LETTER

Riverbank macrolitter in the Dutch Rhine–Meuse delta

Tim van Emmerik, Caspar Roebroek, Winnie de Winter, Paul Vriend, Marijke Boonstra and Merijn Hougee

1 Hydrology and Quantitative Water Management Group, Wageningen University, Wageningen, The Netherlands
2 Stichting De Noordzee, Utrecht, The Netherlands
E-mail: tim.vanemmerik@wur.nl

Keywords: macroplastic, plastic pollution, hydrology, river plastic, OSPAR, observations, monitoring

Supplementary material for this article is available online

Abstract

Anthropogenic litter in aquatic ecosystems negatively impacts ecosystems, species and economic activities. Rivers play a key role in transporting land-based waste towards the ocean. A large portion however is retained within river basins, for example in the estuary, in sediments and on the riverbanks. To effectively identify litter sources, sinks and transport mechanisms, reliable data are crucial. Furthermore, such data can support optimizing litter prevention mitigation and clean-up efforts. This paper presents the results of a 2-year monitoring campaign focused on riverbank macrolitter (>0.5 cm) in the Dutch Rhine–Meuse delta. Between 2017 and 2019, volunteers sampled 152,415 litter items at 212 unique locations. All items were categorized based on the River-OSPAR method (based on the OSPAR beach litter guidelines), which includes 110 specific item categories across ten parent categories. The median litter density was 2060 items/km, and the most observed items were foam, hard, and soft plastic fragments (55.8%). Plastic bottles, food wrappings and packaging, caps, lids and cotton swabs were the most abundant specific items. The litter density and most abundant items vary considerably between rivers, along the river, and over time. For both rivers however, the highest litter density values were found at the Belgian (Meuse) and German (Rhine) borders, and at the Biesbosch National Park, the most downstream location. With this paper, we aim to provide a first scientific overview of the abundance, top item categories, and spatiotemporal variation of anthropogenic litter on riverbanks in the Dutch Rhine–Meuse delta. In addition, we evaluate the used River-OSPAR method and provide suggestions for future implementation in (inter)national long-term monitoring strategies. The results can be used by scientists and policy-makers for future litter monitoring, prevention and clean-up strategies.

1. Introduction

Macrolitter in aquatic environments is an emerging environmental risk, as it may negatively impact ecosystems, endangers aquatic species, and causes economic damage (Thompson et al 2004, Mcilgorm et al 2011, O Conchubhair et al, 2019). Rivers are assumed to play a crucial role in transporting land-based plastic waste to the world’s oceans (Schmidt et al 2017). However, rivers and their ecosystems are also directly affected by macrolitter (van Emmerik and Schwarz 2020). To better quantify global plastic pollution transport and to effectively reduce sources and risks, a thorough understanding of sources, transport, fate and effects of riverine plastic debris is crucial. Litter items have been observed in all compartments of the river system. Depending on the plastic item polymer type, state of degradation and antecedent hydrological regime, items can be mobile in the water column or (temporarily) accumulated. Riverine plastic transport consists of floating items at the surface, suspended plastics along the water column and transport over the riverbed. Accumulation occurs in biota, sediment, riparian vegetation and on riverbanks. Known sources include sewage outlets from wastewater treatment plants (Mintenig et al 2020), recreational activities in the vicinity of riversides (Gasperi et al 2014), and areas with high urban activities (Carson et al 2013). Land-based macrolitter enters river systems through either natural transport
processes or through direct dumping. Natural transport can be caused by wind or rainfall-driven surface runoff (Bruge et al. 2018). Direct dumping can include illegal dumping sites (Rech et al. 2015, Mihai 2018) and unintentional disposal at recreational locations, such as river banks (Kiessling et al. 2019). Once in a river, litter transport and accumulation are influenced by hydrological (water level, flow velocity, discharge) and anthropogenic factors (hydraulic infrastructure, clean-up activities, navigation). Riverbank litter monitoring programs are essential for the reduction of riverine litter, as they provide the data required to identify and characterize litter items, their sources and variation over time and space. In contrast to floating, suspended or sediment litter, riverbank litter can be monitored with simple and cost-effective methods. This makes riverbank litter monitoring attractive for first-order estimates or riverine litter abundance through citizen science data collection strategies. Many riverbank monitoring efforts are inspired by beach litter monitoring methods (Vriend et al. 2020b).

