Comparison of macrolitter and meso- and microplastic pollution on French riverbanks and coastal beaches using citizen science with schoolchildren

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Abstract:

Rivers are the major source of anthropogenic litter entering the ocean, especially plastic debris that accumulates in all ecosystems around the world and poses a risk to the biota. Reliable data on distribution, abundance and types of stranded plastics are needed, especially on riverbanks that have received less attention than coastal beaches. Here, we present the citizen science initiative *Plastique à la loupe* (Plastic under the magnifier), that compares for the first time the distribution of different litter sizes (macrolitter, meso- and microplastics) over 81 riverbanks and 66 coastal beaches sampled in France between 2019 and 2021. A total of 147 school classes (3,113 schoolchildren) from middle to high school collected, sorted and enumerated 55,986 pieces of plastic to provide a baseline of the current pollution by stranded debris at the national level. Single-use plastics (mainly food-related items) were very abundant on riverbanks (43 %), whereas fragmented debris dominated the macrolitter on coastal beaches (28 %). Microplastics were always higher in number compared to mesoplastics and macrolitter, with polystyrene and polyethylene found in equivalent proportions on riverbanks while polyethylene dominated microplastics on coastal beaches. Tracing the source of plastic items was possible only for a small proportion of the numerous collected items, mainly for identifiable macrolitter and microplastic pellets. This study lays out the foundations for further works using the *Plastique à la loupe* citizen science initiative in France and additional comparisons to other studied habitats worldwide, which can be used by scientists and policy-makers for future litter monitoring, prevention and clean-up strategies.

Introduction:

Plastic pollution has been documented in all major ocean basins and a growing number of freshwater and terrestrial environments (Bucci et al., 2020). Despite a growing literature in the last decade, the ultimate fate of plastic debris and its transport mechanisms in terrestrial, freshwater, and marine environments are poorly understood, at both regional and global levels (Zhu, 2021). There is a peculiar, several orders of magnitude, mismatch between projected litter emissions into the ocean (Jambeck et al., 2015) and global estimates based on field data (Eriksen et al., 2023; Van Sebille et al., 2015), indicating hitherto insufficiently accounted sinks such as remote coastal beaches and riverbanks (Bergmann et al., 2017).

The importance of tackling plastic litter worldwide has been globally recognized in the context of the 2030 agenda for sustainable development, adopted by all United Nations Member States in 2015 (see target 14.1 in United Nations, 2014). In the marine environment, plastic litter is one of the 11 descriptors of Good Environmental Status (GES) of the European Marine Strategy Framework Directive (2008/56/EC, MSFD) (Galgani et al., 2013). In freshwater, contamination by plastic litter has not yet been considered as a descriptor of good environmental status, including, for example, the European Water Framework Directive (2000/60/EC, WFD). This gap could be explained by the lack of data relating the occurrence and associated effects of plastic contamination in freshwater ecosystems (Dris et al., 2015). Several studies recognized that plastics with terrestrial usages are the main sources of marine plastic pollution, either by direct emission from coastal zones (Li et al., 2021) or transport through rivers (Lebreton et al., 2017; Schmidt et al., 2017; Weig et al., 2021). Riverine plastic transport remains understudied and a better understanding of the sources and pathways of plastics in freshwater ecosystems is a prerequisite to develop effective prevention and collection strategies (Morales-Caselles et al., 2021).

Gathering sufficient data for scientific research is challenging, with limited sampling time and human resources involved in classical scientific projects (Zettler et al., 2017). Because marine litter items are easily identifiable and their quantification requires relatively little scientific training, it is particularly well suited for engaging citizen scientists to expand our knowledge of the spatial and temporal distribution of marine litter, especially in remote, under-sampled areas (Hidalgo-Ruz & Thiel, 2015; Kawabe et al., 2022). In addition to data provisioning, citizen engagement serves as an outreach mechanism to inform and involve the general public on scientific progress (Silvertown et al., 2013). An increasing number of citizen science initiatives exist on plastic litter, mainly focusing on macro- and microplastics washed or deposited on coastal beaches or shorelines (beach litter) in the United States (Barrows et al., 2018; Uhrin et al., 2020), China (Chen et al., 2020), Indonesia (Syakti et al., 2017), United Kingdom (Nelms et al., 2020), Danemark (Syberg et al., 2020), British Columbia and Canada (Harris et al., 2021), Chile (Bravo et al., 2009), Australia (Carbery et al., 2020; van der Velde et al., 2017), Svalbard (Bergmann et al., 2017), and Lofoten Island (Haarr et al., 2020). Other initiatives with focus on floating plastic debris were carried out in the United States (Davis & Murphy, 2015), Sweden (Gewert et al., 2015), Chile (Hinojosa et al., 2011) and Taiwan (Chiu et al., 2020). Studies on plastic debris on the seafloor were conducted in the United Kingdom (Nel et al., 2020) and across 13 countries in Europe (Lots et al., 2017). Surprisingly, very few of these initiatives considered riverbanks despite the need of data on plastic quantification at the source of the pollution (for exceptions see Rech et al., 2015, Kiessling et al., 2019, 2021).

Plastic debris encompasses a wide size distribution, from large abandoned and derelict consumer litter (often single-use products) to unrecognizable fragments of meso- (from 25 mm to 5 mm) and microplastics (5 mm to 500 µm) (Hinata et al., 2017). Several methodologies for monitoring marine litter already exist. Among them, the OSPAR beach litter protocol is one of the most used to monitor macrolitter on coastal beaches (OSPAR, 2020) and it has been adapted to monitor macrolitter on riverbanks (Van Emmerik & Schwarz, 2020).

This study presents the first citizen science initiative dedicated to the comparison between macrolitter, meso- and microplastic on riverbanks and coastal beaches. *Plastique à la loupe* is the first citizen science initiative conducted in France, engaging 3,113 teenagers and their teachers from 149 schools across the nation collecting and extracting macrolitter, meso- and microplastic samples since 2019. Here, we focused on assessing the composition, distribution and abundance of plastic debris on riverbanks and coastal beach surveys in France based on data collected between 2019 and 2021 (**Fig. 1**). Schoolchildren have used the same scientific protocol as developed during the Tara Microplastic expedition, adapted from the OSPAR protocol (Ghiglione et al., 2023). We ended up with 43,571 macro- and mesoplastic items that were characterized together with 12,415 microplastics for analysis by Fourier transform infrared spectroscopy (FTIR). This study confirms the potential of using citizen science for relevant analysis of macro-, meso- and microplastic pollution on riverbanks and coastal beaches.

Materials and methods

Recruitment and training of the participants

The recruitment of participating classes was organized by the Tara Ocean Foundation in conjunction with the 30 academies representing the administrative divisions of the Ministry of National Education and the regional offices of the Ministry of Higher Education and Research. An online form is available to respond to a call for projects each year on the *Plastique à la Loupe* website (https://plastiquealaloupe.fondationtaraocean.org/). Classes are selected if they commit to a minimum of two teachers to carry out the scientific part of the project, integrate the logistical dimension of the project, respect the project timetable, send in samples and answer the project evaluation questionnaire.

Participants were provided with support documents and video conferences twice a year (September and May, by groups of 10 to 20 classes), allowing to gain confidence in their data-collection skills, which was considered critical for the success of this project. The support document tool kit for teachers included (i) a support guide to explain the general concepts and objectives of the *Plastique à la loupe* initiative together with answers to frequently asked questions (FAQ), (ii) an easy and straightforward protocol guide slightly adapted from the OSPAR beach litter monitoring form (OSPAR, 2010), (iii) a photoguide for the macrolitter identification, and (iv) a video guide for *in situ* training. In addition, at the beginning of the schoolyear, the teams of involved teachers benefited from a one day virtual meeting introduction to the project in the presence of the educational team of the Tara Ocean Foundation.

In order to test the reliability of the sampling, sorting and data acquisition, 8 sampling sites (6 on riverbanks and 2 on coastal beaches) were first analyzed by professional scientists before the on-site visit of teachers and schoolchildren. Professional scientists came on the sampling site a few hours before the schoolchildren and carried out a direct macrodebris count, without removing the plastics to preserve them for the schoolchildren. In the specific case of these 8 sampling sites, the sorting of meso- and large microplastics was carried out back at school by schoolchildren and under the supervision of professional scientists, in order to assess possible confusions with non-plastic particles. All particles identified as plastic debris by the schoolchildren (including those visually labeled as non-plastic particles by the professional scientists) were analyzed by FTIR (see technique details below) to determine the error rate between plastic and non-plastic particles identified by the schoolchildren or by the professional scientists.

