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Abundance and composition of macro- and mesoplastic in the Waal river, the Netherlands

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Abstract

Plastic pollution has been considered an important environmental concern. Although studies on plastic concentrations mainly focus on the marine environment, in the past years, an increasing number of studies point out to large environmental consequences in freshwater environments worldwide. Besides the direct negative impacts on freshwater systems, rivers are potentially the major transport pathway of plastic pollution to the sea. The aim of this study was to assess the quantity and quality of macro- and mesoplastic in the entire water column of the Waal river, the Netherlands. River water column were sampled using a stow net connected to an anchor at low discharges. Plastic type and abundance comparison between sampling locations and local riverbanks were evaluated. Additionally, the assessment gave insight on estimations of plastics particles that go through the Waal River a year, excluding floods. Plastic composition and plastic abundance did not differ between two sampled locations, the main channel and shore channel. However, when compared to the local riverbanks, plastic composition was found to be different. The average abundance of both macro- and mesoplastic was determined to be 0.011 particles.m^{-3} at sampling locations. Based on calculation, a total of 352 million macro- and mesoplastic particles are going through the Waal River yearly during low river discharges. The outcome of the current study could be a relevant contribution for decision makers.

Keywords: freshwater systems, water column, macroplastic, mesoplastic, Rhine River.

Samenvatting

Er is steeds meer aandacht voor de plastic vervuiling van het milieu. Het merendeel van de studies over plastic richten zich vooral op het mariene milieu. Recent wordt steeds meer onderzoek gedaan naar de effecten van plasticvervuiling in zoetwatermilieus. Naast mogelijke negatieve effecten van plastic op zoetwatermilieus fungeren rivieren als belangrijke transportroute van plastic naar het mariene milieu. Het doel van dit onderzoek is om het macro- en mesoplastic in de gehele waterkolom van de Waal te karakteriseren tijdens lage rivierafvoeren. De monitoring van de gehele waterkolom is uitgevoerd door middel van ankerkuil visserij. Daarnaast is het verzamelde plastic in het water vergeleken met verzameld plastic op de rivieroever. Gebaseerd op de waargenomen aantallen is vervolgens een inschatting gemaakt van het totale aantal macro- en mesoplastic dat jaarlijks door de Waal wordt getransporteerd bij lage rivierafvoeren. Er was geen verschil in aantallen en samenstelling tussen een bemonsterde locatie in de hoofdgeul en in een oevergeul. De kunststofsamenstelling van de gehele waterkolom verschilde van de samenstelling op de lokale rivieroevers. De gemiddelde abundantie van zowel macro- en mesoplastic was 0,011 stuks.m^{-3}. Gebaseerd op de aantallen worden er jaarlijks 352 miljoen macro- en mesoplastic stuks getransporteerd door de Waal bij lage rivierafvoeren. Het inzichtelijk maken van de samenstelling, de herkomst en de jaarlijkse aantallen kunnen een bijdrage leveren aan beleid betreffende plasticvervuiling in Nederland.

Trefwoorden: zoetwatermilieus, waterkolom, macroplastic, mesoplastic, Rijn.

Abstrakt

Plastikverschmutzung wird heutzutage als ein wichtiges Umweltproblem angesehen. Obwohl der Fokus der Forschung zu Plastikkonzentrationen klar im Bereich der Meeresverschmutzung lag, weisen in den letzten Jahren immer mehr Studien auf große Umweltfolgen in Süßwasserumgebungen weltweit hin. Neben den direkten negativen Auswirkungen auf Süßwassersysteme sind Flüsse möglicherweise der Haupttransportweg der plastischen Verschmutzung zum Meer. Ziel dieser Studie war es, die Quantität und Qualität von Makro- und Mesoplastik in der gesamten Wassersäule des Flusses Waal in den Niederlanden zu erfassen und zu bewerten. Die Probennahme an zwei Standorten im Flussquerschnitt erfolgte bei Niedrigwassersituationen mit Hilfe eines Staunetzes, welches mit einem Anker verbunden war. In der Analyse der Proben wurden die Parameter Plastiktyp und Häufigkeit zwischen den Probe Entnahmestellen im Fluss bewertet und mit Messungen an lokalen Flussufern bewertet. Hierbei konnten keine signifikanten Unterschiede zwischen den Standorten im Gewässer festgestellt wurden. Im Vergleich zu den örtlichen Flussufern wurde jedoch eine unterschiedliche plastische Zusammensetzung festgestellt. Die durchschnittliche Häufigkeit von Makro- und Mesoplastik wurde an den Probe Entnahmestellen zu 0.011 Partikeln.m^{-3} bestimmt. Darüber hinaus lieferte die Analyse einen Einblick in die Menge an Plastikpartikeln, die jährlich in Niedrigwassersituationen den Waal passieren. Berechnungen ergaben eine Menge von jährlich insgesamt 352 Mio. Makro- und Meso-Plastikpartikeln. Die genannten Ergebnisse der aktuellen Studie sind ein relevanter Beitrag für Entscheidungsträger.

Stichwort: Süßwassersysteme, Wassersäule, Makro-plastik, Mesoplastik, Flusses Rhein.

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1. Introduction

In the 1930s and 40s, the introduction of plastic, defined as synthetic organic polymers (Worm et al., 2017), emerged as an alternative for scarce and non-sustainable resources, contributing to safety, hygiene, comfort and, wellbeing to our society (PlasticsEurope, 2018). Owing to the properties of plastic such as high durability, low density, versatility, and low cost, they have become essential materials in modern life (Andrady and Neal, 2009; Halden, 2010). Plastic products are prevalent in the consumer marketplace (Jambeck et al., 2015) and are extensively used in diverse sectors and applications, for instance, packaging, building materials and consumer products (Andrady and Neal, 2009). Since the 1950s the plastic production expanded from 1.7 million tons to almost 360 million tons in 2018 (PlasticsEurope, 2019). In Europe, the third largest producer of plastics in the world, the production almost reached 62 million tons (PlasticsEurope, 2019). Within the European countries, Germany has the largest relative plastic demand of 24.6% (PlasticsEurope, 2019).

Despite the aforementioned benefits that plastic brings to society, plastic pollution has become one of the most eminent environmental challenges (Winton et al., 2020). Although the majority of studies have focused on plastic concentrations in marine environments (Wagner et al. 2014), plastic presence in the freshwater environment is of increasing concern. Rivers act as main transport pathways and sources of plastics to the ocean (Blair et al., 2017). About 80% of the plastic litter found in the oceans are carried by the rivers (Jambeck et al., 2015; Schmidt et al., 2017). It is estimated that riverine systems contribute to 1.1–2.4 million tons of plastic annually into the marine environment (Lebreton et al., 2017). Field survey have confirmed the presence of plastic particles in lakes (Baldwin et al., 2016; Cable et al., 2017; Yin et al., 2019), rivers (Yonkos et al., 2014; Dris et al., 2015; Estahbanati and Fahrenfeld, 2016) and freshwater organisms (Sanchez et al., 2014; Phillips and Bonner, 2015; Hurley et al., 2017).

The systematic division of plastic particles in the aquatic environment into different groups is often based on size range categories (Hartmann et al., 2019). They are differentiated by adopting the prefixes of macro, meso, and micro (Arthur et al., 2009; González et al., 2016). Moreover, plastics can also be grouped according to their functional origin, shape, and polymer type (Verschoor, 2015). The term macroplastics is used to describe particles larger than 25 mm in size, mesoplastic between 5 mm to 25 mm and microplastic between 100 nm and 5 mm (Arthur et al., 2009; Cheshire et al. 2009).

Once plastics accumulate in the natural environment, they may cause adverse effects and become an environmental hazard (Hartmann et al., 2019; Van Emmerik, 2019). Due to their small size, microplastics can be erroneously taken as food particles and be ingested by organisms (Wright et al., 2013). In addition, they can be transferred through the food chain (Cole et al., 2013; Pinheiro et al., 2017). Studies on effects on macroinvertebrates showed a significant reduction in the growth of the species *Gammarus pulex* (Linnaeus, 1758) as a result of microplastic ingestion (Hasselerharm et al., 2018). While, larger plastic pieces can result in animal entanglement, strangulation, and lacerations (Kühn et al., 2015). Blettler and Wantzen (2019) observed specimen of bird *Pitangus sulphuratus* (Linnaeus,1766) entangled in a piece of a fishing line, and of fish *Pseudoplatystoma corruscans* (Spix and Agassiz, 1829) trapped in an old fish net in Paraná River, Argentina. Yet, according to Blettler et al. (2018), the potential damage of macroplastic on freshwater fauna is underestimated.