For beach litter, monitoring has been standardized in the OSPAR guidelines for beach litter monitoring (OSPAR Commission 2010). OSPAR refers to the Oslo and Paris conventions, which ultimately resulted in the Convention for the Protection of the Marine Environment of the North-East Atlantic (or OSPAR convention). In recent years various initiatives have started to monitor litter on riverbanks, to identify sources and sinks, and quantify the spatiotemporal variation. One of the first attempts to quantify sources of riverine litter was done by Williams and Simmons (1999), who measured litter items along the banks of the River Taff in Wales, UK. Several following efforts have been collecting data using citizen science, as that allows data collection over large areas and timespans (Kiessling et al. 2019). Chilean riverbanks have been monitored by groups of scientists and schoolchildren, and actually discovered several illegal dumping sites along the river (Rech et al. 2015). More recently, Kiessling et al. (2019) reported the firsts results of the Plastic Pirates project, covering 250 sampling spots along all German main rivers (Rhine, Danube, Weser, Elbe). In the Netherlands, the Schone Rivieren (English: Clean Rivers) riverbank litter monitoring program has been launched in 2017. This project adjusted the existing OSPAR beach litter monitoring protocol for better applicability to the Dutch rivers (River-OSPAR method). Data on plastic litter count and category for 100-m riverbank segments are collected twice per year by trained volunteers. Between 2017 and 2019, data have been collected at over 200 locations along the Dutch part of the Meuse and Rhine rivers. In this paper, we present an analysis of the first 2 years of large-scale riverbank macro-litter data collection in the Netherlands. This paper aims to (1) discuss the River-OSPAR method for riverbank litter monitoring, (2) provide insights most abundant litter items and spatiotemporal variation of litter in the Rhine–Meuse delta, and (3) evaluate the applicability of the River-OSPAR method for long-term data collection in rivers in the Netherlands and beyond.

## 2. Methods

### 2.1. River-OSPAR protocol

The River-OSPAR protocol was developed by Stichting De Noordzee (SDN, English: North Sea Foundation) as a way to involve citizens in large-scale data collection of anthropogenic litter deposited on Dutch riverbanks (Schone Rivieren 2017). It is based on the protocol for beach litter identification developed by OSPAR commission. SDN has adapted the protocol to maximize its applicability to citizen science data collection on Dutch riverbanks. The River-OSPAR method is currently being applied at 212 unique locations spread along the Meuse and Rhine rivers in the Netherlands since 2017.

Each monitoring location is sampled twice per year, once in spring and once in fall. For both sampling rounds, a 1-month period is defined during which all volunteers are requested to sample their assigned locations. These periods are selected to avoid hindrance of data collection by riverbank vegetation, increase the likelihood of measurements after a peak discharge, and prevent disturbing the breeding sites of birds. The 1-month period is generally scheduled in September/October (fall) and February/March (spring), but can be subject to change based on weather conditions and vegetation growth.

The locations of the River-OSPAR analysis have been selected by SDN based on four criteria. First, the measuring location should have a stretch of riverbank or a sandy beach that can be submerged with higher water levels. Second, the location should be legally accessible by the volunteers (e.g. no fences or private property). Third, the locations should be well distributed along the length of the river and should be representative for the land uses along the river (e.g. locations should be in natural, industrial, and urban areas etc.). Last, sluices, weirs and pumping stations in the vicinity of the location should be considered since those can influence the litter present in the riverine environment.

Data are collected on 100 m long stretches of riverbank parallel to the waterline (see figure 1). The width of the sampling area is defined as the distance from the waterline (interface of water and bank) and the high water line, with a maximum of 25 m from the waterline. The high water line is recognized by debris (e.g. litter, organic debris) deposited during the last high water peak. Two types of measurements are done: macrolitter and microlitter. For the macrolitter sampling, all litter items that are visible from standing height are collected within the entire sampling area. For the microlitter, a quadrant of 50 × 50 cm is placed within the sampling area.
close to the deposition line (parallel to the waterline). Within this subarea, the upper 3 cm of soil is collected and all remaining litter items are counted, collected and sent to SDN for further analysis. For this paper we only analyzed the macrolitter data. The microlitter samples will be processed and analyzed in future research. The collected litter is classified in predefined categories. The River-OSPAR method identifies nine parent categories (plastic, rubber, textile, paper, wood, metal, glass, sanitary and medical items) and 110 specific item categories, and also offers an option to write down unlisted items. Unlisted items that have been found frequently (>30 times) are added to the item list for future measurement rounds. Volunteers are trained by the Institute for Nature Education and Sustainability (IVN) and the North Sea Foundation to effectively apply the River-OSPAR protocol. The training comprises a full day of theoretical and practical (field) instructions. Once they have received this training, they will be assigned a measurement location. Feedback sessions with volunteers are organized to discuss and validate results of the monitoring.