Study sites

Study sites were first chosen by teachers based on local experience and further validated by the scientists. Selection criteria of the sampling sites were defined based on OSPAR and MSFD recommendations and adapted to the citizen science format in order to guarantee the safety of participants and the quality of the data collected (OSPAR, 2020; MSFD TG ML, 2013), including: (1) absence of danger, (2) easy access, (3) presence of deposited litter, (4) absence of cleaning in the 15 days before the sampling, (5) minimum sections of 10 m and 50 m for riverbanks and coastal beaches, respectively, (6) presence of sand for microplastic sampling. A total of 81 riverbanks and 66 coastal beaches were visited by 147 classes from middle to high school (11 to 18 years old). Sampling sites were spread over the whole metropolitan France, *i.e.* mainland France and Corsica, with 57 sites in the Loire basin, 33 in the Seine basin, 24 in the Rhone basin, 16 in the Garonne basin, 11 in the Rhine basin and 11 sites on Corsica Island. Nearly half of the river sites (42.2%) were sampled in tributaries rather than in the main river (**Fig. 1**). The classes sampled in the field between September and March 2019-2020 and 2020-2021. During a first step, each class was asked to complete a site description form (adapted from the OSPAR beach litter monitoring form; OSPAR, 2010). Information collected includes orientation of the site, sand granulometry, uses (seasonal/annual), accessibility and nature of the site's surroundings (town, village, port, estuary, landfill sites, sewage treatment plant, etc.) as well as the frequency and method of cleaning (if relevant) (Supplementary Table 1).

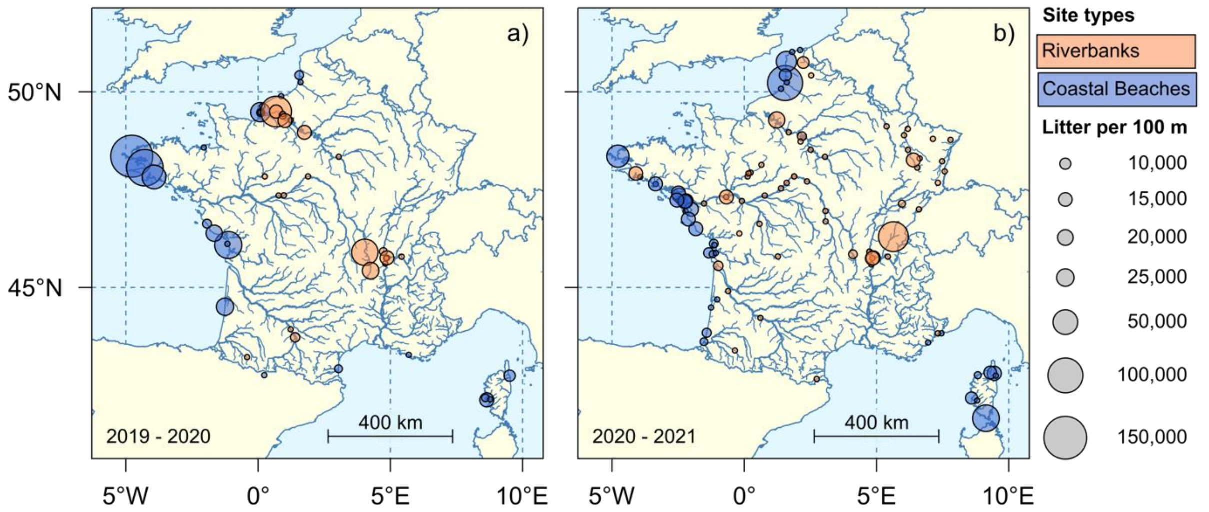

Figure 1. Total number of litter items per site sampled in 2019-2020 (a) and 2020-2021 (b). Coastal beaches are represented by blue dots; riverbanks are represented by orange dots. 24 riverbanks and 25 coastal beaches were sampled in 2019-2020 (a), and 57 riverbanks and 41 coastal beaches were sampled in 2020-2021 (b). The number of litter items corresponds to the sum of macrolitter, meso- and microplastics, normalized for 100 linear meters.

Stranded macrolitter items

Stranded macrolitter items were surveyed using a method adapted from the OSPAR methodology (OSPAR 2020), with a slight difference depending on whether sites presented wrack lines. Schoolchildren collected all visible litter larger than 2.5 cm along one transect for each site, that could range from 50 to 100 meters in length for coastal beaches and from 10 to 25 meters for riverbanks, depending on the size of each site. The transect width extended from the first wrack line near the water to the back of the riverbanks or coastal beaches (**Fig. 2A**). In the absence of a wrack line, sampling was done across the entire width of the riverbank or coastal beach (**Fig. 2B**).

The collected litter was placed in litter bags, except for items that were too large or too heavy, which were left on site and noted for later counting. Collected litter was brought back to the classroom, for estimation of the volume (L) and measurement of the mass (kg) of total macrolitter. All litter items were sorted, identified and counted according to the OSPAR beach litter survey data form. To facilitate the identification of macrolitter items, we added categories to the initial list of items, according to their use (e.g. fishing, medicine...). Some items including single-use plastic items (e.g. straws, lolly sticks,…) and foamed polystyrene fragments were separated for a better focus. The survey data form describing the different categories, types and uses, are presented in Supplementary Table 2. A picture was taken once all litter items were sorted, and litter items were then discarded according to their composition in the appropriate waste disposal center.

Results obtained were expressed in volume, mass and number per 100 linear meters of riverbank or beach, 100 meters being the survey unit adopted for OSPAR and MSFD assessments of beach litter (OSPAR, 2020, MSFD TG ML, 2023). The calculation was performed by dividing the data obtained by the number of linear meters surveyed and multiplying by 100. Data normalization was done relative to 100 linear meters rather than surfaces in order to avoid the bias induced by tides, which changes the surface of the sampling area depending on the time of the sampling and therefore, the density of items on the beach.

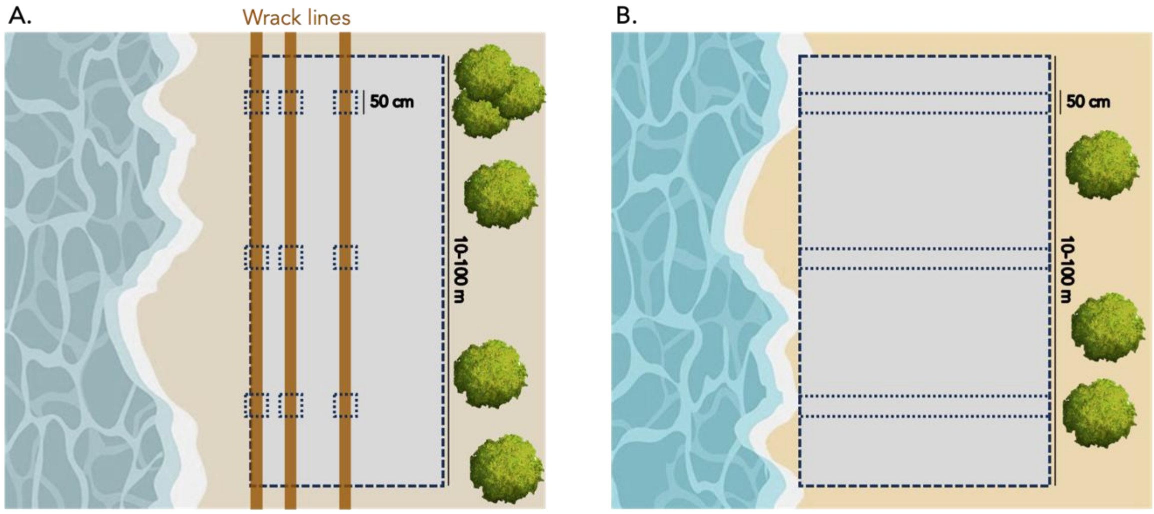

Figure 2. Sampling units for macrolitter items, meso- and microplastics on riverbanks and coastal beaches in situation with (A) and without wrack lines (B). Grey shaded areas represent the sampling space of macrolitter and black dotted squares the sampling spaces of meso- and microplastics (adapted from Vriend et al., 2020); for sites that featured at least one wrack line, three 50 cm x 50 cm quadrats were placed on the wrack line to sample meso- and microplastics (for sites with multiple wrack lines, the quadrats were placed on only one wrack line, i.e. the most recent visible wrack line) (A); but for sites that did not feature wrack lines, then three 50 cm wide strips were placed perpendicular to the waterline to sample meso-microplastics (B).

Sampling and sorting of stranded meso- and large microplastics

Sampling of stranded mesoplastics and large microplastics were assessed using a method proposed at the European level to monitor mesolitter fragments and pellets on the coastline (MSFD TG ML, 2023). Only meso- and microplastics on the sand surface were sampled. The area of sampling depended on each site features (Fig. 2). In case of the presence of at least one wrack line, three 50 cm x 50 cm quadrats were deployed along the transect, evenly distributed on the said wrack line. For sites presenting multiple wrack lines, three quadrats were deployed on only one wrack line, defined as the most recent visible wrack line (Fig. 2A). In the absence of any visible wrack line, three 50 cm-wide strips perpendicular to the waterline and evenly distributed along the transect were deployed, for meso- and microplastics sampling (Fig. 2B). Samplings were done by collecting sand surface (top few centimeters) using a trowel. Materials used for sampling were made of metal or glass to prevent any sample contamination. To limit organic matter and sand collection, meso- and microplastics were extracted directly on site, following the European MSFD monitoring protocol (MSFD, 2013). Briefly, less dense plastic particles were separated by flotation using a saturated sodium chloride (NaCl) solution (final specific gravity of 1.2 g/cm^3) prepared on site by using local seawater (for coastal sites) or freshwater (for river sites). Density separation was achieved by agitating the subsample in the saturated NaCl solution, as described by Thompson et al. (2004). Floating particles were recovered with a metallic cooking sieve with a mesh size of 1 mm, then stored in a metal tray and brought back to classroom for sorting. Once in classroom, samples from the three subsamples were treated separately, by visually sorting organic debris and plastics using a magnifying glass where necessary. Due to potential errors in distinguishing plastics from other organic debris by visual sorting, even with a magnifying glass, small microplastics of < 0.1 cm were not analyzed. Plastics were then sorted according to their size class: mesoplastics [5-25 mm] and large microplastics [1-5 mm].

