figure 1. List of top 10 most frequent found items based on item amount, per location.

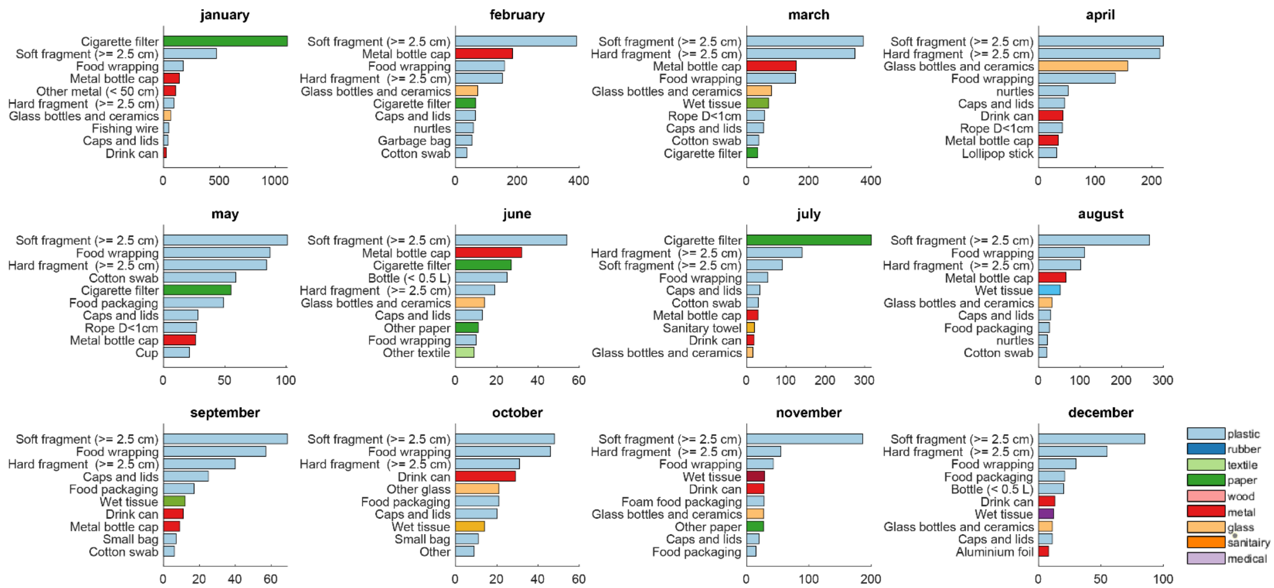

Figure 2. List of top 10 most frequent found items based on item amount, per month.

5 E: Length and mass distribution

Besides expressing anthropogenic litter in terms of mass and item count, item sizes can be used to get an estimation of for example the environmental impact, the amount of ingestible litter, and monitoring net mesh sizes. For describing item size for a river system or a riverbank, cumulative item size distributions for count and mass can be used (Figure 3). Item sizes between 2.0 - 20 cm fall within the 10 and 90-percentile of item count, however those item sizes only represent 36% of the item mass. To capture all mass in the same range, item sizes included are 6.6 - 124 cm (capturing 70% of all items). Unlike plastic found in oceans (Lebreton et al., 2018), and similar to other riverine studies (van Emmerik et al., 2018), most mass is found in the middle percentiles (D_{25}-D_{75}) and not in the largest item sizes (>100 cm; Supplementary materials E).

The size distribution varied between places (mean length 4.1 – 18 cm, median length 2.5 – 8.5 cm), and certain locations such as R1, have a smaller size distribution than other locations (Figure 3). This could be an indication of fragmentation or a different item source, and in case of location R1 it can be attributed to the large amount of cigarette butts (Supplementary materials D). The difference between areas stresses the importance to determine the distinct length distribution of the area.