2.2. Monitoring campaign 2017–2019

The *Schone Rivieren* project collected data on riversbanks of two rivers: the Rhine and the Meuse. The Rhine is approximately 1200 km long and flows through Switzerland, France, Germany Belgium, and discharges in the North Sea through the Netherlands. Its catchment area includes densely populated areas such as the Randstad in the Netherlands, and heavily industrialized areas such as the Ruhr area in Germany and the Port of Rotterdam in the Netherlands. The Meuse is approximately 900 km long and flows through France, Belgium, and draining in the North Sea in the Netherlands.

The study area was defined as the length of both rivers from the point of entry into the Netherlands until the Biesbosch National Park (see figure 2). A total stretch of 153 km of the Rhine was sampled at 76 unique measuring locations, along two distributaries: the Waal (72 locations) and Nederrijn (4 locations). The uppermost measuring location was located at 22 km downstream from the point of entry of the Rhine in the Netherlands. The most downstream measuring location at the Rhine was located at 155 km away from the entry point. For the Meuse, a total stretch of 277 km was sampled at 136 unique measuring locations. The uppermost measuring location was located at 0.1 km downstream from the point of entry of the Meuse in the Netherlands. The most downstream measuring location was located at 277 km away from point of entry of the river to the Netherlands.

Data was collected during four measurement rounds between 2017 and 2019. Two rounds were done in Fall (September–October) and two in Spring (February–March), see table 1. The number of locations depended on the participating volunteers, grouped in pairs. Each pair of volunteers was assigned a location to sample within the sampling month. It was up to the volunteers to determine the exact date of sampling.

2.3. Data analysis

The database with macrolitter data was post-processed by normalizing the data over space. Observations were normalized and expressed in items/km, for better comparison of values along the river length. The River-OSPAR checklist is regularly updated based on adding frequently found (n > 30) unlisted items, and removing listed items that are never found. Around 15% of the original list has been added or removed since the beginning of the project. Note that in this study we only focus on the macrolitter data.

To analyze spatial and temporal variation, the data were lumped in space and time. To analyze the spatial variation, the data were averaged over time for both the total measurement period (four measurement rounds) and for the fall and spring round separately (two rounds each). For the temporal variation, data were lumped over space, for all rivers combined and for each of the three Meuse, Waal and Nederrijn separately.

The litter composition was further analyzed by aggregating categories into the ten parent categories (plastic, granulate (nurdles), rubber, textile, paper, wood, metal, glass, sanitary and medical items). An additional analysis was done focused on plastic polymer composition, for which an eight-category item-based classification was used based on the CrowdWater classification protocol (van Emmerik *et al*).
Figure 2. Overview of all measurement locations, including the number of samples per location and the locations of the reference measurements.

Table 1. Overview of the measured locations per round for the Meuse, Waal and Nederrijn rivers.

| Round | Period         | Meuse | Waal | Nederrijn | Total |
|-------|----------------|-------|------|-----------|-------|
| 1     | 15 Sep–15 Oct 2017 | 3     | 14   | 0         | 17    |
| 2     | 15 Feb–15 Mar 2018 | 84    | 37   | 1         | 122   |
| 3     | 15 Sep–15 Oct 2018 | 51    | 31   | 1         | 83    |
| 4     | 15 Feb–15 Mar 2019 | 108   | 56   | 5         | 169   |
| **Total** |                       | 246   | 138  | 7         | 391   |
| **Total unique locations** |                       | 136   | 72   | 4         | 212   |
| **Total reference locations** |                       | 6     | 4    | 0         | 10    |