The particles were then counted according to their type (industrial plastic pellets, solid fragments with degraded or angular forms, fragments of films, moss or fibers, fragment and beads from expanded polystyrene items), color and opacity (opaque or transparent) based on a list adapted from MSFD microlitter monitoring guidelines (MSFD TG ML, 2023) as presented in the survey data form (Supplementary Table 2). Meso- and microplastic lists were the same except for the industrial plastic pellets (IPP) category (also known as nurdles or pellets), which is only included in the microplastic list. Results were expressed in numbers of particles by 100 linear meters of riverbank or beach, by dividing the number of counted particles by 1.5 (corresponding to the sum of the 3 quadrats (or bands) sampled over a width of 50 cm, *i.e.* 1.5 m) and multiplying by 100 (normalization to 100 m).

After sorting, a picture of each sample was taken. A maximum of 96 putative microplastics were then selected randomly in the sample, placed separately one by one in the wells of a 96-well microplate and sent to the Observatoire Océanologique de Banyuls sur mer (OOB, France) or to the Cedre (Brest, France), for polymer composition analysis by Fourier transformed infrared spectroscopy (FTIR). FTIR analyses were performed with following parameters: large scale absorbance mode in the 4000-600 cm^{-1} region with 4 cm^{-1} resolution and 32 scans. Polymer identification was performed using the POSEIDON tool that contains a spectra bank obtained from microplastics collected during the Tara Mediterranean (2014) and Tara Microplastic (2019) expeditions (Ghiglione et al., 2023; Kedzierski et al., 2019).

Data management and analysis

Survey data forms were gathered for riverbanks and coastal beaches, and raw data were normalized for 100 linear meters. Among the 151 studied sites, four were excluded from the analysis, whether because the length of the sampling section was not mentioned by schools (for one riverbank and two coastal beaches) or because details of sorting were not given (for one riverbank). Data from riverbanks and coastal beaches were treated separately. Proportions of each type of macrolitter, of each item category or size category were calculated from normalized data for each site, and the mean of these proportions was calculated to have information on the dispersion of data of all sites (considering coastal beaches and riverbanks separately, and taking into account that only one transect was carried out at each sampling site). For plastic litter size analysis, only the sites with complete sampling of macro-, meso-, and microplastics on a known section were studied. Standard deviation was expressed in ± of the percentage values.

Correlations between numbers of macro-, meso-, and microplastics were calculated for riverbanks and coastal beaches separately. Data normality was tested using a Shapiro test. As data were not normality distributed (Shapiro test, $p < 0.05$), non-parametric Spearman correlation coefficients between numbers of macrolitter, meso-, and microplastics were calculated for riverbanks and coastal beaches.

Results

Number, mass and composition of macrolitter items on riverbanks and coastal beaches

A total of 81 riverbanks from large and small rivers were sampled in France, together with 66 coastal beaches located along the French coastline either on the coast of the Mediterranean Sea, the Atlantic Ocean or the English Channel. A total of 48,023 macrolitter items were collected. Among all the sites that were studied, only two riverbanks were not polluted with macrolitter in the sampling zone; however, for one of these two sites, the area surrounding the sampling section was highly polluted, mainly with glass debris. The median number of macrolitter items per 100 linear meters collected on riverbanks was approximatively twice lower (median = 232 for 100 linear meters, n = 81) than on coastal beaches (median = 443 for 100 linear meters, n = 66) (**Fig. 3A and Suppl. Table 3**). The opposite tendency was observed when expressing macrolitter amounts by weight, in kg of litter per 100 linear meters (median = 10.0 kg, n = 67 sites and median = 5.1 kg, n = 52 sites per 100 linear meters on riverbanks and coastal beaches, respectively) (**Fig. 3B and Suppl. Table 3**).

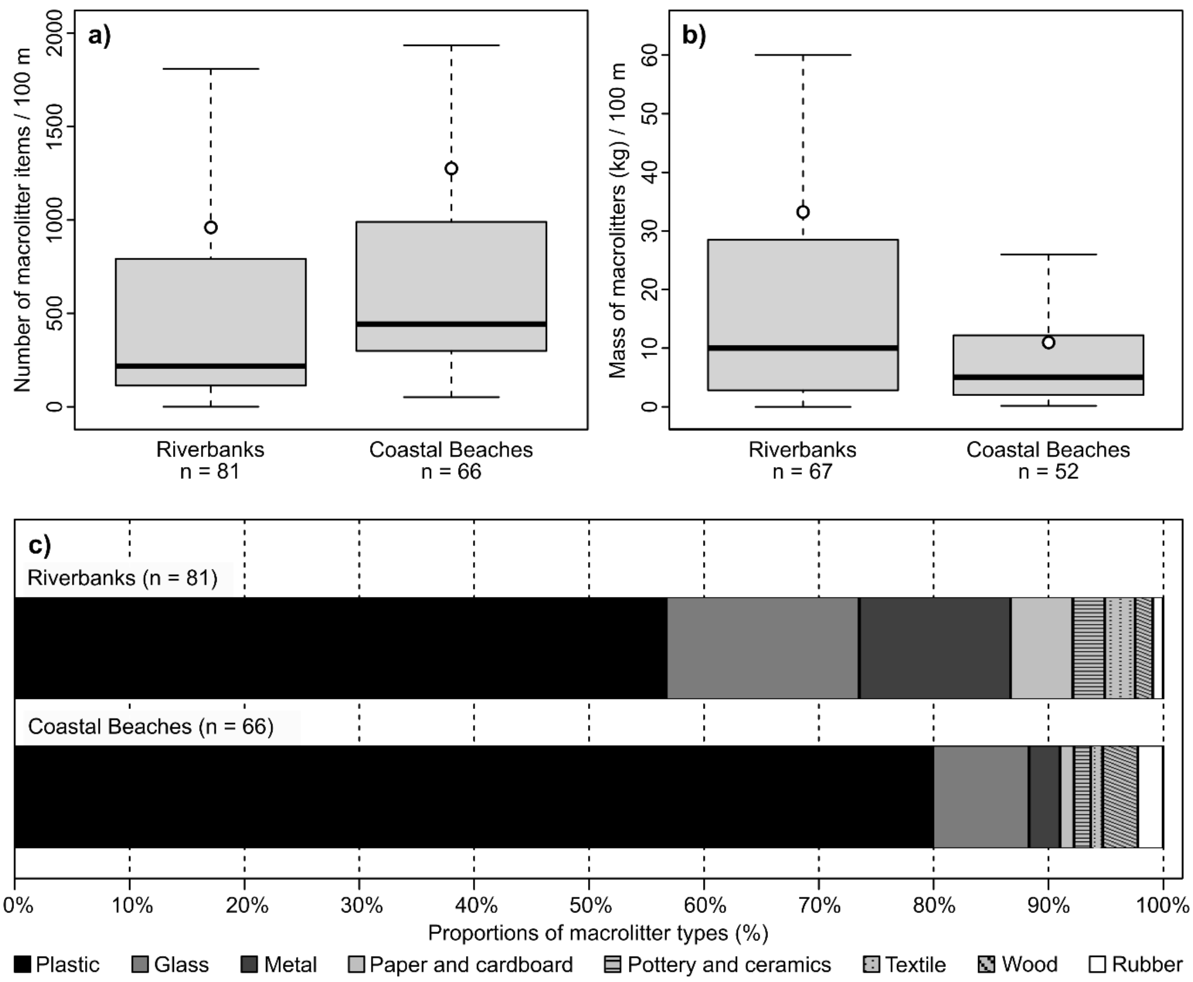

Figure 3. (A) Number of macrolitter items for 100 linear meters (left: riverbanks, n=81; right: coastal beaches, n=66), **(B) mass of macrolitter, in kg for 100 linear meters** (left:

riverbanks, n=67; right: beaches, n=52) and **(C) proportions of types of macrolitter** (top: riverbanks, n=81; bottom: beaches, n=66).

Plastic was the most dominant debris type in number of items compared to the total number of collected litter items, with a lower proportion on riverbanks than on coastal beaches (55.1 ± 30.4 % and 80.0 ± 22.4 %, respectively). In order of abundance, other debris items were composed of glass, metals, paper and cardboard, ceramics, textiles, wood and rubber (**Fig. 3C and Suppl. Table 3**).