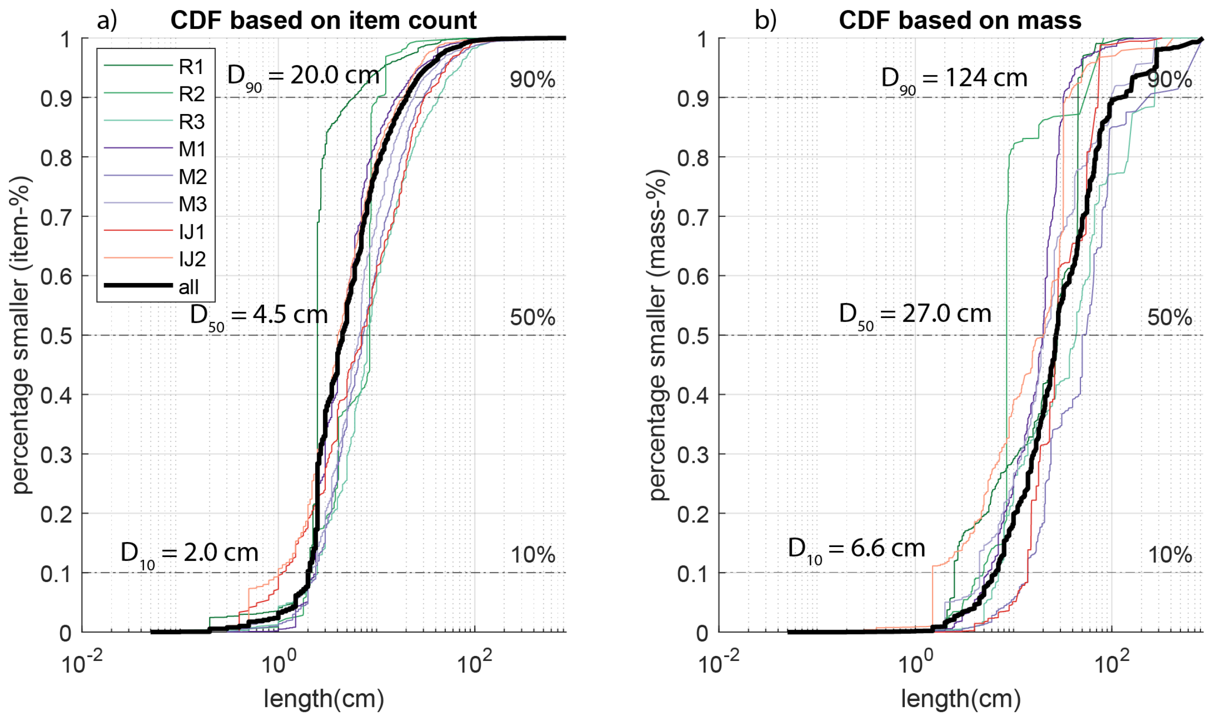

Figure 3. Cumulative density distribution (CDF) based on item count (a) and mass (b) for all study areas. D_{10}, D_{50} and D_{90} of the sum of all study areas (indicated as "all") are shown.

To break down the shown cumulative density distribution, items were subdivided into size classes, and the resulting size distribution, per mass and item amount, give insight in the dominating litter size (Figure 4). The characteristics of individual items are reflected in the size distribution. This resulted in for example a relatively large amount of mass in the 1.5-5 cm class in Nijmegen, due to the large amount of cigarette filters found here.

Most found items consisted of plastic (70%). To give insights into the build-up of plastic litter, an additional analysis was focused on plastic polymer category. Items were classified in eight polymer categories, based on the Crowd-Water classification protocol (van Emmerik et al., 2020): Polyethylene terephthalate (PET; e.g. bottles), polystyrene (PS, e.g. cutlery, cups, toys), expanded polystyrene (EPS, e.g. foams, food boxes), hard polyolefin (POhard, e.g. bottle caps, containers, rigid items), Soft polyolefin (POsoft, e.g. bags, foils), multilayer (ML, e.g. combined materials, food wrappings and packaging), other plastic, and no plastic (e.g. wood, paper, glass).
To explore the influence of item types on the size distribution, the item categories were broken down in 8 polymeric plastic types (Figure 5). Relatively homogeneous categories such as PET showed a narrow size distribution, while broad categories such as 'other plastic' had a wider distribution. Based on the mass-size-distribution, a clean-up protocol can be improved. For example, a location with mostly PET pollution has a clear size signature, on which the protocol can be based.