To improve the understanding of riverine plastic transport, an increasing number of studies have investigated plastic abundance in freshwater resources. The most common abiotic compartment investigated by studies, is the water surface, where researchers focus on analyzing floating plastics (Blettler et al., 2018). This highlights a clear lack of more information. In Switzerland, Faure et al. (2015) investigated the macro- and microplastic abundance in surface water of Aubonne, Venoge, Vuachere, and Rhone Rivers. For this study, an average of 0.012 macroparticles.m^{-3} and 7.0 microparticles.m^{-3} were found.

There are currently limited studies on plastic particles concentration conducted in the Dutch part of the Rhine River. Most published studies are biased towards floating plastic debris (Mani et al., 2015; Vriend et al., 2020). Understanding of which size range and type of plastic is prevalent in the aquatic environment is important to develop mitigation and management measures. Therefore, this study aims to assess the quantity and quality of macro- and mesoplastic in the entire water column of the Waal River. Additional insight focused on making a comparison of plastic composition between the water column and the local riverbanks. The postulated research questions are: 1) what is the composition of macro- and mesoplastics sampled in the water column of the Waal River; 2) what are the possible country sources of sampled plastic; 3) does the composition differ between the main channel and connected backwaters; 4) what is the link between plastic composition found in the water column and on riverbanks; 5) what is the quantity of macro- and mesoplastics in the water column of the Waal River in a set time frame; 6) does the quantity differ between the main channel and connected backwaters; and 7) what is the effect of water discharge on plastic concentration? We hypothesize that the local flow regimes are expected to result in a higher macro- and mesoplastic concentration in the shore channel compared to the main channel, as well as a difference in plastic composition between the locations. Moreover, it is expected that plastic composition in the water column of the Waal River is influenced by plastic transport from land (riverbanks) toward the river.

2. Methods

2.1. Study area

Macro- and mesoplastic monitoring was performed in the lowland Waal River, the largest distributary of the Rhine River in the Netherlands (Fig. 1a, b) (Japenga, 1990). The Waal River is an important European inland shipping route connecting the port of Rotterdam to the German hinterland (EnviCom, 2013). To maintain navigability the river is intensively dredged and is characterized by a high commercial shipping intensity (Ten Brinke et al., 1999). The average water discharge in the Waal River is 1500 $m^3.s^{-1}$ and represents about two-thirds of the water discharge from Rhine River into the North Sea (Spaink et al., 1998).

Recently, three longitudinal training dams (LTDs) have been constructed in the inner bend of the Waal River over a 10 km long stretch (Verbrugge et al., 2017). The LTDs have been built from kilometer 911 to 922 as a novel ecosystem-based river management strategy, in the replacement of the classical transverse groynes (De Ruijsscher et al., 2018). The new structures divide the river into two parts with different widths: a main channel for ship navigation and a shore channel along the inner bank, where only recreational navigation is permitted (Collas et al., 2018). Macro- and mesoplastic monitoring was performed at two different locations within the river: 1) edge of the main channel of the Waal River (51°53'39.4"N 5°31'35.4"E) (Fig. 2a, b) and 2) a shore channel of one LTD (51°52'50.3"N 5°26'28.5"E) (Fig. 2a, c).

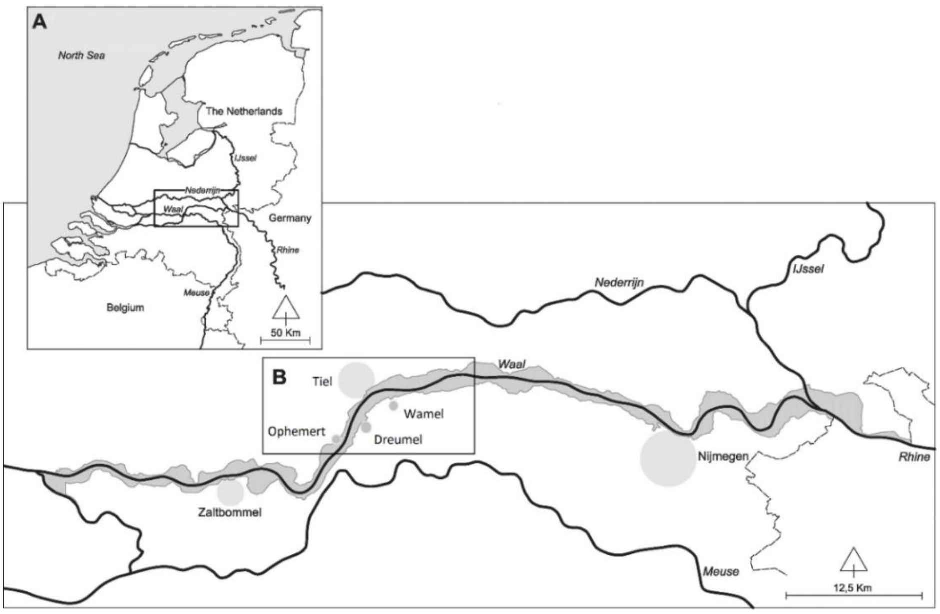

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Fig. 2. (a) Plastic sampling locations in the Waal River, (b) close-up of main channel (location 1), where plastics were sampled near to the village of IJzendoorn, (c) close-up of shore channel (location 2) of plastic sampling behind the second LTD near Wamel (source: Google Earth).

2.2. Sampling approach

Plastic monitoring was performed using a stow net connected to an anchor (Fig. 3a, b and Fig. 4) (Nienhuis, 2008). This method consists of a static stow net (bag-shaped) attached to an anchored fishing-boat (Hoek, 1888; Nienhuis, 2008), thereby passively monitoring plastic pieces in the entire water column (Floating + Suspended + Bed-Load). In this study, the interval of each sampling session ranged between 0.5 and 2.67 hours. Subsequently, the net was retrieved and the fine mesh was opened and all plastics particles were put in a wide container. The used stow net had a length of 50 m and a width of 8 m. As the net was tapered, mesh size varied from 160 mm of the big mesh leading to the end section of the net with a mesh size of 15 mm and a length of 20 m. The mesh size is measured with stretched meshes.

Monitoring on both locations was performed in November 2018, and September and October 2019. Sampling was performed in four consecutive days in each month, totaling 12 field days. In November 2018 monitoring was limited to the main channel due to extremely measured low water levels of the Waal River. In September and October 2019 sampling was performed two days at each location. Because of safety, sampling protocols differed between the locations. In the main channel, collection of plastic was performed between 11 am and 10 pm and in the shore channel between 1 pm and 2 am. In the shore channel, both right and left sides of the boat were monitored, while in the main channel only the left side was monitored. The sampling depth during monitoring ranged from 2.8 m to 3.9 m. A total of 72 samples were carried out, 33 from the shore channel and 39 from the main channel.

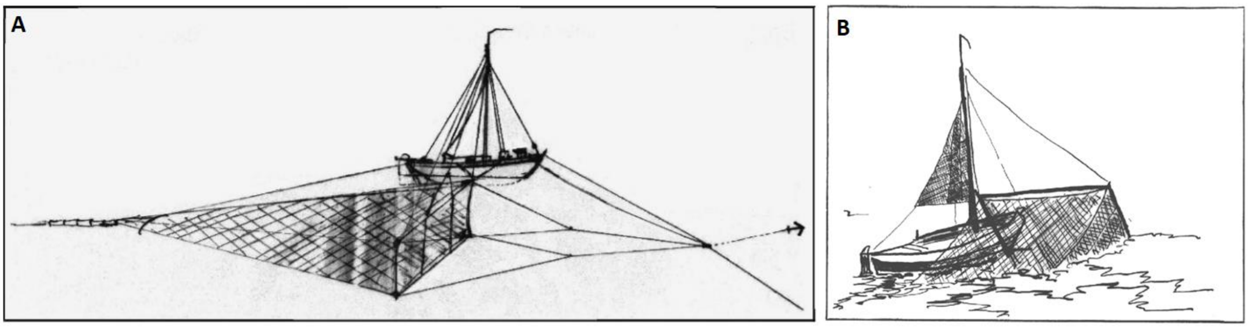

Fig. 3. Sketches of a stow net on an anchor fastened to a frame. Side (a) and back view (b) (Source: Nienhuis, 2008; Ganita Mare, 2017).