Common macroplastic types and composition on riverbanks and coastal beaches

Macroplastic debris found across all riverbanks (n = 81 sites) were dominated by single-use disposable plastics 43.4 ± 26.2 %), whereas single-use plastics represented only 27.6 ± 17.4 % on coastal beaches (n = 66 sites) (**Fig. 4A and 4C, Suppl. Table 4**). Plastic fragments were the second dominant plastic type collected on riverbanks (23.2 ± 24.8 %), despite it dominated the plastic debris on coastal beaches (28.7 ± 24.5 %). Items related to marine activities (fishing, aquaculture and maritime gears) were more present on coastal beaches than on riverbanks (mainly ropes and fishing nets related to recreational fishing activities). In contrast, bags and wrappers were more abundant on riverbanks compared to coastal beaches. The same trend was found for sanitary and medical items. A significant number of unclassified items (recognizable items that were not listed in the survey data form) were found on both riverbanks and coastal (**Fig. 4A and 4B, Suppl. Table 4**), limiting the description of macrolitter items at the studied sites.

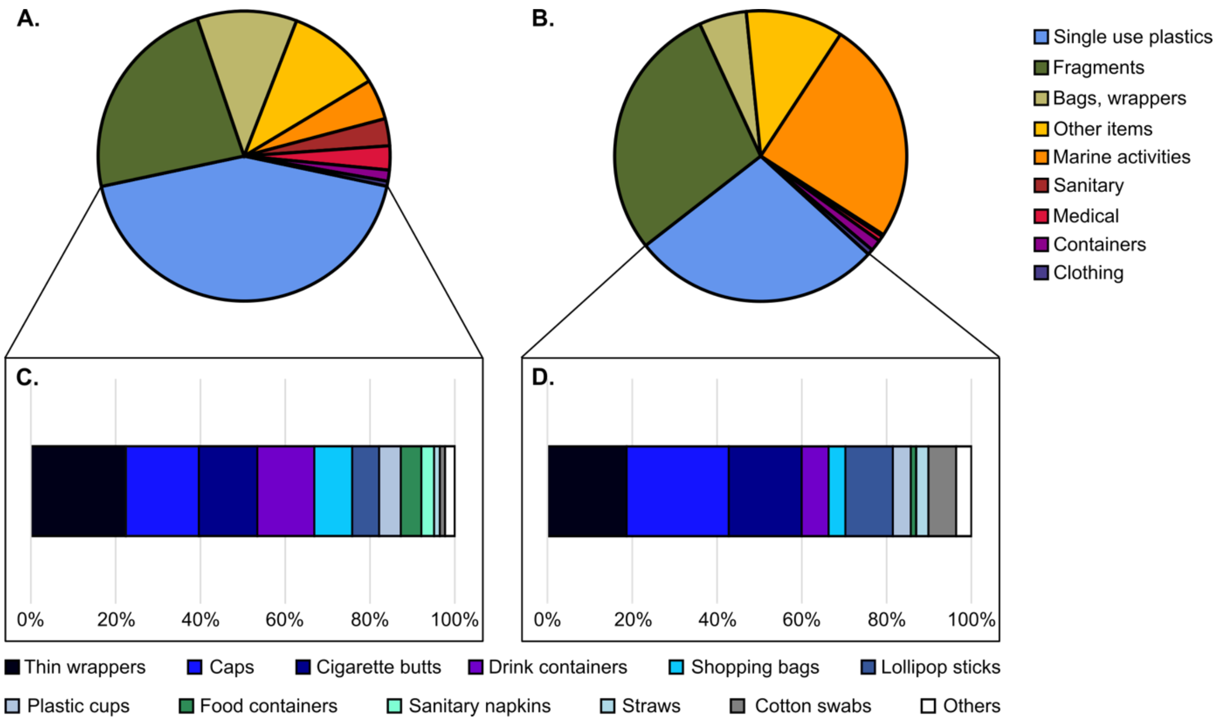

Figure 4. Types of plastics and single-use plastics on riverbanks (A and C respectively, n = 81) and coastal beaches (B and D respectively, n = 66). The mean proportions from all sites for each item category are presented. The category “other items” in A and B correspond to recognizable macroplastics that were not detailed in the survey form. The category “others” in C and D comprises foamed polystyrene food containers and cups, tampon and applicators, disposable plates and cutleries, and stirrers. These former items were found in proportions < 1 %, except for foamed polystyrene food containers on coastal beaches.

Focus on single-use disposable plastics on riverbanks and coastal beaches

Single-use disposable plastics represented 43.3 ± 26.2 % and 27.6 ± 17.4 % of all macrolitter on riverbanks and coastal beaches, respectively. They were dominated by thin wrappers and caps on both riverbanks and coastal beaches (**Fig. 4C and 4D, Suppl. Table 4**). Drink containers, shopping bags and food containers were found in higher proportions on riverbanks, despite they were also present on coastal beaches. In contrast, cigarette butts, lollipop sticks and cotton swabs were found in higher proportions on coastal beaches compared to riverbanks (**Fig. 4C and 4D, Suppl. Table 4**).

Comparison between macro-, meso- and microplastics on riverbanks and coastal beaches

Three size categories were distinguished in this study, i.e. macroplastics [> 2.5 cm], mesoplastics [5-25 mm] and large microplastics [1-5 mm]. The numbers of macro- and microplastics, as well as meso- and microplastics, showed a positive correlation with one another on both riverbanks and coastal beaches (**Suppl. Fig. 1**). Microplastics represented a major part of the number of plastics found on both riverbanks (47.0 ± 34.2 %, n = 67 sites) and coastal beaches (45.7 ± 25.5 %, n=51 sites) (**Fig. 5 and Suppl. Table 5**). It is noteworthy that the IPP represented around a quarter of the microplastics found on riverbanks and coastal beaches (22.5 ± 28.1 % and 25.2 ± 28.1 % of sampled microplastics respectively, corresponding to 13.1 ± 22.4 % and 13.3 ± 19.5 % of total plastics, respectively), while the rest of microplastics was mostly dominated by fragmented pieces. The second-most dominant plastics on riverbanks were fragmented mesoplastics (size range between 5 mm and 25 mm). On beaches, macroplastics were found in lowest proportion. Here, it is noticeable that a large proportion of macroplastics found on coastal beaches were too fragmented to be identified (**Fig. 5 and Suppl. Table 5**), whereas the other parts were recognizable macroplastics as depicted in **Fig. 4A** and **Fig. 4B**.

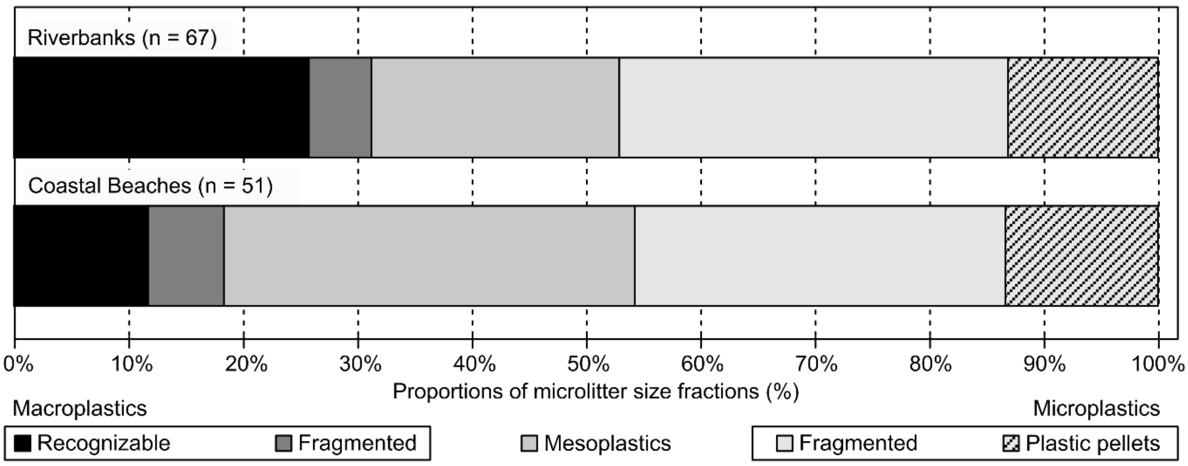

Figure 5. Size fractions of plastic litter. The mean proportions for each size category are represented for riverbanks on top (n=67) and coastal beaches on the bottom (n=51).

Polymer composition of microplastics on riverbanks and coastal beaches

A total of 12,415 putative microplastic items have been sampled by schoolchildren. Because ATR-FTIR analysis is very time consuming, we decided to limit the amount of analysis for each school class to a maximum of 96 microplastics randomly selected by the schoolchildren. As only a portion of the putative microplastics was analyzed by ATR-FTIR (on average about 53% of microdebris sampled), the data are presented as a percentage of each polymer type (the quantity of microplastics at each sampling site could therefore not be estimated).

Similar polymer types were found for putative microplastics collected both on riverbanks (n = 49 sites) and on coastal beaches (n = 39 sites), but with a clear difference in their relative proportions (**Fig. 6**). On riverbanks, most of these items identified as microplastics were made of polystyrene (PS) and polyethylene (PE) (30.7 ± 36.8 % and 30.6 ± 27.7 %, respectively) whereas coastal beaches were clearly dominated by PE (52.1 ± 26.2 %). On coastal beaches, PS and polypropylene (PP) were found in similar proportions (16.3 ± 23.8 % and 16.1 ± 17.5 % respectively). Among microplastics studied on riverbanks, only 6.4 ± 12.7% were made of PP. Ethylene-vinyl acetate (EVA) represented only 1.6 ± 5.2 % and 0.8 ± 2.4% on riverbanks and coastal beaches, respectively.