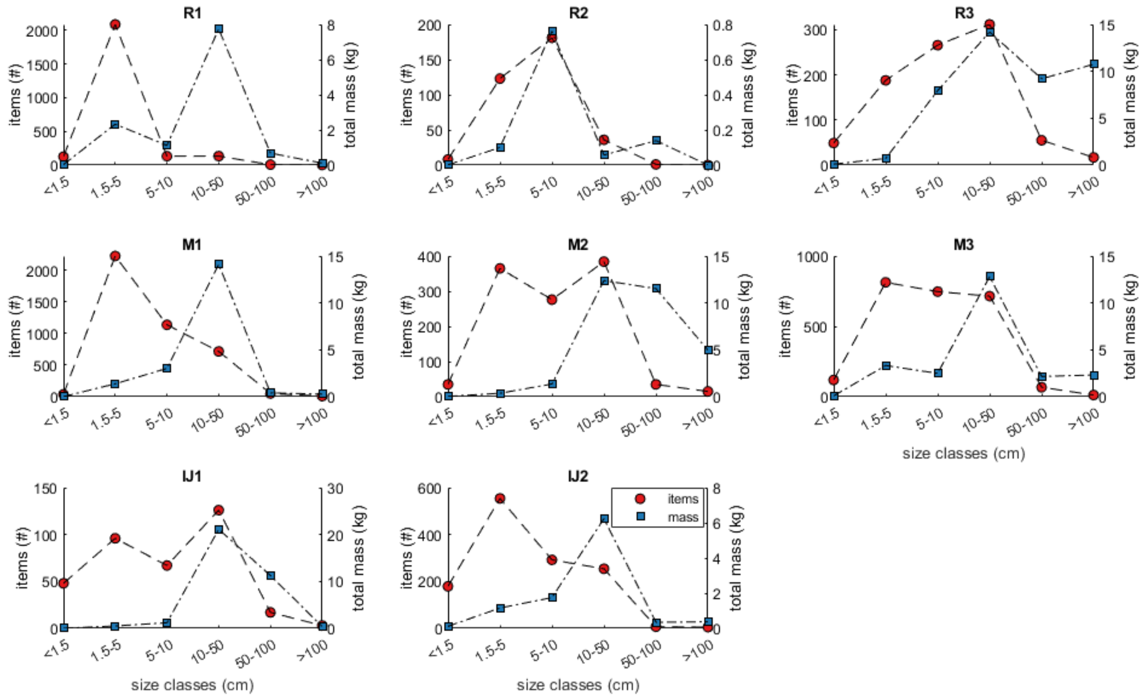
R1
R2
R3
M1
M2
M3
IJ1
IJ2
items (#)
total mass (kg)
size classes (cm)
<1.5
1.5-5
5-10
10-50
50-100
>100
items
mass

Figure 4. Size distribution, per mass and item amount, of litter found at all location.

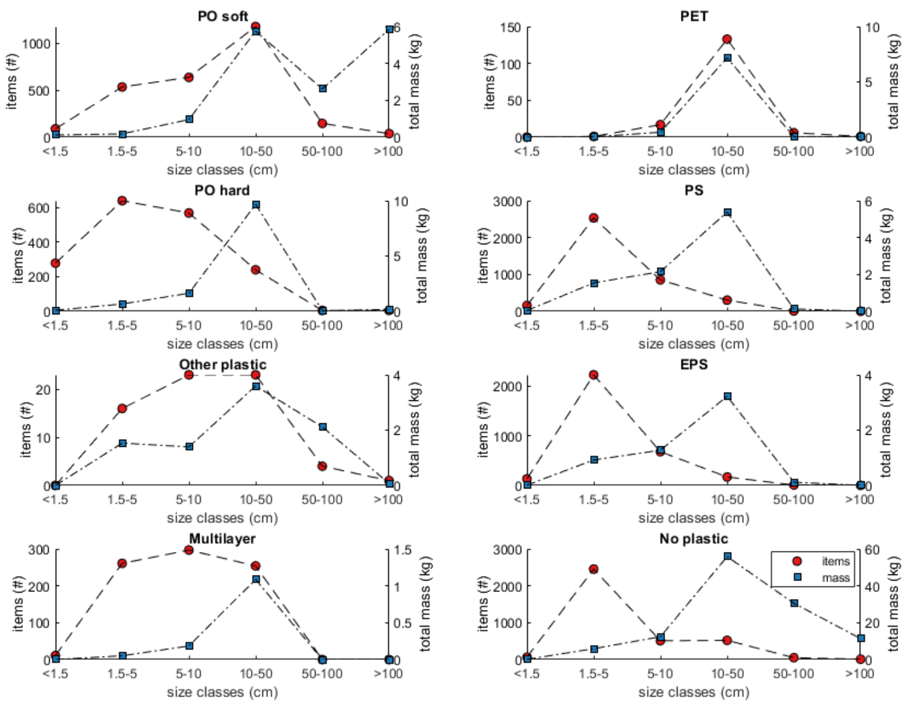

Figure 5. Size distribution, per mass and item amount, of plastic litter subdivided in polymer categories.

6 F: Conversion table

Table 4. To facilitate direct comparison with other categorization methods in future research efforts, we included a ‘conversion table” for rapid re-categorization in one of the other categorization methods.