2020). All items assigned to a polymer category based on their common use: polyethylene terephthalate (PET: bottles), polystyrene (PS: cutlery, cups, plates), expanded polystyrene (EPS: foams, food boxes), hard polyolefin (POhard: bottle caps, containers, rigid items), Soft polyolefin (POsoft: bags, foils), multilayer (combined materials, food wrappings and packaging), other plastic, and no plastic. Note that polyolefins include polyethylene (PE) and polypropylene (PP). A first-order polymer classification gives additional insights in the build-up of litter, and its potential sources or sinks.
3. Results

3.1. Top items and categories
Between 2017 and 2019, a total of 152,415 items were sampled on the Meuse (n = 113,812) and Rhine (Waal: n = 31,324; Nederrijn: n = 7,279) riverbanks. The majority of items was identified as foam, hard and soft fragments, both in total (55.8%) and in the individual rivers (Meuse: 59.2%, Waal: 37.4%, Nederrijn: 83.1%). The most abundant specific items featuring in the top 20 (84.4% of total) are food wrappings, caps and lids, and rope. Specific items featuring in the top 10 of Meuse (76.2% of total), Waal (57.9% of total), and Nederrijn (90.8% of total) include (flower) pots, cigarette filters and cotton swabs. A complete overview of the total top 20 and the top 5...
Figure 5. Spatial distribution of litter item density [item km$^{-1}$] for each kilometer riverbank along the Meuse, Waal (Rhine) and Nederrijn (Rhine) rivers.

10 for the Meuse, Waal and Nederrijn is presented in figure 3. When aggregated to the eight plastic categories, 85.1% of the total items were identified as plastics (figure 4). Plastic made up a larger share in the Meuse (88.6%) and Nederrijn (93.5%) compared to the Waal (70.3%). The most abundant plastic categories considering all sampled items were POsoft (33.4%), EPS (17.4%) and POhard (16.1%), but changed per river. POsoft varied between 17.2% (Nederrijn) and 34.8% (Meuse), EPS between 6.9% (Waal) and 64.3% (Nederrijn), and POhard between 7.2% (Nederrijn) and 16.9% (Meuse). PET is in all cases the least abundant plastic (1.7%). In the Waal, other abundant parent categories were glass (8.1%), sanitary items (5.8%) metal (5.7%) and glass (5.4%). For the Meuse and Nederrijn, no other parent category has a share larger than 4.0%. A complete summary of the absolute and relative abundance of each parent category is presented in supplementary table 1 (available online at https://stacks.iop.org/ERL/15/104087/mmedia).

3.2. Variation over space and time
The median litter density for all measurements combined is 2060 items/km. The highest litter river specific median density was measured for the Nederrijn (3990 items/km), followed by the Meuse (2430 items/km) and the Waal (1550 items/km). The spatial variation of the time-averaged litter density is shown in figure 5. For the Meuse, the highest litter densities were measured at the most upstream locations and most downstream location. At the upstream locations, the high values were measured between the city of Maastricht and the Belgian border.
Downstream, the high values were measured around the Biesbosch National Park. The Waal showed a similar pattern, with also the highest values upstream between Nijmegen and the German border, and downstream around the Biesbosch National Park.

For all rivers combined, the space-averaged median litter density is higher during spring (2430 items/km) than during fall (1060 items/km). The difference is the largest for the Nederrijn (4260 items/km vs 2170 items/km), followed by the Meuse (2830 items/km vs 845 items/km) and the Waal (1660 items/km vs 1140 items/km). In all cases, the mean item densities measured in spring were larger than the item densities measured in the preceding fall.