It is noteworthy that a non-negligible proportion of putative microplastics were natural particles, certainly mistaken for microplastics when sorted out, representing the sampling error for microplastics (16.5 ± 21.6 % and 4.3 ± 8.1% on riverbanks and coastal beaches, respectively). A proportion of microplastics was not identified (called “unknown” hereafter and representing 7.9 ± 13.6 % and 7.1 ± 13.7 % of the sampled particles on riverbanks and coastal beaches, respectively) (**Fig. 6**). In these cases, the FTIR spectra presented plastic-specific features, but were not clear enough to conclude on the nature of the polymers composing the samples.

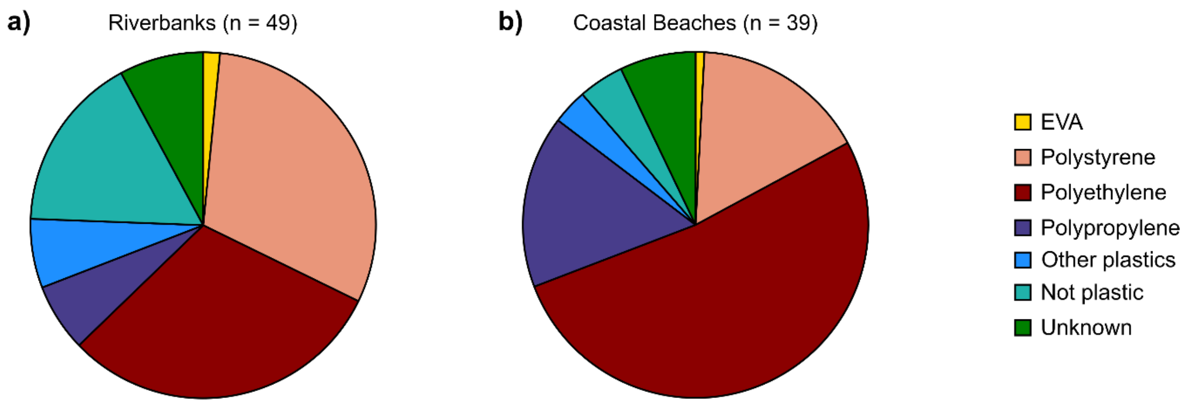

Figure 6. Nature of microplastics on A. Riverbanks and B. Coastal beaches. The mean proportions for each chemical category are represented for riverbanks (n=49 sites, representing 1,726 particles analyzed by FTIR) and coastal beaches (n=39 sites, representing 1,901 particles analyzed by FTIR).

A comparison of sampling, sorting and data acquisition was carried out at 8 sampling sites (6 riverbanks and 2 coastal beaches), based on debris first sampled by experienced scientists (without removing plastics) and then sampled by schoolchildren under the supervision of teachers. No significant difference with results gathered by both groups was found for macrolitters or mesoplastics (t test, $p<0.05$). However, more errors were found by the schoolchildren for the microplastics, with non-plastic particles accounting for an average of 7.7 % of the total number of fragments sampled on riverbanks and marine beaches (average error of 0.2 % for experienced scientists) (**Suppl. Table 6**).

Discussion

Citizen scientists monitor plastic litter on river banks and marine beaches

Monitoring efforts for stranded debris have mostly focused on coastal beaches (Serra-Gonçalves et al., 2019). Riverbanks are constantly supplied with plastic debris from the rivers, driving the need for more research and management of marine debris. Riverbanks were poorly investigated, with generally very few numbers of studied sites per river (Bruge et al., 2018; Rech et al., 2015). Only one citizen science initiative called 'Plastic Pirates' has investigated a large number of river sites, starting in Germany since 2016 (Kiessling et al., 2019; Kiessling et al., 2021) and further implemented in eleven European Union countries (Kiessling et al., 2023, Uogintė et al., 2024).

Citizen science monitoring provides a baseline understanding of debris composition, concentration and sources, and helps inform policies to reduce environmental impacts of plastic debris (Nelms et al., 2022). Numerous initiatives exist all around the world (Kawabe et al., 2022), but this study provides the first citizen science initiative for a direct comparison between debris found on riverbanks and coastal beaches with the exact same protocols. This baseline study presents the application of debris citizen science monitoring called "*Plastique à la loupe*" to establish the first large-scale and long-term debris dataset for France, making it accessible to facilitate cost-effective research efforts. In this study, conscientious collection by 3,113 schoolchildren from 149 classes removed a total of 48,023 macrolitter items on riverbanks (n = 81 sites) and coastal beaches (n = 66 sites) in two years. This labor-intensive monitoring effort would not have been feasible by a group of scientists, thus highlighting the power of the *Plastique à la loupe* citizen science initiative for a French national survey. Nevertheless, coordinating this initiative with schoolchildren requires extensive indirect (long-term national educational work carried out by the teaching profession) and direct costs (coordination with administrative districts of the French Ministry of National Education here, together with the labor intensive and time-consuming FTIR analysis of microplastics, as well as data analyses and validation) that should not be overlooked (Thiel et al., 2023). Since 2022, this dataset is used as complementary data in the national assessments of aquatic litter pollution conducted by Cedre for French authorities in the context of the MSFD or other international monitoring programs. It should be noted that sampling took place from September to February (autumn and winter) to enable results to be reported to the schoolchildren in the following June, corresponding to the end of the French school year. In view of the extended sampling period and the fact that weather conditions can vary in the different regions of France, it was recommended that sampling be carried out outside periods of river flooding or heavy rainfall. This period allowed teachers to organize training and sampling at their convenience in order to adapt to the weather conditions, which is preferable to the restrictive organization of a more limited sampling period.

Data quality controls

A main concern regarding citizen-science studies is whether the collected data are reliable and comparable to professional studies (Dittmann et al., 2022, 2023). At 8 sites successively sampled by professional scientists and schoolchildren groups (6 on riverbanks and 2 on coastal beaches), we found no macrodebris counted by experienced scientists that had not been collected by schoolchildren. Similar efficacy has been found by other citizen science studies (Thiel et al., 2014). More errors were observed by the schoolchildren that mistook microplastics with non-plastic particles (error of less than 7% of total sampled meso- and large microplastics). As previously observed, it was found that glass shards for example had been misidentified as small plastic debris (Hidalgo-Ruz & Thiel, 2015). This error can be easily corrected by the FTIR analysis that helps to detect non-plastic particles, which mitigates the impact of such error on the results.

Once the sampling site validation step was performed by professional scientists, only four sites were excluded from the analysis because the length of the section was missing or because of the lack of details regarding the sorting, thus underlying the high levels of coordination and personal motivation. Here, we underlined the importance of several steps including encouraging schoolchildren and teachers to describe any uncertainties to researchers, data auto-evaluation and communication of results as a concluding activity to enhance their commitment to the activity, as previously mentioned by other authors (Vriend et al., 2020; Thiel et al., 2023).

Distribution and composition of all debris on riverbanks and coastal beaches

We observed that around 55 % of all debris collected on riverbanks for 100 linear meters were plastic, which was much lower than on coastal beaches (around 80 % for 100 linear meters). This result is consistent with another study in Chile showing that plastics were the prevailing litter items and were more frequently found on coastal beaches than on riversides (Rech et al., 2014; Honorato-Zimmer et al., 2019). Other studies on European riverbanks found similar proportions of plastics among all debris (Kiessling et al., 2019; Kiessling et al., 2023). Other studies at local or regional scales found much higher proportions of plastics among all debris in the Adour riverbank (94 %) and closed coastal beaches (95 %) (Bruge et al., 2018) or in the riverbanks of the Dutch Rhine-Meuse delta (85 %) (Van Emmerik & Schwarz, 2020). Such discrepancy may be explained by local or regional disparities on the number of other types of debris (glass, metal, ceramics, paper, wood, rubber and textile) and on the modest sampling effort. As previously observed in other studies, a significant percentage of all debris on riverbanks was made of glass and metals in our study, thus explaining the higher weight of all debris on riverbanks compared to marine beaches (median of 10 kg and 5 kg for 100 linear meters, respectively (Honorato-Zimmer et al., 2019; Rech et al., 2014). These non-buoyant litter items are frequently attributed to non-riverine sources like direct litter dumping (Bravo et al., 2009; Honorato-Zimmer et al., 2019), in contrast to the high abundance of plastic items that in addition can be transported by rivers and deposited on riverbanks and coastal beaches due to their buoyancy and extreme persistence (Derraik, 2002; Moore, 2008; Rech et al., 2014).