River-OSPAR				Vriend et al. 2020		Schwarz et al. 2019	Kiessling et al. (2019)	Marine debris toolkit for educators (Na	JRC Joint litter list (Fleet	
ID	nameNL	nameEN	category OSPAR	Category plastic	Material type	Function	Plastic pirates	NOAA	Type code 1	Type code 2
1	plastic_6_packringen	Six pack ring	plastic	PO soft	plastic	Consumer	Plastic	6-pack rings	pl	fc
2	plastic_tassen	Plastic bag	plastic	PO soft	plastic	Consumer	Plastic	Bags	pl	re
3	plastic_kleine_plastic_tasjes	Small bag	plastic	PO soft	plastic	Consumer	Plastic	Bags	pl	re
4.1	plastic_drankflessen_groterdan_halveliter	Bottle (>= 0.5 L)	plastic	PET	plastic	Packaging	Plastic	Beverage bottles	pl	fc
4.2	plastic_drankflessen_kleinerdan_halveliter	Bottle (< 0.5 L)	plastic	PET	plastic	Packaging	Plastic	Beverage bottles	pl	fc
4.3	plastic_wikkels_van_drankflessen	Bottle label	plastic	PO soft	plastic	Packaging	Plastic	Beverage bottles	pl	fc
5	plastic_verpakking_van_schoonmaakmiddelen	Cleaning product packaging	plastic	PO hard	plastic	Packaging	Plastic	Other/unclassifiable	pl	hy
6	plastic_voedselverpakkingen_frietbakjes_etc	Food packaging	plastic	PS	plastic	Packaging	Plastic	Food wrappers	pl	fc
7	plastic_cosmeticaverpakkingen	Cosmetics packaging	plastic	PO hard	plastic	Packaging	Plastic	Personal care products	pl	hy
8	plastic_motorolieverpakking_kleinerdan50cm	Motor oil packaging (< 50 cm)	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	vk
9	plastic_motorolieverpakking_groterdan50cm	Motor oil packaging (>= 50 cm)	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	vk
10	plastic_jerrycans	Jerrycan	plastic	PO hard	plastic	Packaging	Plastic	Other jugs and containers	pl	nn
13	plastic_kratten	Plastic crate	plastic	PO hard	plastic	Fishery	Plastic	Other/unclassifiable	pl	fi
14	plastic_auto_onderdelen	Car part	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	vk
15	plastic_doppen_en_deksels	Caps and lids	plastic	PS	plastic	Packaging	Plastic	Bottle or container caps	pl	fc
16	plastic_aanstekers	Lighter	plastic	PO hard	plastic	Consumer	Plastic	Disposable cigarette lighters	pl	sm
20	plastic_speelgoed	Toy	plastic	PS	plastic	Consumer	Plastic	Other/unclassifiable	pl	re
21	plastic_plastic_bekers_of_delen_daarvan	Cup	plastic	PS	plastic	Consumer	Plastic	Cups	pl	fc
24	plastic_netzakken	Net bag	plastic	PO soft	plastic	Packaging	Plastic	Other/unclassifiable	pl	nn
25	plastic_handschoenen_huishoudelijk	Cleaning glove	plastic	PO soft	plastic	Consumer	Plastic	Other/unclassifiable	pl	hy
113	plastic_handschoenen_professioneel	Glove	plastic	PO soft	plastic	Industrial	Plastic	Other/unclassifiable	pl	co
31	plastic_touw_diameter_groterdan_1cm	Rope D>1cm	plastic	PO soft	plastic	Industrial	Plastic	Plastic rope/small net pieces	pl	nn
32	plastic_touw_diameter_kleinerdan_1cm	Rope D<1cm	plastic	PO soft	plastic	Industrial	Plastic	Plastic rope/small net pieces	pl	nn
35	plastic_sportvisspullen	Fishing gear	plastic	PO soft	plastic	Fishery	Plastic	Other/unclassifiable	pl	fi
36	plastic_breekstaafjes	Glowstick	plastic	PO hard	plastic	Fishery	Plastic	Other/unclassifiable	pl	re
38	plastic_emmers	Bucket	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	nn
40	plastic_industrieel_verpakkingsmateriaal	Industrial packaging	plastic	PO shoft	plastic	Packaging	Plastic	Other/unclassifiable	pl	nn
42	plastic_helmen	Helmet	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	co
43	plastic_geweerpatronen	Rifle cartridge case	plastic	PO hard	plastic	Consumer	Plastic	Other/unclassifiable	pl	hu
117.1	plastic_plastic_stukjes_0_2_5cm_hard_plastic	Hard fragment (< 2.5 cm)	plastic	PO hard	plastic	Unknown	Plastic	Plastic fragments hard	pl	nn
46.1	plastic_plastic_stukjes_2_5_50cm_hard_plastic	Hard fragment (>= 2.5 cm)	plastic	PO hard	plastic	Unknown	Plastic	Plastic fragments hard	pl	nn
117.2	plastic_plastic_stukjes_0_2_5cm_zacht_plastic	Soft fragment (< 2.5 cm)	plastic	PO soft	plastic	Unknown	Plastic	Plastic fragments film	pl	nn
46.2	plastic_plastic_stukjes_2_5_50cm_zacht_plastic	Soft fragment (>= 2.5 cm)	plastic	PO soft	plastic	Unknown	Plastic	Plastic fragments film	pl	nn
48	plastic_overig_plastic	Other	plastic	Other plastic	plastic	Other	Plastic	Plastic other; Buoys & floats; Balloons - Mylar	pl	nn
1172	plastic_piepschuim_0_2_5cm	Foam fragment (< 2.5 cm)	plastic	EPS	plastic	Unknown	Plastic	Plastic fragment foamed	pl	nn
462	plastic_piepschuim_2_5_50cm	Foam fragment (>=2.5 cm)	plastic	EPS	plastic	Unknown	Plastic	Plastic fragment foamed	pl	nn
6.1	plastic_piepschuim_voedselverpakkingen	Foam food packaging	plastic	EPS	plastic	Packaging	Plastic	Other/unclassifiable	pl	fc