Fig. 4. Vessel used for macro- and mesoplastic sampling in the current study (Source: author).

2.3. Processing samples

In- situ, the plastic particles were visually separated from organic debris and fish captured by the net. Subsequently, the plastic particles collected per haul were stored and preserved under freezing conditions. After all sampling events, the plastic particles per haul were washed in the laboratory to remove remaining organic matter. Hereafter, the plastic particles were grouped into two different size ranges, macroplastics (> 25 mm) and mesoplastics (> 5 mm ≤ 25 mm) based on the longest diameter of each plastic item (Vriend et al. 2020).

2.4. Efficiency of the collection net

Due to the larger mesh size, the catching efficiency of the net was reduced. In addition, plastics were found to be entangled in the big mesh and as a result were not collected in the fine mesh and were thus not retrieved. Therefore, a test was performed to evaluate the collection efficiency of the net. To this end, plastic pieces were prepared with dimensions of 75 by 90 mm (macroplastic) and 25 by 25 mm (mesoplastic). Pieces were made of both hard plastic, and soft plastic. For each combination of plastic hardness and size 80 pieces were made, which were subsequently separated into four replicates of 20 pieces. Each plastic piece was marked and released right in front of the stow net at a depth of 50 cm. The plastic pieces were released in batches to allow a time interval to retrieve as many plastics as possible that passed through the net to reduce the environmental impact of the efficiency test. After all plastics were released the stow net remained in the water for a total of 1.5 hours to allow plastics entangled in the big mesh to potentially end up in the fine mesh. Subsequently, the standard collection protocol was used as described above. Based on the retrieval rate for each replicate of 20 pieces, the net efficiency was determined. Then for each hardness size combination the average big mesh efficiency was determined.

2.5. Plastic identification, counting and origin

All collected macro- and mesoplastics per haul were classified using the River-OSPAR plastic checklist (Schone Rivieren, 2017). The River-OSPAR method has been developed as an alternative of the OSPAR Guidelines for beach litter monitoring developed by OSPAR commission (2010) (Van Emmerik et al., 2020). For the study, a total of 61 plastic categories (Appendix A and B) were considered. One extra category named “food packaging (soft plastic)” was added to the list. In addition, a higher plastic classification system was used: hard plastic, foam, plastics films (soft plastic), and filaments (Gündoğdu and Çevik, 2017). Simultaneously with classifying the plastic items, all pieces were counted and the proportion of each plastic category was calculated. Each plastic item was checked for information that would allow to determine the country of origin.

The plastics found under the category “string and cord (diameter < 1 cm)”, listed in the River-OSPAR protocol (Schone Rivieren, 2017), were evaluated in order to identify the possible presence of geotextile material used to prevent the erosion of the soil foundation of the groynes structures.

2.6. Statistical analyses

2.6.1. Hydraulic analysis

In order to calculate the discharge of the Waal River on the sampling days, daily mean measured water level at Tiel, water level at Pannerdensche kop and discharge at Lobith coupled with the Rijkswaterstaat equal-river-stage levels 2018 and the Rijkswaterstaat stage discharge relation 2019 were used. In addition, for the two sampling locations, relevant discharges available from standard calculations with 2D hydraulic model from Rhine River at Lobith were adapted to the Waal River discharge. Subsequently for each day, the Waal River discharge were linearly interpolated into flow velocity (data acquired from Daniël van Putten, Rijkswaterstaat – Oost Nederland). Results obtained were used in the equation 2 and 3.

2.6.2. Plastic type

The plastic category data was used to perform the following analysis: 1) does the plastic signature (*viz.* categories) change through time; 2) does the plastic signature differ between locations and 3) does the plastic signature match with local riverbank plastic?

Plastics sampling of the present project only included measurement of macro- and mesoplastic in the water column of the Waal River. Although, to verify a correlation of plastics signatures from the river water column and local riverbank areas, results of current plastic monitoring campaigns were compared with the data set from Schone rivieren project (River- OSPAR) (database acquired from Marijke Boonstra (Schone Rivieren) and Frans Buschman (Deltares) on May 25th 2020).

As the amount of plastic was different due to diverse factors, e.g. measurements durations, the correlation was made based on the percentage in the sample of each category of the item identification River-OSPAR checklist (Schone Rivieren, 2017).

All analyses were performed using a linear regression method, which allows to observe the correlation of plastic composition (River-OSPAR categories and plastic type) with the variables time and location.

2.6.3. Plastic abundance

Based on the collected macro- and mesoplastics an assessment was made of plastic abundance in the river. The abundance was expressed in several different endpoints, namely: 1) sampled particles per hour (particles.h^{-1}), 2) particles per sampled volume (particles.m^{-3}), and 3) particles per hour (particles.h^{-1}) extrapolated for the whole river section. All results were calculated for the sum of macro- and mesoplastics, but also individually for each size range in the two different locations. The endpoint particles per hour for whole river section were used to derive the total amount of plastics pieces that go through the Waal River a year.

Macro- and mesoplastics quantification were checked for normality using the Shapiro-Wilk test in R v. 3.5.3 (R Core Team, 2019). A statistical analysis of variance (ANOVA) was implemented to analyze the effect of 'location' (i.e., main channel and shore channel), and 'month of sampling' (i.e., November 2018, September and October 2019) on quantity average per hour of macro- and mesoplastics sampled using the stow net. Finally, a Student's t test was performed to verify if there was statistically difference between macroplastic and mesoplastic. Both the ANOVA and Student's t test were performed in R v. 3.5.3 (R Core Team, 2019).

The sampled particles per hour (particles.h^{-1}) were derived based on equation 1.

$$\text{Eqn 1: } ((P_{sum} - (P_{sum} \times (N_{fraction} / (W_{depth} \times N_{width})))) \times (100/N_{efficiency})) + (P_{sum} \times (N_{fraction} / (W_{depth} \times N_{width})))$$

With P_{sum} being the primary sum of macro- and mesoplastics. $N_{fraction}$ is the fraction of the fine mesh of the net, W_{depth} is the water depth during sampling, N_{width} the width of the net, and $N_{efficiency}$ being the catching efficiency of the net.

The particles per sampled volume (particles.m^{-3}) were derived based on equation 2.

$$\text{Eqn 2: } P_{quantity} / (W_{depth} \times N_{width} \times V_{mean} \times T)$$

With $P_{quantity}$ being the sum of macro- and mesoplastics taking the net efficiency into account, calculated in the equation 1. W_{depth} is the water depth during sampling, N_{width} the width of the net, v_{mean} the depth averaged flow velocity at the sampling location acquired from Rijkswaterstaat and T being the sampling time.

The particles per hour (particles.h^{-1}) for whole river section were derived based on equation 3.

$$\text{Eqn 3: } P_{quantity} \text{ x } (1/ (W_{depth} \text{ x } N_{width} \text{ x } V_{mean} /Q_{Tiel})$$

With $P_{quantity}$ being the sum of macro- and mesoplastics taking the net efficiency into account, calculated in the equation 1. W_{depth} is the water depth during sampling, N_{width} the width of the net, V_{mean} the depth averaged flow velocity at the sampling location acquired from Rijkswaterstaat and Q_{Tiel} being the water discharge calculated at Tiel acquired from Rijkswaterstaat.