4. Discussion

4.1. Top litter items compared

The top 20 for all sampled items and top 10 for the individual rivers mainly consist of foam, hard and soft fragments (55.8% of total), of which their original item identity remains unknown. This is in line with the findings from the European ‘Riverine and Marine floating macro litter Monitoring and Modeling of Environmental Loading (RIMMEL)’ project, which observed and identified 8599 floating macrolitter items in 53 European rivers from 2016 to 2017 (González-Fernández and Hanke 2018). The overall most common items were also fragments (43.2%). In the North-East Atlantic region, including the Meuse, Elbe, Weser and Ems, the share of fragments was even higher (70.2%). Also in the Rhône (France) and Tiber (Italy), Llobregat (Spain) rivers, fragments were the most abundant floating litter items (Crosti et al 2018, Castro-Jiménez et al 2019, Schirinzi et al 2020). There is also overlap for the most common specific items, such as bottles, food wrapping and packaging. In contrast to the RIMMEL project, plastic bags were not found among the most common items on the Rhine–Meuse delta riverbanks. This may be explained by a higher fragmentation rate of riverbank plastics compared to floating plastics. Several previous studies have suggested that higher residence times of plastics in river systems may result in fragmentation of macroplastics, due to increased exposure to wind, water, and abrasion by sediment. The residence time of macroplastics can be increased through complex tidal dynamics (bidirectional flow leads to low net export into the ocean), or (temporary) storage of macroplastics on riverbanks or in riparian vegetation (Browne et al 2010, Ivar Do Sul et al 2014, Tramoy et al 2020). Bag fragments may have therefore been counted as one of the soft fragment categories. The relative low abundance of bags may also be the consequence of government discouragement (including bans) of using single-use plastic bags in recent years. The results also show similarities to the sampled riverbank litter on the Seine (France) riverbank. Tramoy et al (2019) analyzed 20,259 items sampled between 1965 and 2010. Nurdles (pellets) and fragments combined accounted for 88% of the items.

4.2. Top item polymer categories

With respect to the plastic polymer categories, the abundance of POhard and EPS fit the available global data on floating macroplastics, as these polymer categories are globally the most abundant (van Calcar and van Emmerik 2019). However, previous measurements of floating plastics in the Rhône showed a larger portion of POhard (Vriend et al 2020a). For the Waal (Rhine), this category is indeed larger than for the Meuse and Nederrijn. The total plastic fraction of the litter items in the Meuse (88.6%) and Nederrijn (93.5%) is relatively high compared to other rivers. In the Waal the plastic fraction was somewhat lower (70.3%). Schönlein-Arget et al (2020) identified only 40%–60% of the sampled riverbank items as plastics in the Elbe, Weser and Ems rivers (Germany). On riverbanks of the more upstream (German) regions of the Rhine catchment, the plastic fraction was even lower. Of the 3390 sampled items between 2016 and 2017, only around 30% was plastic (Kiessling et al 2019). In the case of floating litter in the Rhône, Tiber, Llobregat and Besos, 49.3% to 77% was identified as plastic (Crosti et al 2018, Castro-Jiménez et al 2019, Schirinzi et al 2020). The variation may be explained by natural variation between the river systems, but also by the used method and total amount of sampled items. Most interesting is the comparison with the upstream riverbank measurements for the Rhine, as the difference is quite large within the same river system (30% upstream vs 74.3–95.4% downstream). Kiessling et al (2019) used data collected by schoolchildren. A factor that may explain the low plastic fraction is the higher minimum detectable item size. Given that in our dataset most items were (small) fragments, these may not have been detected by the schoolchildren.

4.3. Missing the mass

Detailed classification of litter items is often justified with the assumption that such information yields insights in their potential sources. For fragments this is more complex, as it cannot be directly related to a specific item. The great abundance of EPS (foam) fragments in the Rhine–Meuse delta does demonstrate the problematic issue of plastic leakage into nature. Especially foam items are rather brittle and fragment into smaller pieces, that can in turn more easily be ingested by (aquatic) fauna. In other rivers, as much as 50% of the sampled items were identified as foam fragments (van Emmerik et al 2019). Because foam fragments are often white colored, they are relatively easy to detect, even at smaller sizes. Measuring the abundance only in terms of item count is only one of the important metrics. Others relevant metrics
include mass and size distributions, especially for specific risk assessments. For example, the likelihood of ingestion is related to the size, urban drainage infrastructure is mainly blocked by large items, and chemical leaching and adsorption strongly depends on the total item surface rather than mass (Jáms et al 2020; Honig et al 2020, van Emmerik and Schwarz 2020). As EPS easily fragments, a high number of small fragments may have the same mass as a single large item. We therefore encourage to also measure the mass of items collected during future measurement campaigns, to determine the mass distribution statistics of item and polymer categories. These statistics can in turn be used to estimate the litter density in terms of mass, rather than only item count. Expressing plastic stocks and fluxes in mass makes it also easier to link these to estimates of floating plastic transport, or production, consumption and recycling statistics.