47.1	plastic_plastic_folies_groterdan_50cm	Soft fragment (>50 cm)	plastic	PO soft	plastic	Unknown	Plastic	Plastic fragments film	pl	nn
47.2	plastic_hard_plastic_groterdan_50cm	Hard fragment (>50 cm)	plastic	PO hard	plastic	Unknown	Plastic	Plastic fragments hard	pl	nn
22.1	plastic_rietjes	Straw	plastic	PS	plastic	Consumer	Plastic	Straws	pl	fc
19	plastic_snoep_snack_chipsverpakking	Food wrapping	plastic	Multilayer	plastic	Consumer	Plastic	Food wrappers	pl	fc
472	plastic_piepschuim_groterdan_50cm	Foam (> 50 cm)	plastic	EPS	plastic	Unknown	Plastic	Plastic fragment foamed	pl	nn
212	plastic_piepschuim_bekers	Foam cup	plastic	EPS	plastic	Consumer	Plastic	Cups	pl	fc
22	plastic_bestek	Cutlery	plastic	PS	plastic	Consumer	Plastic	Plastic utensils	pl	fc
481	plastic_biofilm_waterfiltertjes	Water filter	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	nn
11	plastic_kitspuiten	Caulking nozzle	plastic	PO hard	plastic	Construction	Plastic	Other/unclassifiable	pl	co
39	plastic_kunststof_band_tiewraps	Cable tie	plastic	PO hard	plastic	Industrial	Plastic	Other/unclassifiable	pl	co
19.1	plastic_lolliestokjes	Lollipop stick	plastic	PO hard	plastic	Consumer	Plastic	Other/unclassifiable	pl	fc
2.1	plastic_vuilniszakken	Garbage bag	plastic	PO soft	plastic	Consumer	Plastic	Other/unclassifiable	pl	nn
17	plastic_schrijfwaren	Pen	plastic	PO hard	plastic	Consumer	Plastic	Other/unclassifiable	pl	nn
35.1	plastic_visdraad	Fishing wire	plastic	PO soft	plastic	Fishery	Plastic	Fishing lures & lines	pl	fi
43.1	plastic_vuurwerk	Firework	plastic	PO hard	plastic	Consumer	Plastic	Other/unclassifiable	pl	nn
22.3	plastic_borden_new	Plastic plate	plastic	PS	plastic	Consumer	Plastic	Other/unclassifiable	pl	fc
22.2	plastic_roerstaafjes_new	Swizzle stick	plastic	PS	plastic	Consumer	Plastic	Other/unclassifiable	pl	fc
38.1	plastic_bloempotten_new	Plastic plant pot	plastic	PO hard	plastic	Consumer	Plastic	Other/unclassifiable	pl	ag
39.1	plastic_plakband_new	Tape	plastic	PO soft	plastic	Consumer	Plastic	Other/unclassifiable	pl	nn
49	rubber_ballonnen	Balloon	rubber	No plastic	rubber	Consumer	Other	Balloons - latex	ru	re
52	rubber_banden	Tire	rubber	No plastic	rubber	Consumer	Other	Tires	ru	vk
53	rubber_overig_rubber	Other rubber	rubber	No plastic	rubber	Other	Other	Rubber fragments/other; Rubber glove	ru	nn
54	textiel_kleding	Clothing	textile	No plastic	textile	textile	Other	Clothing & shoes	ct	cl
55	textiel_vloerbedekking	Carpet	textile	No plastic	textile	textile	Other	Other/unclassifiable	ct	co
57	textiel_schoeisel	Shoeware	textile	No plastic	textile	Consumer	Other	Clothing & shoes; Flipflops	ct	cl
59	textiel_overig_textiel	Other textile	textile	No plastic	textile	Other	Other	Other cloth/fabric; towels/rags; Fabric pieces; rope/net pieces (non nylon)	ct	nn
60	papier_tassen	Paper bag	paper	No plastic	paper	Consumer	Paper	Paper bags	pp	nn
61	papier_karton	Cartboard	paper	No plastic	paper	Other	Paper	paper and cardboard	pp	nn
63	papier_sigarettenverpakking	Cigarette pack	paper	No plastic	paper	Consumer	Paper	Other/unclassifiable	pp	sm
64	papier_sigarettenfilters	Cigarette filter	paper	No plastic	paper	Consumer	Cigarette	Cigarettes;Cigar tips	pp	sm
65	papier_kartonnen_bekers	Cartboard cup	paper	No plastic	paper	Consumer	Paper	Cups	pp	fc
66	papier_kranten	Newspaper	paper	No plastic	paper	Consumer	Paper	Other/unclassifiable	pp	re
67	papier_papier_overig	Other paper	paper	No plastic	paper	Other	Paper	Other/unclassifiable	pp	nn
62.1	papier_drankkarton	Drink carton	paper	No plastic	paper	Packaging	Paper	Cardboard cartons	pp	fc
67.1	papier_ondefinieerbaar	Other paper	paper	No plastic	paper	Unknown	Paper	Other/unclassifiable	pp	nn
68	hout_kurk	Cork	wood	No plastic	wood	Consumer	Other	Other/unclassifiable	wo	fc
69	hout_pellets	Pellet	wood	No plastic	wood	Industrial	Other	Other/unclassifiable	wo	co
72	hout_ijsstokjes	Popsicle stick	wood	No plastic	wood	Consumer	Other	Other/unclassifiable	wo	fc
73	hout_kwasten	Paintbrush	wood	No plastic	wood	Construction	Other	Other/unclassifiable	wo	co
74	hout_overig_hout_keinderdan_50cm	Other wood (< 50 cm)	wood	No plastic	wood	Unknown	Other	Other wood;Lumber/building material	wo	nn
75	hout_overig_hout_groterdan_50cm	Other wood (>= 50 cm)	wood	No plastic	wood	Unknown	Other	Other wood	wo	nn
81	metaal_aluminiumfolie	Aluminium foil	metal	No plastic	metal	Other	Other	Other/unclassifiable	me	fc
81.1	metaal_capsules	Metal capsule	metal	No plastic	metal	Consumer	Metal	Other/unclassifiable	me	fc