The yearly number of plastics going through the Waal River was determined based on a bootstrapping procedure. Plastic particles per hour for whole river section of each sample were used to acquire a probability density function (PDF) of plastic particles per hour. These particles per hour PDF were then used to sample 24 particles per hour which were added up resulting in a value describing plastic particles per day. The sampling of 24 values from the particles per hour PDF was repeated 1000 times. Subsequently, a normal distributed PDF was fitted to the 1000 values of plastic particles per day. This PDF was then used to sample 365 values resulting in plastic particles per year. This step was again repeated 1000 times to assess the variability in plastic particles per year. Hereafter, the median and 95% interval of plastic particles per year was determined.

2.6.4. Hydrological effect on plastic particles

The water discharge data at Tiel, obtained in the hydraulic model, were used to perform the following analysis: 1) Does the water discharge affects the quantity of macro- and mesoplastic particles in the water column of the Waal River? The relationship was evaluated by using a statistical linear regression analysis.

3. Results

3.1. Efficiency of the net

The catching efficiency of the net was different for each combination of size and hardness of plastics (Fig. 4). The catching efficiency of the net proved to be positive for sampling hard macroplastic, being able to sample 95% of them. However, the method used has low catching efficiency for soft macroplastic (8.75%), hard mesoplastic (9.38%) and soft mesoplastic (5.63%) (Fig. 5).

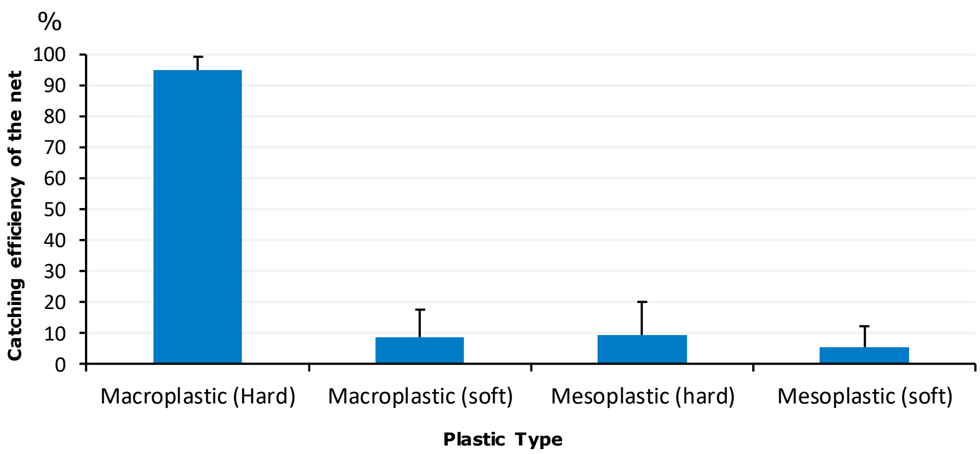

Fig. 5. Results of the catching efficiency of the net, for each combination of size and hardness of plastics.

3.2. Plastic identification

A total of 7,255 plastic debris were individually counted and classified by category during the monitoring. General results of all sizes combined showed that undefined soft plastic 2.5 - 50 cm (soft plastic), undefined plastics film 0 - 2.5 cm (soft plastic), candy- snack- and chips packaging, string and cord (diameter < 1 cm), and tampons and tampons packages, were the five dominant plastic items recorded in this study (Table 1; Fig. 6; Appendix B).

Table 1. Summary of the main macro- and mesoplastic items recorded in the water column of the Waal River, according to the fraction of categories.

Plastic category	Plastic type	% items
Plastic film 2.5 - 50 cm (soft plastic)	Film (soft)	39.37%
Plastic film 0 - 2.5 cm (soft plastic)	Film (soft)	28.07%
Candy- snack- and chips packaging	Film (soft)	6.67%
String and cord (diameter < 1 cm)	Filament	4.85%
Tampons and tampons packages	Film (soft)	3.79%

Within the category string and cord with diameter < 1 cm, possibly, 29% among collected plastics were compatible with the geotextile material used to prevent the erosion of the soil foundation of the groynes. In a yearly based about 5 million pieces of geotextile material flows thought the Waal River (for picture comparison see Appendix D).

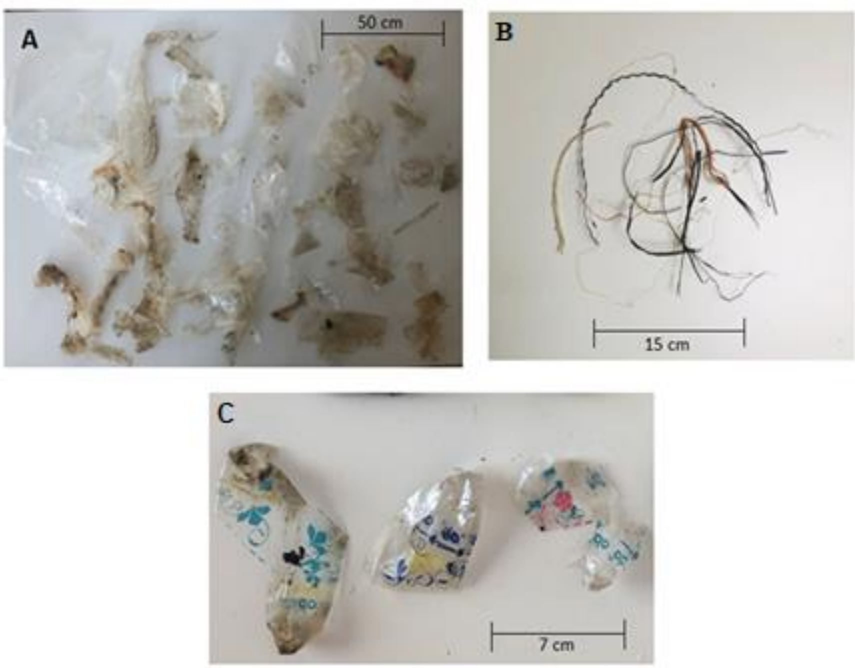

Fig. 6. (a) Undefined film plastics 2.6 - 50 cm (soft plastic), (b) string and cord (diameter <1 cm) and (c) tampons packaging.

3.2.1. Macroplastic

Based on 61 plastic categories from River- OSPAR classification (Schone Rivieren, 2017) (Appendix B), plus the category added by the current author, a total of 28 and 40 categories of macroplastic were recorded in the main channel and shore channel, respectively. Undefined plastics film 2.5 – 50 cm (soft plastic) (65.6%), String and cord with diameter < 1 cm (10%), and Candy- snack- and chips packaging (7.6%) were the dominant macroplastic items recorded, in the main channel (Fig. 7). Undefined plastic film 2.5 - 50 cm (soft plastic) (51.8%), Candy- snack- and chips packaging (11%), and tampons and tampons packages (5.8%) were the dominant macroplastic items recorded, in the shore channel (Fig. 7; for proportions see Appendix B).