Detailed plastic litter analysis in relation to their origin

Single-use plastics together with packaging (bags and wrappers) dominated most of the riverbanks (around 44.4 %), in a higher proportion than on coastal beaches (around 32.9 %). In particular, food-related items dominated the top 10 single-use plastics. It was dominated by caps (mainly from plastic bottles) and thin wrapper on both riverbanks and coastal beaches. Drink containers, shopping bags and food containers were found in higher proportions on riverbanks, they were also present on coastal beaches, as previously described (Morales-Caselles et al. 2021). Most of these items are typically used by individuals and are classically found on riverbanks (Al-Zawaidah et al., 2021) and coastal beaches (Lacroix et al., 2022). Either thrown away because of incivility (close to “take-away” restaurants), involuntary loss, or mismanagement (discarded during collection operations or transport by local authorities), they are ending up on city grounds, pushed away by the wind and runoff to rainwater collection systems, which take them either straight to the closest river or to the next Waste

Water Treatment Plant (WWTP) (Bruge et al., 2018). Cigarette butts, lollipop sticks and cotton swabs were found in higher proportions on coastal beaches compared to riverbanks, probably due to incivility. Indeed, it has been shown that cigarette butts may not be considered littering by many smokers (Rath et al., 2012). As for the former three items, marine activities-related items (rope, fishing nets, buoys, floats, lures/lines, packaging straps) were much more present on coastal beaches (24.9 ± 21.7 %) than on riverbanks (4.5 ± 9.8 %, mainly ropes and fishing nets related to recreational fishing activities), probably reflecting the importance of higher losses from professional and recreative fishing activities in the marine environment in France. Together with fishing gears lost at sea during storms, discarding damaged nets is a common practice that results in debris accumulations on coastal beaches or the seafloor, close to zones of high fishing activity such as the north and south-west of the Gulf of Lion, and in the South Brittany region (Galgani et al., 2000). Here, we observed that around 87 % of marine litter originated from land-based uses, which is in line with results compiled worldwide (GRID-Arendal, 2016).

Together with the numerous broken glass and sharp metal objects, sanitary and medical litter represented a smaller portion of all the riverbank debris (around 5 %), but higher than counted on coastal beaches (around 0.8 %). They represent potentially dangerous items to human health, together with other items that were found less frequently such as decomposing food leftovers (which could attract disease-carrying animals or harm small children upon accidental ingestion) and litter items containing chemicals (e.g. aerosol cans, batteries, paint containers) (Kiessling et al., 2019). Special awareness was encouraged in the support guide, in the protocol guide and in the photoguide of *Plastique à la Loupe* initiative, to prevent risks for schoolchildren participants during sampling and sorting.

Litter types classified as "others" represented a significant proportion of all debris (10.5 ± 16.9 and 10.8 ± 17.9 % on riverbanks and coastal beaches, respectively). They included car parts, electronics, oil drums, batteries, etc. Attribution to this category is part of the OSPAR data collections scheme (OSPAR, 2020) and we decided to retain these data in our analyses. It diminished our ability to identify the source of debris, and we recognize that there are challenges regarding the source allocations for this category; yet, it gives information on macrolitter fragmentation, since the corresponding items are still recognizable. Photographs could have been used to go deeper in one specific item, but it is time consuming.

Interestingly, macroplastic fragments (>2.5 cm) were the second dominant plastic type collected on riverbanks (23.2 ± 24.8 %) and it also dominated the plastic debris on coastal beaches (28.7 ± 24.5 %). Fragmented plastic is a direct result of weathering and photodegradation together with mechanical abrasion, resulting in surface embrittlement and microcracking, yielding particles that are carried into the closest river or the next WWTP by wind and runoff to rainwater collection systems and also by wind and wave action when transported to coastal beaches (Andrady, 2011; Chubarenko et al. 2020). They mainly consist of foam, hard and soft fragments, of which their original item identity remains unknown. Overall the detailed litter analysis provided more information to identify specific sources of (plastic) litter, and support policy-makers to implement prevention measures targeted at specific items (Kiessling et al., 2023).

Macro-, meso- and microplastics

To date, studies on microplastics mainly concerned ones floating at sea, while land-based studies of the stranded plastic litter on riverbanks and coastal beaches focused more on macro- and mesoplastics (Vriend et al., 2020). Very few data exist on the comparison of all plastic sizes, despite a growing interest on understanding the "plastic cycle" (Hoellein & Rochman, 2021). The *Plastique à la loupe* initiative offers the possibility of tracking the different plastic sizes in a large set of riverbanks and coastal beaches data. However, only a part of the collected samples could eventually help to identify the main sources of plastic pollution, i.e., identifiable macroplastics (representing 25.8 ± 29.7 % of all plastic size on riverbanks and 11.7 ± 19.0 % on coastal beaches) and microplastic pellets (representing 13.1 ± 22.4 % on riverbanks and 13.3 ± 19.5 % on coastal beaches). Most of the plastic items were non identifiable, resulting from the fragmentation of macroplastics into meso- and microplastics by breaking down in smaller size after exposure to ultraviolet light or mechanical forces once lost in the environment (Weinstein et al., 2016). Mesoplastics, originating from macroplastics fragmentation, represented a lower proportion of total plastic items on riverbanks than on coastal beaches (21.7 ± 25.9 % and 35.9 ± 22.0% respectively). However, it was difficult to conclude on any relation between the abundance of fragmented plastic debris and the distance to the upstream sources, because of the lack of sufficient number of sites per river. We observed that abundances of meso- and micro-plastics were the most strongly correlated in both riverbanks and coastal beaches.

Numbers of macro- and microplastics, and meso- and microplastics were positively correlated among each other on both riverbanks and coastal beaches. On coastal beaches, there was a higher correlation between the abundances of meso- and microplastics than between macro- and microplastics, which is congruent with previous studies (Lee et al., 2013). The evaluation of the number of mesoplastics was proposed to serve as a better proxy of microplastic pollution than macroplastics, thus helping easier surveys to identify hot spots of microplastic pollution in large geographical areas with limited resources (Lee et al., 2013). That was not the case on riverbanks, where correlations between meso- and microplastics gave the same values as between macro- and microplastics.

Microplastics represented a major part of plastics found on both riverbanks (47.0 ± 34.2 % of all plastic debris) and coastal beaches (45.7 ± 25.5 %). On riverbanks, a large proportion of microplastics were made of polystyrene (43 %), which is congruent with previous results showing that such floating plastics tend to beach sooner and accumulate on riverbanks or lake beaches due to wind effects (Corcoran, 2015). On coastal beaches, polyethylene dominated the microplastics (61.1 %), as classically found in seawaters (Erni-Cassola et al., 2019). Interestingly, we observed on both riverbanks and coastal beaches that a quarter of the microplastics were made of industrial pellets (primary microplastics, also known as virgin pellets or nurdles, recognized by their regular shape, usually cylindrical or ovoid), which form the feedstock of the plastics industry. These pellets enter the environment when they are spilled during transport, storage, loading and cleaning (Karlsson et al., 2018). Tracing plastic pellets back to the point of leakage is challenging since they can be transported kilometers away from the source. Previous observations identified plastic producers as direct sources of pellets in rivers in Austria, Germany and Sweden (Lechner and Ramler, 2015; Kiessling et al., 2021; Karlsson et al., 2018). Consistent patterns were also observed between the density of industrial pellets on coastal beaches and proximity to urban and industrial centers (Ryan et al. 2018), while spills during cargo loading and sea transport were considered other sources of pollution (Karlsson et al., 2018). The release or loss of plastic pellets at sea is prohibited for many years according to the MARPOL Protocol of 1978 and the Basel convention of 1989. Overly generous legislation has been criticized in the past, such as that of Austria that allowed an upper limit of industrial primary microplastic discharge from a production plant into the River Danube as 30 mg l^{-1} (equivalent to 259.2 kg per day during heavy rainfalls) (Lechner & Ramler, 2015). More recently, the Anti-waste and the circular economy (AGEC) law (No. 2020-105) adopted in 2020 in France requires sites producing, handling and transporting industrial plastic pellets to have equipment and procedures to prevent losses and leaks of industrial plastic pellets. Our results pave the way for further description on the effect of such legislation on the quantity of plastic granules in the French riverbanks and on coastal beaches.

Conclusion

Previous mathematical model based on estimations of river discharge and mismanaged plastic waste resulted in a total global riverine emission of plastics into the ocean in the range of million metric tons per year (Lebreton et al., 2017; Schmidt et al., 2017). A recent study based on in-depth statistical reanalysis of updated data on microplastics demonstrated that current river flux assessments are overestimated by two to three orders of magnitude (Weiss et al., 2021). Such discrepancy demonstrates the need for more field data to improve the modeling estimation to quantify land-based marine debris transport into the ocean. Monitoring all plastics sizes (macro-, meso-, and microplastics) both in riverine and marine environments is a prerequisite for understanding how plastic is transported and where it accumulates, as well as how fragmentation occurs. This study presents the power of the *Plastique à la loupe* initiative that follows the recent recommendation for harmonization of monitoring efforts on riverbanks (Vriend et al., 2020), as previously done for floating macroplastics through the RIMMEL project (González-Fernández & Hanke, 2017). It confirms the potential of using citizen science for relevant analysis of macro-, meso- and microplastic pollution on riverbanks and coastal beaches. Consistent and harmonized sampling and quantification methodologies are required to gather comparable data from the increasing number of scientific and citizen science initiatives around the world. This study presents the first two years data of the *Plastique à la loupe* initiative in France that is still running for the next coming years with the same protocol and with higher national coverage, both in metropolitan France and overseas territorial departments. Schoolchildren removed more than 55,980 pieces of plastic from riverbanks and coastal beaches in two years and prevented the formation of millions of micro- and nanoplastics through degradation over time (Ryan et al., 2020). The increasing number of classes per year (49 in 2019, 98 in 2020, ~ 300 in 2021 and 2022, ~ 350 in 2023, ~ 400 in 2024) in the *Plastique à la loupe* initiative will undoubtedly contribute to the incredibly valuable litter collecting by citizens over the world (European Environment Agency, 2018) and to detect meaningful trends in litter volumes over time on riverbanks and coastal beaches. Maintaining rigorous citizen science required considerable effort in terms of training, coordination and validation, which has necessitated ever-greater investment. Engagement went beyond riverbanks or beach clean-ups and instead the *Plastique à la loupe* initiative was used as a tool to bridge gaps between communities and scientists, while also raising awareness of the plastic pollution, increasing schoolchildren interest for science and inspiring solutions to act.