78	metaal_drankblikjes	Drink can	metal	No plastic	metal	Packaging	Metal	Aluminum/tin cans	me	fc
79	metaal_elektriciteitsdraad	Electrical wire	metal	No plastic	metal	Electornic	Metal	Other/unclassifiable	me	co
83	metaal_oud_ijzer	Old iron scrap	metal	No plastic	metal	Unknown	Metal	Other/unclassifiable	me	nn
77	metaal_kroonkurken	Metal bottle cap	metal	No plastic	metal	Consumer	Metal	Other/unclassifiable	me	fc
84	metaal_oliedrum	Oil drum	metal	No plastic	metal	Industrial	Metal	Other/unclassifiable	me	nn
88	metaal_omheinigsdraad_prikkeldraad	Barbed wire	metal	No plastic	metal	Other	Metal	Other/unclassifiable	me	nn
76	metaal_spuitbussen	Spray can	metal	No plastic	metal	Construction	Metal	Aerosol cans	me	co
86	metaal_verfblik	Paint can	metal	No plastic	metal	Construction	Metal	Other/unclassifiable	me	co
80	metaal_vislood	Fish lead	metal	No plastic	metal	Fishery	Metal	Fishing lures & lines	me	fi
82	metaal_voedselblikken	Food can	metal	No plastic	metal	Consumer	Metal	Other/unclassifiable	me	fc
120	metaal_wegwerpbarbecues	Single use grill	metal	No plastic	metal	Consumer	Metal	Other/unclassifiable	me	fc
89	metaal_overig_metaal_kleinerdan_50cm	Other metal (< 50 cm)	metal	No plastic	metal	Unknown	Metal	Metal fragments/other	me	nn
90	metaal_overig_metaal_groterdan_50cm	Other metal (>= 50 cm)	metal	No plastic	metal	Unknown	Metal	Metal fragments/other	me	nn
91	glas_flessen_pottten	Glass bottles and ceramics	glass	No plastic	glass	Unknown	Glass	Other/unclassifiable	gc	fc
92	glas_lampen_tl_lampen	Tube lamp	glass	No plastic	glass	Consumer	Glass	Other/unclassifiable	gc	co
93	glas_overig_glas	Other glass	glass	No plastic	glass	Other	Glass	Other/unclassifiable	gc	nn
7	sanitair_cosmetica	Cosmetics	sanitary	PO Hard	plastic	Consumer	Other	Personal care products	pl	hy
98	sanitair_plastic_wattenstaafjes	Cotton swab	plastic	PO Hard	plastic	Consumer	Other	Personal care products	pl	hy
982	sanitair_kartonnen_wattenstaafjes	Carton cotton swab	sanitary	No plastic	paper	Consumer	Other	Personal care products	pp	hy
102.2	sanitair_vochtige_doekjes	Wet tissue	sanitary	No plastic	textile	Consumer	Other	Personal care products	ct	hy
97	sanitair_condooms	Condom	sanitary	rubber	rubber	Consumer	Other	Personal care products	ru	hy
99	sanitair_maandverband_en_verpakkingen_ervan	Sanitary towel	sanitary	No plastic	textile	Consumer	Other	Personal care products	ct	hy
18	sanitair_plastic_kam_borstel	Hair brush	plastic	PO Hard	plastic	Consumer	Other	Personal care products	pl	hy
100	sanitair_tampons_en_tamponapplicators	Tampon (applicator)	sanitary	No plastic	textile	Consumer	Other	Personal care products	ct	hy
102.3	sanitair_tissues_wc_papier	Toilet paper	sanitary	No plastic	textile	Consumer	Other	Personal care products	ct	hy
101	sanitair_toiletverfrissers	Toilet refresher	plastic	PO Hard	plastic	Consumer	Other	Personal care products	pl	hy
102	sanitair_overig_sanitair	Other sanitary	sanitary	No plastic	textile	Other	Other	Personal care products	ct	hy
103	medisch_verpakkingen	Medical packaging	plastic	Multilayer	plastic	Consumer	Other	Other/unclassifiable	pl	md
104	medisch_spuiten	Syringe	medical	PO Hard	plastic	Consumer	Other	Other/unclassifiable	pl	md
105	medisch_overig_medisch	Other medical	medical	No plastic	plastic	Other	Other	Other/unclassifiable	pl	md
0	nurdles	nurtles	plastic	PO hard	plastic	Consumer	Other	Other/unclassifiable	pl	nn