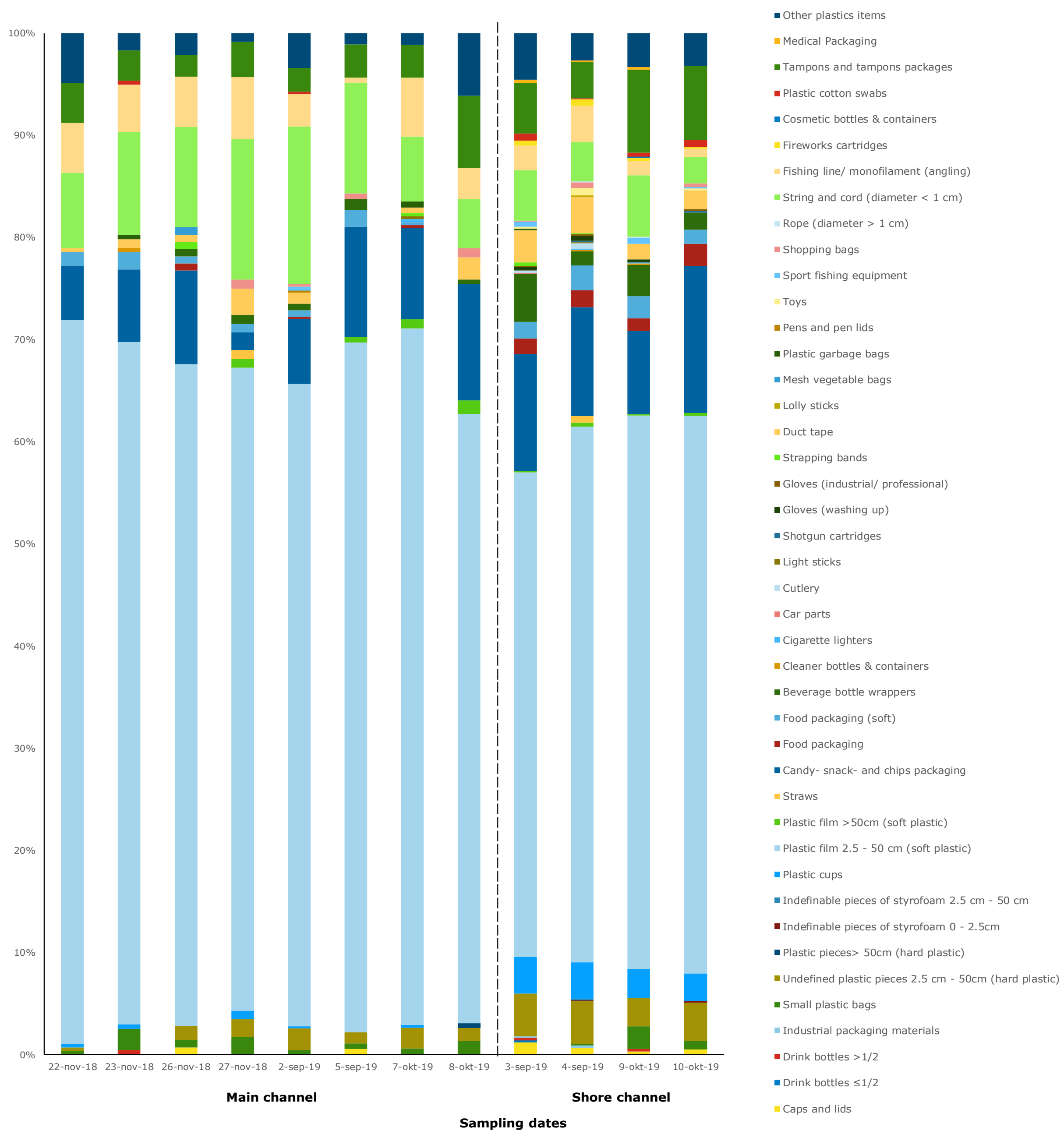

Fig. 7. River-OSPAR categories of macroplastic items recorded during sampling campaigns, in the diferent locations.

Subsequently, the River-OSPAR categories were summarized into 4 categories of plastic type: hard plastic, plastic film (soft plastic), filaments, and foam (Gündoğdu and Çevik, 2017) (Appendix B). For both locations, plastic films (soft plastic) were the dominant macroplastic category recorded, with an average fraction of 95% in the main channel and 88% in the shore channel (Fig. 8). Although, the following dominant categories distinguished between the locations, while filaments stands out in the main channel, hard plastic stands out in the shore channel. Foam plastics had the smallest fraction within sampled plastics (Fig. 8).

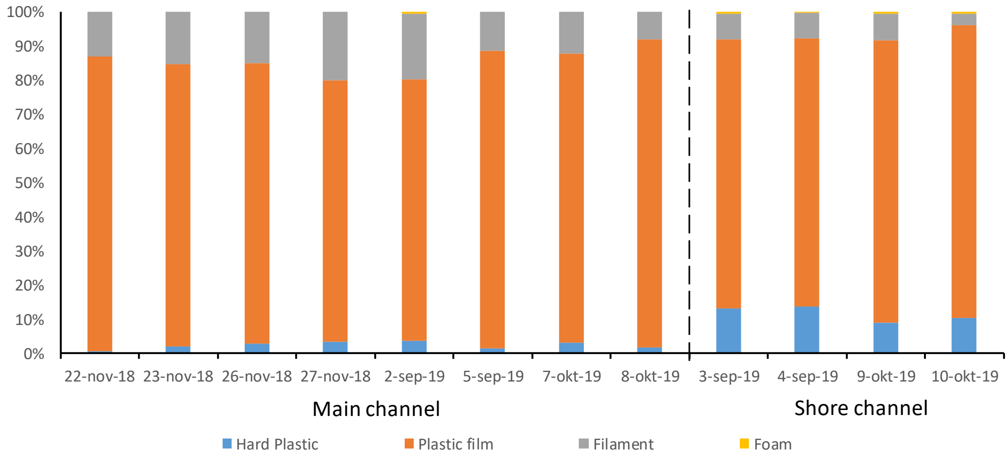

Fig. 8. Proportions of macroplastic types in the main channel and shore channel, according classification method used by Gündoğdu and Çevik (2017).

3.2.2. Mesoplastic

A total of 11 and 15 River-OSPAR categories of mesoplastic were recorded in the main channel and shore channel, respectively. A similarity between locations were observed, where undefined plastic film 0 - 2.5 cm (soft plastic), undefined plastic pieces 0 - 2.5 cm (hard plastic), and tampons and tampons packages were the dominant mesoplastic items recorded, in both channels (Fig. 9). The category undefined plastic film 0 - 2.5 cm (soft plastic) shows a supremacy over other categories, 93.60% (main channel) and 85.6% (shore channel) (Fig. 9; for proportions see Appendix B).

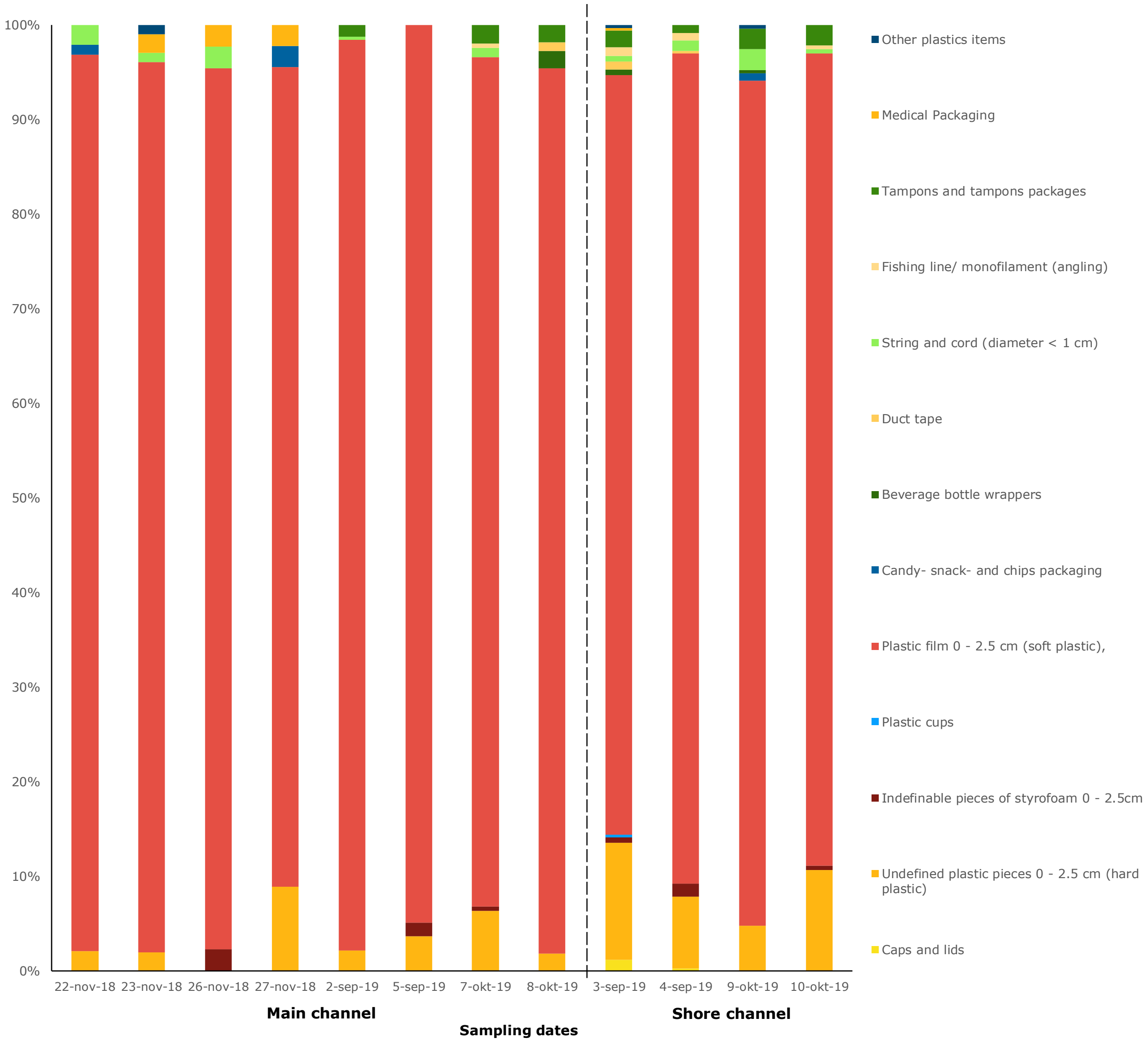

Fig. 9. River-OSPAR categories of mesoplastic items recorded during sampling campaigns in the different locations.