4.4. Improving the method

Using the River-OSPAR protocol to quantify riverbank litter along Dutch rivers has yielded a large dataset of unprecedented detail. With over 100 specific items and ten parent categories, the data give a nuanced overview of the abundance of litter items in river systems. Such information can be directly used by policy-makers to implement effective policies to tackle plastic pollution by its source. The temporal resolution of the dataset is still insufficient for long-term analysis of seasonality and temporal trends, but this will be overcome as the monitoring efforts continue. As no multi-year datasets exist, it is not yet clear how many years of data will allow meaningful and statistically significant seasonal and temporal trend analysis. Increasing the sampling frequency may give additional insights in the seasonality of riverbank litter. Currently, sampling is done twice a year. Increased measurement frequency may imply that less locations can be measured per monitoring round. To determine what locations should be skipped depends on location characteristics, such as vegetation, type of riverbank and terrain gradient. Such trade-offs are however strongly dependent on the available resources and volunteers.

4.5. Outlook for future riverbank litter monitoring

We have identified several ways forward for riverbank litter monitoring in the Dutch Rhine–Meuse delta. First, we recommend to include the monitoring of floating litter items at several locations along the Rhine and Meuse rivers. Floating litter items are an important component of total litter transport from source to sink, and may give additional insights in spatiotemporal distribution of litter items through river basins. Floating litter can be monitored using cost-effective methods, such as visual counting from bridges (Gonzalez-Fernandez & Hanke 2017, van Emmerik et al 2018). Here, observers stand on bridges and count all floating litter items for a period of 2–30 min. Binoculars can be used to also detect smaller items. In general, the minimum detectable item size is 1 cm, with is the same order of magnitude as the River-OSPAR protocol. Second, new advanced technology can be used to monitor riverbank litter. Several studies demonstrated the potential of using unmanned aerial vehicles (UAV) to monitor litter on beaches and riverbanks (Martin et al 2018, Geraeds et al 2019). UAV imagery can be used to complement the existing measurement locations, and support the selection of new River-OSPAR monitoring locations. Finally, the data shows there is a need for joint data collection with the other countries in the Rhine and Meuse river basins. Harmonized data collection facilitates comparing data from the river spring to river mouth, and allows for better identification of potential litter sources and sinks.

5. Conclusions

Between 2017 and 2019, 152 415 litter items were sampled on riverbanks in the Dutch Rhine–Meuse delta. Based on all measurement locations, a median litter density of 2060 items/km was measured. Plastic fragments (foam, hard, soft) were the most observed item (55.8%). The litter densities and litter category composition does show considerable variation between the observed rivers, which may be influenced by local and remote (upstream) litter sources, waste infrastructure and driving transport mechanisms. Plastic bottles, food wrappings and packaging, caps, lids and cotton swabs were the most abundant specific items observed in the Rhine–Meuse delta. Data on the most frequently observed items may be used to identify specific sources of (plastic) litter, and support policy-makers to implement prevention measures targeted at specific items.

The litter density was higher on the Meuse riverbanks compared to the Rhine. Both rivers show peak item densities at the borders with Belgium and Germany, respectively. Another density peak was observed around the Biesbosch National Park, a nature reserve in the tidal zone where distributions of both rivers meet. The observations support the assumptions that this area is a (temporary) sink of anthropogenic litter, which negatively impacts species and the ecosystem. The data suggest that litter item density inhibits some seasonality, with increased density in the spring. The spring sampling period is generally preceded by periods of increased river discharge in the Rhine and Meuse, which potentially mobilizes additional litter from upstream sources.

The River-OSPAR method provides data on litter density and category with unprecedented detail. These data, especially when collected for extended time periods, can be used to identify litter sources, sinks and driving transport mechanisms. Furthermore, they give insights in the litter distribution over
tions, some volunteer teams can also monitor floating items at strategic locations, to relate changes in riverbank litter to active litter transport. Additional UAV surveys may be included to optimize measurement location selection.

With this paper, we aim to provide a first overview of the abundance, top item categories, and spatiotemporal variation of anthropogenic litter on riverbanks in the Dutch Rhine–Meuse delta. Furthermore, we discuss several suggestions to further optimize future long-term riverbank monitoring efforts. The paper demonstrates the added value of using a detailed monitoring protocol, but also emphasizes the importance of harmonized data collection across country borders and long-term data series.

Acknowledgments

We thank all the volunteers of the Clean River Project (Schone Rivieren) who collected and categorized the more than one hundred thousand (and counting) litter items. We also thank the Schone Rivieren project partners: Instituut voor Natuureducatie (IVN) and the Plastic Soup Foundation.