7 G: Sample set size requirements

Table 5. Sample set size requirements for all categories in our database with more than 10 items. Requirements are given for various confidence boundaries and deviations from mean. Red numbers indicate that the number of items needed to represent the mean mass is equal to the total number of items collected. N/A means that this level of uncertainty (confidence boundary and deviation from the mean) is never reached, and more items need to be collected.

						Deviation from mean											
						20%				10%				5%			
						Confidence boundary											
OSPAR-ID	Name	Total number of items	μ_{mass} (g)	σ_{mass} (g)	Ψ (-)	0.5	0.75	0.9	0.95	0.5	0.75	0.9	0.95	0.5	0.75	0.9	0.95
3	Small bag	44	12.5	26.4	2.1	30	36	39	40	34	39	42	43	38	41	43	44
4.1	Bottle (>= 0.5 L)	34	80.0	176.7	2.2	1	1	29	30	1	32	34	34	30	32	34	34
4.2	Bottle (< 0.5 L)	127	40.4	75.1	1.9	34	63	82	90	74	110	120	120	110	120	N/A	N/A
4.3	Bottle label	23	4.6	9.4	2.1	18	21	22	23	21	22	23	23	22	23	23	23
6	Food packaging	170	9.1	18.6	2.0	42	79	110	120	95	140	150	160	150	160	170	170
7	Cosmetics packaging	19	17.0	16.7	1.0	8	13	15	16	14	17	18	18	18	19	19	19
15	Caps and lids	300	3.2	7.5	2.4	50	130	170	190	160	220	250	260	240	270	290	300
16	Lighter	38	11.7	3.5	0.3	1	3	6	8	4	10	16	18	12	22	28	30
20	Toy	18	52.3	111.2	2.1	14	16	18	18	15	17	18	18	17	18	18	18
21	Cup	116	3.2	7.7	2.5	51	77	90	95	88	110	110	N/A	110	110	N/A	N/A
31	Rope D>1cm	29	216.0	340.2	1.6	16	22	25	26	24	27	28	29	28	29	29	29
32	Rope D<1cm	170	11.0	88.5	8.1	1	150	170	170	130	150	170	170	140	160	170	170
35	Fishing gear	20	6.6	5.4	0.8	6	11	14	16	13	17	18	19	18	20	20	20
40	Industrial packaging	39	51.1	169.6	3.3	1	35	38	38	32	35	38	38	35	37	39	39
117.1	Hard fragment (< 2.5 cm)	323	0.3	0.4	1.4	21	56	96	130	74	150	210	230	180	250	290	300
46.1	Hard fragment (>= 2.5 cm)	1140	7.0	39.9	5.7	310	590	760	820	660	910	1000	1100	980	1100	N/A	N/A
117.2	Soft fragment (< 2.5 cm)	197	0.1	0.1	2.6	1	110	140	150	1	170	180	190	180	190	N/A	N/A
46.2	Soft fragment (>= 2.5 cm)	2045	2.0	6.7	3.3	81	310	560	690	410	880	1300	1400	1100	1600	1800	1900
48	Other	73	129.5	351.8	2.7	41	58	63	65	62	67	70	72	69	71	73	73
1172	Foam fragment (< 2.5 cm)	1127	0.2	0.2	1.0	12	33	65	89	45	130	230	300	170	370	560	670
462	Foam fragment (>=2.5 cm)	2399	2.3	21.5	9.3	1	1400	1500	1600	1800	2100	2300	N/A	1800	2200	2300	N/A
6.1	Foam food packaging	53	1.0	2.0	2.1	1	39	43	46	44	49	51	52	47	50	52	53
47.1	Soft fragment (>50 cm)	69	36.0	72.0	2.0	36	48	54	57	53	61	66	68	60	65	67	68