Plastic film (soft plastic) was the most commonly type of mesoplastic recorded in this study (91.5%), followed by hard plastic, for both locations. Filaments and foam had a low representativeness of mesoplastics (Fig. 10). A slightly higher fraction of hard plastic was observed in the shore channel than in main channel.

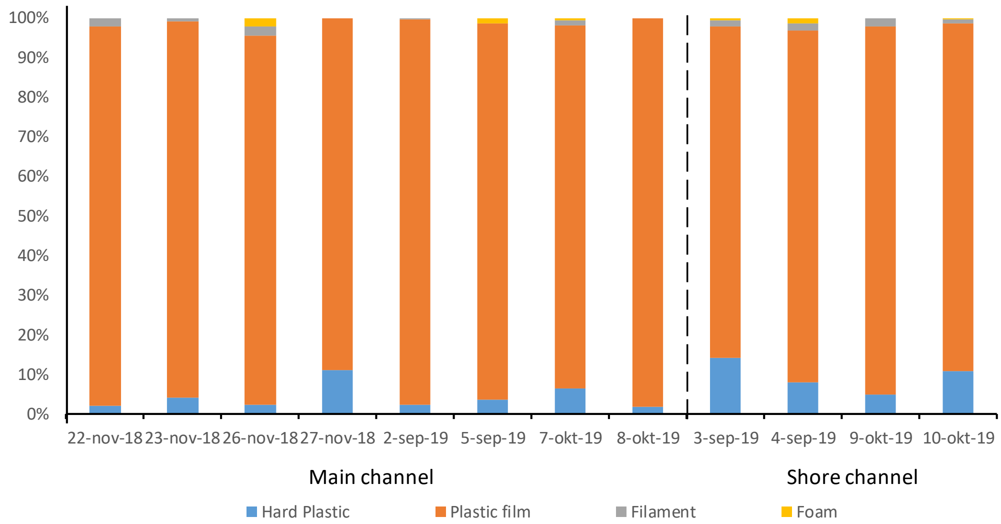

Fig. 10. Proportions of mesoplastic types in the main channel and shore channel, according classification method by Gündoğdu and Çevik (2017).

3.2.3. Country of origin

Unfortunately, for the majority of the plastics collected, the country of origin was not identifiable. The country of origin could only be identified on 4.04% of all collected plastic. In these, 19 source countries could be identified among the macro- and mesoplastic samples (Fig. 11), only 5 of them belong to the Rhine river basin (Switzerland, Austria, France, Germany and the Netherlands). The majority of plastic particles collected in the current project, originated from Germany (71%). Plastic particles from the Netherlands, where samplings were performed, only represents a fraction of 9% of the total.

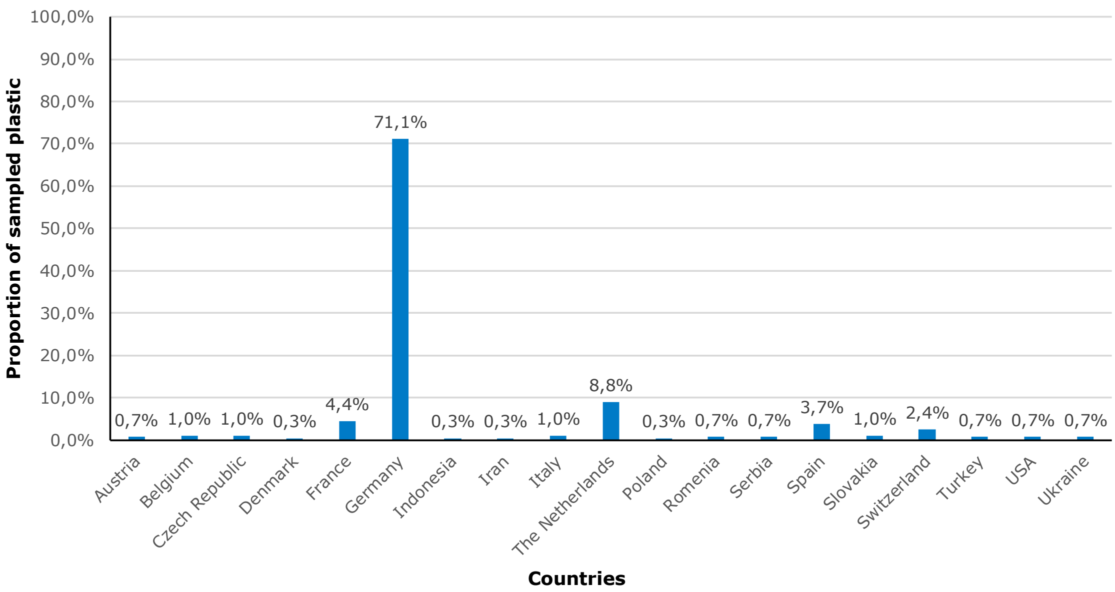

Fig. 11. Identification of the plastics origin at a country level.

3.3. Statistical analysis

3.3.1. Hydraulic analysis

The water discharge of the Waal River on the sampling days, based on calculations acquired from Rijkswaterstaat, ranged between 537 $m^3.s^{-1}$ and 1164 $m^3.s^{-1}$. All these discharges are below the median discharge of the river Waal. The mean flow velocity at the sampling locations from model calculations ranged between 0.51 $m.s^{-1}$ and 0.82 $m.s^{-1}$ (see appendix E for detailed information).

3.3.2. Plastic identification

Plastic signature (viz. categories) through time

Percentages of plastic categories based on River-OSPAR classification method, from November 2018 *vs* October 2019 and October *vs* September 2019 are plotted below (Fig 12a, b). Based on the proximity of the trend line, calculated for both month comparison, to the one to one line, there was no changes in the categories of macro- and mesoplastics through time. Additionally, the correlation coefficient (r^2) shows a very strong positive linear correlation between November 2018 and October 2019 (r^2 = 0.9688) and between September and October 2019 (r^2 = 0.9842). In other words, based on r^2 the same categories scored high or low percentages between locations.

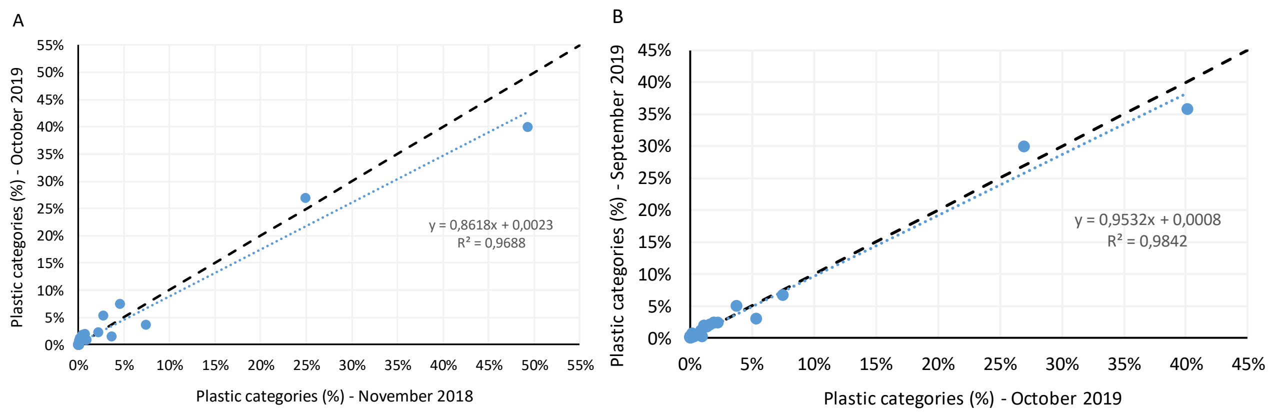

Fig. 12. Correlation of plastic categories through time, according classification method by River-OSPAR classification (a) November 2018 *vs* October 2019 (b) September 2019 *vs* October 2019.