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Supplementary materials

Supplementary Table 1. Form for site description.

Year of sampling :		
The sampling site is located on the coastline or on a river bank?		
Specify the name of the river or sea associated with the sampling site?		
The participants	School name :	
	School municipality :	
	Grade level of the class :	
	Number of students :	
	Academy name :	
Study site	Study site name :	
	Study site code :	
	Study site region :	
	Study site municipality :	
Date and time	Collect date :	
	Hour :	
Sea tide	Tidal coefficient :	
	High tide hour :	
Collect	Number of person who participated to the collect :	
	Collect time (in h) :	
Sorting	Number of person who participated to the sorting :	
	Sorting time (in h) :	
Length of the beach or river bank studied section (in m) :		
Back of your study site (example: dunes/forest/road/…) :		
GPS coordinates of the beginning of the studied section :	Latitude (Decimal degrees) :	
	Longitude (Decimal degrees) :	
GPS coordinates of the end of the studied section :	Latitude (Decimal degrees) :	
	Longitude (Decimal degrees) :	
Collect date (day/ month/ year) :		/ /
Direction of prevailing currents : (during the sampling season)		
Direction of prevailing winds : (during the sampling season)		
How is your oriented your study site :		
What type of material covers the study site, in % coverage (e.g. 60% fine sand and 40% rocks)?	Rocks [20mm : 200mm]	
	Gravels [2mm : 20mm]	
	Coarse sands [0,2mm : 2mm]	
	Fine sands [20µm : 2mm]	
	Silt [2µm : 20µmm]	
	Clays [<2µm]	
Are there elements in the sea or in the river that are likely to influence the pollution (e.g. a dike that could trap waste)? If so, which ones?		

What are the 3 main uses of your site? (check the corresponding boxes, with an "x")	Walk (seasonal)	
	Walk (annual)	
	Swimming (seasonal)	
	Swimming (annual)	
	Water activity (seasonal)	
	Water activity (annual)	
	Fishing (seasonal)	
	Fishing (annual)	
	Other (please specify)	
Accessibility of the site by foot (walking distance required from the road): (check the corresponding box, with an "x")	Direct (<200m)	
	200m < d < 1km	
	1 km < d < 5 km	
	> 5km	
What is the nearest urban area?		
What is the size (number of inhabitants) of the nearest agglomeration?		
Distance of the agglomeration from the study site (km)?		
Is there any infrastructure in the immediate vicinity of your site?		
Are there any takeaway businesses in the immediate vicinity of your site?		
What is the distance between your site and the nearest shipping line (in km)?		
The nearest harbour	Distance (in km)	
	Name	
	Type of harbour (fishing/yachting…)	
	Harbour size	
The nearest estuary (for coastal sites)	Distance (in km)	
	Name	
	Name of the nearest river	
	Orientation of the estuary	
Landfills and wastewater discharges	Is your study site located near a landfill or a wastewater discharge?	
	Distance (in km)	
	Orientation	
Cleaning of the study site	Was a site cleanup performed within 15 days prior to sampling?	
	How often is your study site cleaned?	
	Which method is used (manual or mechanical)?	
	Who is in charge of the cleaning?	
	Is there a tidal tank near your site?	
Special weather events	Could particular events (heavy rain, flooding, storms, etc.) have influenced the quantity of waste on the site?	
	If yes, which ones? (heavy rain, flood, storm,…)	
	If so, how do you interpret this (more or less waste,…)?	
Additional comments:		

Supplementary Table 2. Table for macrolitter, meso- and microplastics referencing.

Macrolitter

Did the collect occured (Yes/No)	
If "yes": have you encountered the particular case where no waste was found? (Yes/No)	
If "no": possible comments :	

General information		
Total macro-waste collected	Weight of macro-waste collected (in kg)	
	Volume of macro-waste collected (in L)	
	Total number of macro-waste collected	

Code	Catégory	Use	Item	Nombre	Comments
26			Trap (fishing)		
114			Brand (shellfish, fish,...)		
27			Octopus pots		
115			Nets and pieces of net (< 50 cm)		
116			Nets and pieces of net (> 50 cm)		
331		**Related to fishing**	Tangled nets/cord/rope and string		
332			Perruque de chalut		
341			Plastic fish boxes		
342			Foamed polystyrene fish boxes		
35			Fishing line (angling)		
36			Light sticks (tubes with fluid)		
28			Oyster nets or mussel bags including plastic stoppers		
29		**Fish farming**	Oyster trays (round from oyster cultures)		
30			Plastic sheeting from mussel culture (Tahitians)		
31			Rope (diameter more than 1 cm)		
32		**Related to other marine activity**	String and cord (diameter less than 1 cm)		
37			Floats/Buoys		
41			Fibre glass		
25			Gloves (typical washing up gloves)		
113		**Clothing**	Gloves (industrial/professional gloves)		
42			Hard hats		
44			Shoes/sandals		
4			Drinks (bottles, containers and drums)		
5			Cleaner (bottles, containers and drums)		
061			Food containers incl. plastic fast food containers		
062			Food containers incl. Foamed polystyrene fast food containers		
7			Cosmetics (bottles & containers e.g. sun lotion, shampoo, shower gel, deodorant)		
8		**Container**	Engine oil containers and drums <50 cm		
9			Engine oil containers and drums >50 cm		
10			Jerry cans (square plastic containers with handle)		
11			Injection gun containers		
12			Other bottles, containers and drums		
13			Crates		
15			Caps/lids		
38			Buckets		
1			4/6-pack yokes		
2			Bags (e.g. shopping)		
3			Small plastic bags, e.g., freezer bags		
112			Plastic bag ends		
19	**Plastic**	**Bag/packaging**	Crisp/sweet packets		
23			Fertiliser/animal feed bags		
24			Mesh vegetable bags		
39			Strapping bands		
40			Industrial packaging, plastic sheeting		
121			Bagged dog faeces		
64			Cigarette butts		
19			Lolly sticks		
211			Plastic cup		
212		**Single-use plastic**	Foamed polystyrene cup		
22			Disposable cutlery		
22			Disposable plate and dish		
22			Straw		
22			Coffee stirrer		
97			Condoms		
98			Cotton bud sticks		
99			Sanitary towels/panty liners/backing strips		
100		**Sanitary**	Tampons and tampon applicators		
101			Toilet fresheners		
102			diapers		
102			Other sanitary items (please specify in comments)		
103			Containers / tubes		
104			Syringes		
105			Special covid19 crisis : Disposable mask (including elastics)		
105		**Medical**	Special covid19 crisis : Disposable glove		
105			Special covid19 crisis : Visor		
105			Special covid19 crisis : Bottle of hydroalcoholic solution		
105			Special covid19 crisis : other items related to the health crisis		
105			Other medical item (compress, bandage, dressing, etc.)		
14			Car parts		
16			Cigarette lighters		
17			Pens		
18		**Various**	Combs/hair brushes		
20			Toys & party poppers		
43			Shotgun cartridges		
481			Biomedia		
45			Foam sponge		
461			Plastic pieces 2,5 cm > < 50 cm		
471		**Fragment**	Plastic pieces > 50 cm		
462			Foamed polystyrene pieces 2,5 cm > < 50 cm		
472			Foamed polystyrene pieces > 50 cm		
48		**Other**	Other plastic items (please specify in comments)		

49	**Rubber**	**with plastic elements**	Balloons, including plastic valves, ribbons, strings etc.		
50		**Clothing**	Boots		
52		**Various**	Tyres and belts		
53		**Other**	Other rubber pieces (please specify in comments)		
54	**Textile**	**Clothing**	Clothing		
55		**Various**	Furnishing		
56			Sacking		
59		**Medical**	Special covid19 crisis : fabric mask		
59		**Other**	Other textiles (please specify in comments)		
60	**Paper/cardboard**	**Bag/packaging**	Bags		
61			Cardboard		
63			Cigarette packets		
118		**Container**	Cartons e.g. tetrapak (milk)		
62			Cartons e.g. tetrapak (other)		
65			Cups		
66		**Various**	Newspapers & magazines		
67		**Other**	Other paper items (please specify in comments)		
68	**Wood (machined, worked)**	**Container**	Corks		
70			Crates		
69		**Bag/packaging**	Pallets		
71		**Related to fishing**	Crab/lobster pots		
119			Fish boxes		
72		**Divers**	Ice lolly sticks / chip forks		
73			Paint brushes		
74		**Autre**	Other wood < 50 cm (please specify in comments)		
75			Other wood > 50 cm (please specify in comments)		
76	**Metal**	**Container**	Aerosol/Spray cans		
77			Bottle caps		
78			Drink cans		
81			Foil wrappers		
82			Food cans		
84			Oil drums		
86			Paint tins		
87		**Related to fishing**	Lobster/crab pots and tops		
80			Fishing weights		
83		**Various**	Industrial scrap		
120			Disposable BBQ's		
79			Electric appliances		
88			Wire, wire mesh, barbed wire		
89		**Other**	Other metal pieces < 50 cm (please specify in comments)		
90			Other metal pieces < 50 cm (please specify in comments)		
96	**Ceramics/pottery**	**Various**	Other ceramic/pottery items (please specify in comments)		
91	**Glass**	**Various**	Bottles (including fragments)		
92			Light bulbs/tubes		
93			Other glass items (please specify in comments)		