47.2	Hard fragment (>50 cm)	19	103.8	302.9	2.9	1	17	19	19	15	17	19	19	16	17	19	19
22.1	Straw	78	0.9	2.1	2.3	39	57	64	67	63	71	75	77	71	75	77	78
19	Food wrapping	882	1.5	11.2	7.4	500	620	690	730	670	780	850	870	730	810	850	870
39.1	Cable tie	41	4.3	9.8	2.3	17	27	32	34	30	37	38	39	38	40	41	41
39	Lollipop stick	110	2.2	3.3	1.5	4	14	26	34	20	42	60	70	50	78	92	97
19.1	Garbage bag	82	0.3	0.2	0.7	30	51	63	67	57	72	76	77	75	79	80	81
2.1	Pen	10	12.6	24.8	2.0	2	4	6	7	5	8	9	9	8	9	10	10
35.1	Fishing wire	85	1.2	2.7	2.2	37	58	67	71	65	76	80	81	77	81	83	85
39.1	Tape	25	4.3	9.8	2.3	19	22	24	25	20	23	24	25	23	24	25	25
49	Balloon	23	2.4	1.7	0.7	5	10	14	16	12	18	20	21	19	22	22	22
53	Other rubber	34	34.8	59.3	1.7	18	26	29	30	27	32	33	34	33	34	34	34
54	Clothing	31	151.2	178.9	1.2	12	19	24	25	22	27	29	29	29	31	31	31
59	Other textile	102	172.4	665.9	3.9	1	84	91	94	89	96	100	N/A	91	97	100	N/A
61	Cartboard	11	20.0	20.8	1.0	7	9	10	10	11	11	11	11	11	11	11	11
64	Cigarette filter	1308	0.5	0.1	0.2	1	1	3	7	1	1	11	19	1	1	47	67
67	Other paper	75	7.4	10.5	1.4	19	36	49	54	42	59	66	68	64	70	73	73
62.1	Drink carton	11	35.7	32.0	0.9	6	8	10	10	10	10	11	11	11	11	11	11
67	Undefinable paper	85	7.4	10.5	1.4	10	22	36	43	29	50	64	68	57	72	78	81
68	Cork	34	7.9	5.6	0.7	4	12	17	19	16	24	28	29	26	30	33	34
74	Other wood (< 50 cm)	38	225.4	529.6	2.3	26	32	34	35	34	36	38	38	35	37	38	38
81	Aluminium foil	98	4.3	11.1	2.6	54	71	81	84	77	87	94	96	86	92	95	96
78	Drink can	172	38.1	69.2	1.8	33	69	98	120	82	130	150	160	140	160	170	170
83	Old iron scrap	18	699.8	1101.0	1.6	14	16	18	18	14	16	18	18	16	17	18	18
77	Metal bottle cap	616	2.0	0.8	0.4	2	3	8	17	4	14	38	54	19	69	130	170
89	Other metal (< 50 cm)	159	125.1	526.5	4.2	1	130	140	150	1	150	N/A	N/A	1	N/A	N/A	N/A
90	Other metal (>= 50 cm)	12	927.8	1059.5	1.1	7	10	10	11	12	12	12	12	12	12	12	12
91	Glass bottles and ceramics	452	35.6	80.5	2.3	53	130	200	240	160	280	350	370	310	390	420	430
93	Other glass	73	14.7	55.7	3.8	1	63	67	68	64	69	72	73	64	69	72	73
7	Cosmetics	19	17.0	16.7	1.0	8	12	15	16	14	17	18	18	18	19	19	19
98	Cotton swab	215	0.2	18.7	0.1	1	1	1	1	1	1	1	1	1	1	1	N/A
102.2	Wet tissue	209	8.7	12.5	1.4	18	53	85	100	69	130	160	170	140	180	200	200
99	Sanitary towel	31	3.9	3.7	0.9	9	16	21	23	18	25	28	29	27	30	30	31
100	Tampon (applicator)	12	0.4	1.0	2.6	1	1	12	12	1	11	12	12	10	11	12	12
102	Other sanitary	13	10.9	15.0	1.4	9	12	13	13	11	12	13	13	13	13	13	13
105	Other medical	22	2.5	3.1	1.2	1	16	18	18	1	20	21	22	1	20	21	22
0	nurtles	140	0.0	0.0	0.9	4	22	38	48	26	57	83	94	70	110	120	130