Plastic signature and type comparison between sampling locations

Percentages of plastic categories based on River-OSPAR classification method and plastic type classification (Gündoğdu and Çevik, 2017), between sampling locations are plotted below (Fig 13a, b). Based on the proximity of the trend line to the one to one line, there was no changes in the categories of macro- and mesoplastics between locations. The correlation coefficient (r^2) shows a very strong positive linear correlation of plastic categories ($r^2 = 0.9774$) and plastic type ($r^2 = 0.9823$) between main channel and shore channel.

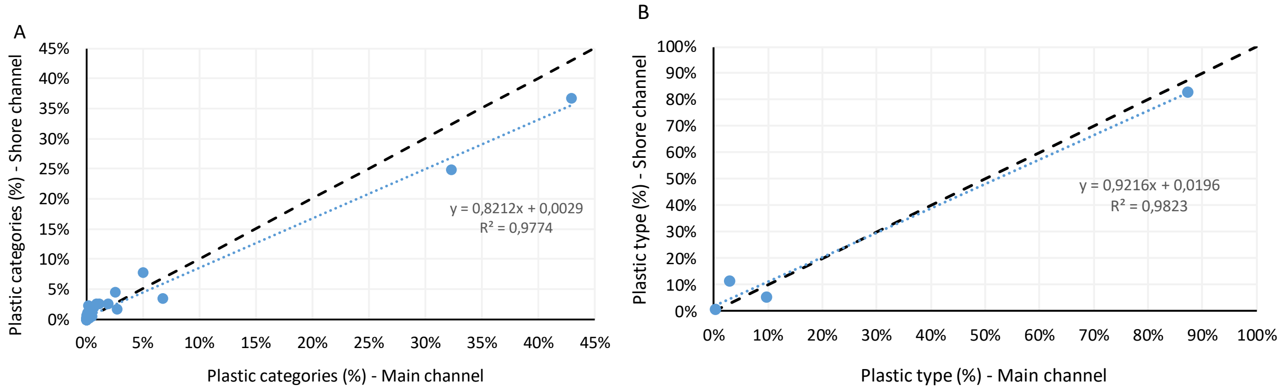

Fig. 13. Correlation of plastic categories and type between main channel and shore channel, according classification method by (a) River-OSPAR classification and (b) Gündoğdu and Çevik (2017). LTD vs main channel (liner)

Plastic signature comparison between riverbank plastic.

Percentages of plastic categories based on River-OSPAR classification method and type classification (Gündoğdu and Çevik, 2017), between acquired data base from local riverbank and water column of the Waal River are plotted below (Fig 14a, b). Here, the trend line deviates quite a bit from the one to one line, showing that the categories found on the local riverbank differed from the categories found in the water column of the Waal River. Additionally, based on the r^2 a moderate positive linear correlation of plastic categories is observed between local riverbank and water column ($r^2 = 0.6094$) and a very weak positive linear correlation of plastic types ($r^2 = 0,4788$). (for proportions comparison see Appendix F and G).

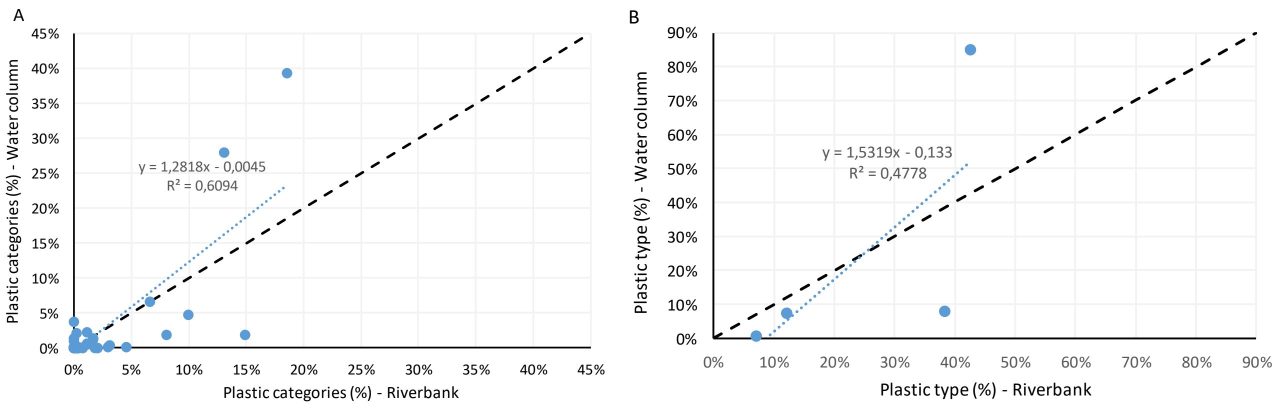

Fig. 14. Correlation of plastic categories and type between local riverbank and water column, according classification method by (a) River-OSPAR classification and (b) Gündoğdu and Çevik (2017).

3.3.3. Plastic abundance

Overall, macroplastic had a higher concentration of particles per hour (particles.h^{-1}*), and consequently higher concentrations of particles per sampled volume (particles.m^{-3}), and particles per hour (particles.h^{-1}**) for whole river section than mesoplastics (Table 2). However, in the sampling days September 2nd and September 5th, mesoplastic concentration surpassed the macroplastic concentrations. The highest average concentration of total macro- and mesoplastic particles per sampled volume were observed in the sampling day September 2nd (0.018 particles.m^{-3}) in the main channel and September 4th (0.014 particles.m^{-3}) in the shore channel (Table 2). An average, of 0.006 macroplastics and 0.005 mesoplastics particles per sampled volume were recorded (particles.m^{-3}).

Table 2. Average of quantity of macro- and mesoplastic sampled per day in the two sampled locations.

			Total			Macroplastic			Mesoplastic		
Location	Month	Day	Particles.h^{-1} *	Particles.m^{-3}	Particles.h^{-1} **	Particles.h^{-1} *	Particles.m^{-3}	Particles.h^{-1} **	Particles.h^{-1} *	Particles.m^{-3}	Particles.h^{-1} **
			Mean								
All data			756	1.1 x 10^{-2}	35712	424	0.6 x 10^{-2}	19969	332	0.5 x 10^{-2}	15743
			Mean								
Main Channel	November	22-nov-18	699	1.7 x 10^{-2}	33001	460	1.1 x 10^{-2}	21724	239	0.6 x 10^{-2}	11277
		23-nov-18	498	1.2 x 10^{-2}	23528	298	0.7 x 10^{-2}	14053	201	0.5 x 10^{-2}	9475
		26-nov-18	347	0.8 x 10^{-2}	16384	232	0.6 x 10^{-2}	10971	115	0.3 x 10^{-2}	5413
		27-nov-18	274	0.6 x 10^{-2}	12921	171	0.4 x 10^{-2}	8071	103	0.3 x 10^{-2}	4849
	September	2-sep-19	1413	1.8 x 10^{-2}	74114	677	0.8 x 10^{-2}	35501	736	0.9 x 10^{-2}	38613
		5-sep-19	597	0.7 x 10^{-2}	29276	276	0.3 x 10^{-2}	13546	321	0.4 x 10^{-2}	15730
	October	7-okt-19	965	1.2 x 10^{-2}	42957	501	0.7 x 10^{-2}	22307	464	0.6 x 10^{-2}	20650
		8-okt-19	621	0.7 x 10^{-2}	28056	351	0.4 x 10^{-2}	15880	269	0.3 x 10^{-2}	12176
			Mean								
Shore Channel	September	3-sep-19	871	0.9 x 10^{-2}	39207	511	0.6 x 10^{-2}	22988	360	0.4 x 10^{-2}	16220
		4-sep-19	1252	1.4 x 10^{-2}	57880	676	0.8 x 10^{-2}	31229	577	0.7 x 10^{-2}	26651
	October	9-okt-19	780	1.0 x 10^{-2}	36463	480	0.6 x 10^{-2}	22431	300	0.4 x 10^{-2}	14032
		10-okt-19	755	0.9 x 10^{-2}	34763	454	0.5 x 10^{-2}	20930	300	0.3 x 10^{-2}	13833

*: Sampled Particles per hour

**: Particles per hour for whole river section

Plastic abundance, statistically, did not differ between main channel and shore channel in the different months (Table 3). The quantity of macroplastic and mesoplastic for both locations were significantly different ($t = 3.723$, $df = 12.163$, p-value = 0.003).