Author contributions

Conceptualization: TvE, CR, WdW, PV; Methodology: TvE, CR, MG; Formal Analysis: TvE; Investigation: TvE, CR; Resources: WdW, MB; Data Curation: WdW, MB, MG; Writing—original draft preparation: TvE; Writing—review and editing: all authors; Visualization: CR, TvE; Project administration: TvE; Funding acquisition: TVE

Conflict of interest

WdW, MB and MH are employed by Stichting De Noordzee. All other authors declare no conflict of interest.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).

Funding

This research was partly funded by the Dutch Ministry of Infrastructure and Water Management, Directorate-General for Public Works and Water Management (Rijkswaterstaat). The Clean River project is financed by Gieskes Strijbis Foundation, Adessium Foundation and the National Postcode Lottery Netherlands.

ORCID iDs

Tim van Emmerik https://orcid.org/0000-0002-4773-9107
Caspar Roebroek https://orcid.org/0000-0002-1733-0845
Paul Vriend https://orcid.org/0000-0002-4008-8612

References

Brown M A, Galloway T S and Thompson R C 2010 Spatial patterns of plastic debris along estuarine shorelines Environ. Sci. Technol. 44 3404–9
Bruche A, Barreau C, Calrot J, Collin H, Moreno C and Maisonn P 2018 Monitoring litter inputs from the Adour River (Southwest France) to the marine environment J. Mar. Sci. Eng. 6 24
Carson H S, Lamson M R, Nakashima D, Toloumz D, Hafner J, Maximenko N and Mederimid K 2013 Tracking the sources and sinks of local marine debris in Hawaii ’i Mar. Environ. Res. 84 76–83
Castro-Jiménez J, González-Fernández D, Fornier M, Schmidt N and Sempere R 2019 Macro-litter in surface waters from the Rhine River: plastic pollution and loading to the NW Mediterranean Sea Mar. Pollut. Bull. 146 60–66
Costi R, Arcangeli A, Campana I, Paraboschi M and González-Fernández D 2018 ‘Down to the river’: amount, composition, and economic sector of litter entering the marine compartment, through the Tiber river in the Western Mediterranean Sea Rend. Lincei Sci. Fis. Nat. 29 859–66
Gasperi J, Dris R, Bonin T, Rocher V and Tassin B 2014 Assessment of floating plastic debris in surface water along the Seine River Environ. Pollut. 195 163–6
Gerads M, van Emmerik T, de Vries R and Bin Ab Razak M S 2019 Riverine plastic litter monitoring using unmanned aerial vehicles (UAVs) Remote Sens. 11 2045
González-Fernández D and Hanke G 2017 Toward a harmonized approach for monitoring of riverine floating macro litter inputs to the marine environment Frontiers Mater. Sci. 4 86
González-Fernández D and Hanke G and the RiLON network 2018 Floating Macro Litter in European Rivers—Top Items, (https://www.researchgate.net/publication/329537406_Floating_Macro_Litter_in_European_Rivers_Top_Items) Publications Office of the European Union Luxembourg
Honihing D, van Emmerik T, Uijttewaal W, Kardhana H, Hoes O, van de Giesien N 2020 Urban River Water Level Increase Through Plastic Waste Accumulation at a Rack Structure Data_Sheet_1.pdf. Front. Earth Sci. 8
Ivar Do Sul J A, Costa M F, Silva-Cavalcanti J S and Araujo M C B 2014 Plastic debris retention and exportation by a mangrove forest patch Mar. Pollut. Bull. 78 252–27
Jams I B, Windsor F M, Poudveigne–Durance T, Ormerod S J and Durance I 2020 Estimating the size distribution of plastics ingested by animals Nat. Commun. 11 1–7
Kiessling T, Knickmeier K, Kruse K, Brenneck D, Nauendorf A and Thiel M 2019 Plastic Pirates sample litter at rivers in Germany—Riverside litter and litter sources estimated by schoolchildren Environ. Pollut. 245 545–57
Martin C, Parkes S, Zhang Q, Yang W, Mccabe M F and Duarte C M 2018 Use of unmanned aerial vehicles for efficient beach litter monitoring Mar. Pollut. Bull. 131 662–73
McCormick A, Campbell H F and Rule M J 2011 The economic cost and control of marine debris damage in the Asia-Pacific region Oceans Coast. Manag. 34 643–51
Mihai F C 2018 Rural plastic emissions into the largest mountain lake of the Eastern Carpathians R. Soc. Open Sci. 5 172396
Mintenig S M, Kooi M, Erih M W, Primpke S, Redondo-Hasselerharm P E, Dekker S C and van Wezel A P 2020 A systems approach to understand microplastic occurrence and
variability in Dutch riverine surface waters Water Res. 176 115723