Mesoplastics

ıse where no waste was found? (Yes/No)	
site (Yes/No)	

Type	Image	Color	Texture	Number in sample 1	Number in sample 2	Number in sample 3	Total
ed fragment (aged, l, damaged by time)		Black	Opaque				
			Transparent				
		White	Opaque				
			Transparent				
		Red	Opaque				
			Transparent				
		Blue	Opaque				
			Transparent				
		Yellow	Opaque				
			Transparent				
		Green	Opaque				
			Transparent				
		Other					
r fragment (broken, sharp, rough)		Black	Opaque				
			Transparent				
		White	Opaque				
			Transparent				
		Red	Opaque				
			Transparent				
		Blue	Opaque				
			Transparent				
		Yellow	Opaque				
			Transparent				
		Green	Opaque				
			Transparent				
		Other					
Film fragment		Black	Opaque				
			Transparent				
		White	Opaque				
			Transparent				
		Red	Opaque				
			Transparent				
		Blue	Opaque				
			Transparent				
		Yellow	Opaque				
			Transparent				
		Green	Opaque				
			Transparent				
		Other					
iber fragment		Black	Opaque				
			Transparent				
		White	Opaque				
			Transparent				
		Red	Opaque				
			Transparent				
		Blue	Opaque				
			Transparent				
		Yellow	Opaque				
			Transparent				
		Green	Opaque				
			Transparent				
		Other					
ge foam fragment		Black	Opaque				
			Transparent				
		White	Opaque				
			Transparent				
		Red	Opaque				
			Transparent				
		Blue	Opaque				
			Transparent				
		Yellow	Opaque				
			Transparent				
		Green	Opaque				

Microplastics

ollect occured (Yes/No)	
ssible comments :	
commentaires éventuels :	
a visible river/sea at the study site (Yes/No)	

Category	Type	Image	Color	Texture	Number in sample 1	Number in sample 2	Number in sample 3	Total	Comments
Hard plastic	Pellets		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
	Degraded fragment (aged, rounded, damaged by time)		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
	Angular fragment (broken, sharp, rough)		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
Film	Film fragment		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
Fiber	Fiber fragment		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
Sponge foam	Sponge foam fragmen		Black	Opaque					
				Transparent					
			White	Opaque					
				Transparent					
			Red	Opaque					
				Transparent					
			Blue	Opaque					
				Transparent					
			Yellow	Opaque					
				Transparent					
			Green	Opaque					
				Transparent					
			Other						
Foamed polystyrene	Foamed polystyrene fragment and bead		White						
			Other						

Supplementary Table 3. Proportions of types of macrolitter for 100 linear meters in riverbanks (n = 81 sites) and coastal beaches (n = 66 sites) (SD: standard deviation, Freq: frequence of occurrence among all the sampling sites).

	Riverbanks				Coastal beaches			
	Mean (%)	SD	Freq	Rank	Mean	SD	Freq	Rank
Plastic	55.1	30.4	96.3	1	79.9	22.37	100	1
Glass	16.3	20.8	73.2	2	8.36	17.78	77.3	2
Metal	13.0	15.3	78.0	3	2.67	4.46	74.2	4
Paper and cardboard	5.3	9.1	50.0	4	1.24	2.24	66.7	7
Ceramics	2.7	7.9	30.5	5	1.43	3.85	39.4	6
Textile	2.7	5.0	51.2	6	1.07	2.59	59.1	8
Wood	1.5	4.5	31.7	7	3.03	6.74	69.7	3
Rubber	0.9	2.7	28.0	8	2.23	4.01	75.8	5

Supplementary Table 4. Types and proportion of single-use and other plastics on riverbanks and marine beaches (SD: standard deviation, Freq: frequence of occurrence among all the sampling sites) for all categories (top) and for single used plastics (bottom).

	Riverbanks				Coastal beaches			
	Mean (%)	SD	Freq	Rank	Mean (%)	SD	Freq	Rank
Single use plastics	43.3	26.2	90.2	1	27.6	17.4	100.0	2
Fragments	23.2	24.8	65.9	2	28.7	24.5	92.4	1
Bags. wrappers	11.1	16.5	61.0	3	5.3	7.9	80.3	5
Other items	10.5	16.9	63.4	4	10.8	17.9	90.9	4
Marine activities	4.5	9.7	31.7	5	24.9	21.7	95.5	3
Sanitary	3.0	10.1	30.5	6	0.2	0.5	33.3	8
Medical	2.7	11.9	26.8	7	0.6	1.2	59.1	7
Containers	1.2	2.6	30.5	8	1.3	4.1	50.0	6
Clothing	0.5	1.8	17.1	9	0.6	2.5	30.3	7

	Riverbanks		Coastal beaches	
	Mean (%)	SD	Mean (%)	SD
Thin wrappers	20.51	28.06	18.67	19.74
Caps	15.68	23.07	24.09	23.21
Cigaret butt	12.61	24.04	17.19	21.61
Drink container	12.29	18.84	6.35	15.28

Shopping bags	8.2	19.29	3.94	10.88
Lollipop stick	5.8	16.77	11.22	13
Plastic cup	4.63	12.56	4.27	13.62
Food container	4.48	9.46	1.22	3.85
Sanitary napkin	2.75	9.88	0.05	0.31
Straw	1.25	2.97	2.89	4.88
Cotton swab	1.08	4.72	6.51	15.2
Others (*see below in italic*)	2.07		3.6	
Styrofoam food container	*0.7*	*2.83*	*1.43*	*5.99*
Styrofoam cup	*0.54*	*3.22*	*0.54*	*3.15*
Tampon and applicator	*0.33*	*1.14*	*0.45*	*1.1*
Disposable plates	*0.21*	*1.27*	*0.51*	*2.63*
Stirrer	*0.18*	*0.97*	*0.11*	*0.63*
Disposable cutlery	*0.11*	*0.76*	*0.55*	*1.36*

Supplementary Table 5. Size fractions of plastic litter for each size category for all riverbanks (n=67) and coastal beaches (n=51).

	Riverbanks		Coastal beaches	
	Mean (%)	SD	Mean (%)	SD
Macro Recognizable	25.79	29.69	11.75	19.04
Macro Fragmented	5.47	8.4	6.61	13.64
Mesoplastics	21.69	25.92	35.89	21.99
Micro Fragmented	33.96	28.29	32.44	21.84
Micro Pellets	13.09	22.4	13.3	19.54

Supplementary Table 6. Comparison of sampling, sorting and data acquisition between experienced scientists and schoolchildren on the same sampling site. N= number of items. Particular attention was paid to the percentage error (% error) of sampled elements of MP size (N sampled), compared to elements confirmed as MPs by FTIR.

Site ID	PAL_20-21_No_7		PAL_20-21_Na_5		PAL_20-21_Ren_2		PAL_20-21_Bo_1		PAL_20-21_Ren_1		PAL_20_21_Co_6	
River/coastal beaches	Riverbank (Seine)		Riverbank (Loire)		Riverbank (Odet)		Riverbank (Garonne)		Coastal (Atlantic)		Coastal (Med)	
GPS coodinates	49.31039N 1.22767E		47.37092N 0.67496W		47.97250N 4.09895W		45.57583N 0.98250W		48.40722N 4.77701W		42.6776N 9.30010E	
Transect lenght (m)	10 m		18 m		24 m		50 m		20 m		50 m	
	Scientists	School	Scientists	School	Scientists	School	Scientists	School	Scientists	School	Scientists	School
Macrodebris (N)	218	218	42	42	151	150	346	365	384	387	476	480
Macrodebris (Weight - in kg)	3.2	3.2	1.1	1.1	18.5	18.5	5.4	5.4	1.1	1.1	2.3	2.3
Mesoplastics (N)	157	153	2	2	38	38	22	22	152	151	48	48
Microplastics (N sampled)	85	94	23	31	75	75	68	74	94	96	84	84
Microplastics (N confirmed)	85	85	23	23	74	74	68	68	94	96	83	83
Microplastics (% error)	0.0	9.5	0.0	25.8	1.3	1.3	0.0	8.1	0.0	0.0	1.1	1.1

Supplementary Figure 1. Linear correlation between the numbers of macro-, meso- and microplastics on riverbanks and coastal beaches.