Ó Conchubhair D, Fitzhenny D, Lusher A, King A L, van Emmerik T, Lebret On and O’Rourke E 2019 Joint effort among research infrastructures to quantify the impact of plastic debris in the ocean Environ. Res. Lett. 14 065001

OSPAR Commission 2010 Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area (London: OSPAR Commission) pp 84

Rech S, Macaya-Cajulpán V, Pantajo J F, Rivadeneira M M, Campodónico C K and Thiel M 2015 Sampling of riverine litter with citizen scientists—findings and recommendations Environ. Monit. Assess. 187 335

Schirinzi G F, Köck-Schulmeyer M, Cabrera M, González-Fernández D, Hanke G, Farré M and Barceló D 2020 Riverine anthropogenic litter load to the Mediterranean Sea near the metropolitan area of Barcelona, Spain Sci. Total Environ. 714 136807

Schmidt C, Krauth T and Wagner S 2017 Export of plastic debris by rivers into the sea Environ. Sci. Technol. 51 12246–53

Schöneich-Argent R I, Dau K and Freund H 2020 Wasting the North Sea?–A field-based assessment of anthropogenic macrolitter loads and emission rates of three German tributaries Environ. Pollut. 263 114367

Schöne Rivieren. (2017). Handleiding voor monitoring (available at: https://schonerivieren.org/images/Onderzoek/DEF_Handleiding_monitoring_-_Schone_Rivieren_2018-2019.pdf) (Accessed 21 April 2020)

Schön-Richter A, Dau K and Freund H 2020 Wasting the North Sea?–A field-based assessment of anthropogenic macrolitter loads and emission rates of three German tributaries Environ. Pollut. 263 114367

Thompson R C, Olsen Y, Mitchell R P, Davis A, Rowland S J, John A W and Russell A E 2004 Lost at sea: where is all the plastic? Science 304 838–838

Tramoy R, Colasse L and Tassin B 2019 Plastic debris dataset on the Seine river banks: plastic pellets, unidentified plastic fragments and plastic sticks are the Top 3 items in a historical accumulation of plastics Data Brief 23 103697

Tramoy R, Gasperi J, Colasse L and Tassin B 2020 Transfer dynamic of macroplastics in estuaries—New insights from the Seine estuary: part 1. Long term dynamic based on date-prints on stranded debris Mar. Pollut. Bull. 152 110894

van Calcar C J and van Emmerik T H M 2019 Abundance of plastic debris across European and Asian rivers Environ. Res. Lett. 14 124051

van Emmerik T, Kieu-Le T C, Loozen M, van Oeveren K, Strady E, Bui X T and Schwarz A 2018 A methodology to characterize riverine macroplastic emission into the ocean Frontiers Mater. Sci. 5 372

van Emmerik T and Schwarz A 2020 Plastic debris in rivers Wiley Interdiscip. Rev. Water 7 e1398

van Emmerik T, Seibert J, Strobl B, Etter S, Den Oudendammer T, Rutten M, Ab Razak M S B and Van Meerveld I 2020 Crowd-based observations of riverine macroplastic pollution Frontiers Earth Sci. 8 298

van Emmerik T, Strady E, Kieu-Le T C, Nguyen L and Gratiot N 2019 Seasonality of riverine macroplastic transport Sci. Rep. 9 1–9

Vriend P, Roebroek C and van Emmerik T 2020b Same but different: a framework to design and compare riverbank plastic monitoring strategies Front. Water 24 Aug 2020

Vriend P, Van Calcar C, Kooi M, Landman H, Pikaar R and Van Emmerik T 2020a Rapid assessment of floating macroplastic transport in the Rhine Frontiers Mater. Sci. 7 10

Williams A T and Simmons S L 1999 Sources of riverine litter: the river Taff, South Wales, UK Water Air Soil Pollut. 112 197–216