Table 3. Analysis of Variance results. Groups are september-main channel, september-shore channel, october-main channel and october-shore channel.

	Df	**Sum Sq**	**Mean Sq**	**F-value**	**P-value**
Groups	3	913.48	304.49	0.472	0.718
Residuals	4	2582.26	645.57		

Based on generated probability distributions of plastic particles per hour and, subsequently plastic particles per day calculated in the bootstrapping procedure (Appendix C), 352 million (95% confidence interval) macro- and mesoplastic particles are going through the Waal River yearly during the evaluated discharge (Fig. 15). As the Waal discharge during the measurements was during the assessed discharged of 79% of the Boven Rijn (Lobith), the total estimated amount of plastics entering the Netherlands is about 445 million particles. This is a kind of base flow, while we did not measure plastic quantity during floods.

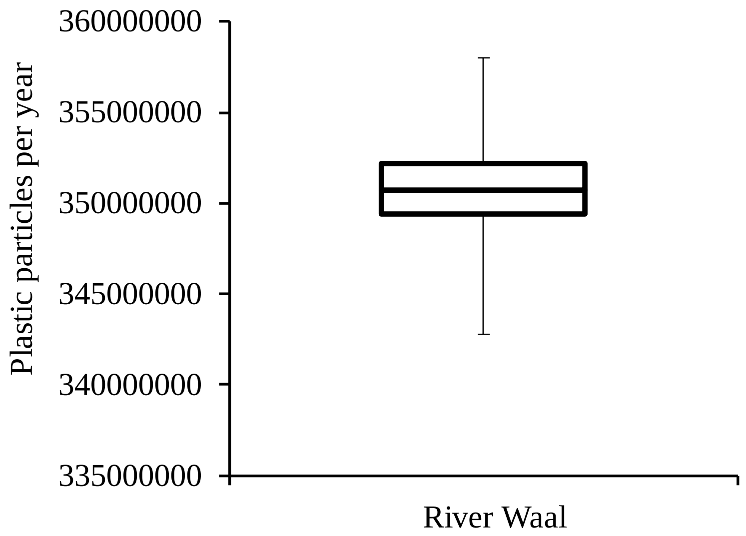

Fig. 15. Whisker plots of range of yearly number of plastic particles going through the Waal River.

3.3.4. Hydrological effect on plastic particles

No relationship was found between discharge of the river Waal and the collected plastic particles per hour ($r^2 = 0.0465$) (Fig. 16).

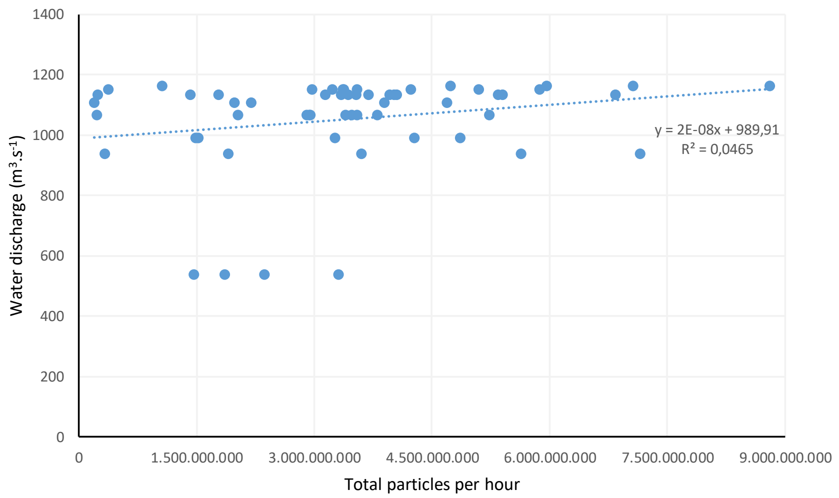

Fig. 16. Relationship between Waal River water discharge ($m^3.s^{-1}$) and total particles per hour ($particles.h^{-1}$).

4. Discussion

The large variation of the catching efficiency of the net among each combination of size and hardness of plastics, may affect the macro- and mesoplastic quantity. Calculations could result either in an over or underestimation of plastic abundance. Therefore, for future plastic monitoring with the current sampling method, another catching efficiency test is necessary.

Owing to the versatility of the plastic, they are present in several sectors and products of our modern society (Andrady and Neal, 2009). Corroborating this idea, a large variety of plastic categories could be identified during the monitoring period of the present study. About 75% of the plastic categories listed in the River-OSPAR classification were present in the water column of the Waal River. Van Emmerik et al. (2020) has demonstrated that the River-OSPAR protocol has provided a detailed item categorization, which can assist decision making in plastic prevention, mitigation and reduction measures. Overall, a significant proportion of macroplastic under the category undefined film plastics 2.5 – 50 cm (soft plastic) and mesoplastic under undefined film plastics 0- 2.5 cm (soft plastic) was widely recorded. According to Bergmann et al. (2015), plastic litter items in rivers are mostly parts or fragments of products. In water, macroplastic can break down over time under ultraviolet light (UV radiation), mechanical rubbing and biological degradation (Cole et al., 2011; Hartmann et al., 2019). In addition to this 'natural' degradation, Van Franeker et al. (2004) suggest that plastic items are intentionally shredded on board of some ships in order to hide the plastic waste in food waste discharged in the water, or even shredded by boat and ship propellers (Parliament of Australia, 2016).

The majority of plastic identified at a country level were from Germany, suggesting a transport of macro-and mesoplastic flowing from the Rhine River through the Waal River, towards the North Sea. According to Blair et al. (2017), rivers are considered one of the main pathways of transporting plastics into the ocean. Higher concentration of plastic originated from Germany, can be explained as Germany has the largest representation in plastics demand within Europe (PlasticEurope, 2019). Simultaneously, Germany has the largest share (57 %) in the Rhine River basin (IAWR, 2020). Other sources of macro- and mesoplastic could be results of commercial shipping of which part of the fleet going through the river Waal are from eastern Europe potentially explaining the presence of Eastern European countries, e.g. Poland, Romania, Serbia. Sources such as Indonesia, United of States, Turkey, and Iran could be a result of the increased river cruise activity on the Rhine River of which crew members and tourist may be from countries aforementioned.

A consistent pattern of macro- and mesoplastic categories were observed between sampling location, although, plastic composition significantly differed when compared with the riverbank database from Schone Rivieren project (River-OSPAR). Yet, additional data is required to draw final conclusions. As present study only monitored macro- and mesoplastic at low and very low discharges, this might differ during floods and higher discharge. Van Emmerik et al. (2019) suggests that increased water levels allows the transport of accumulated plastics on riverbanks or in riparian vegetation towards the water or vice versa.

Currently, there is a knowledge gap on plastic particles concentration in the entire water column of the Dutch part of the Rhine River. Studies conducted in the region by Mani et al. (2015) and Vriend et al. (2020) focused on floating plastic. In the present study, the average abundance of sampled macroplastic particles per hour was determined to be 171 – 676 particles.h^{-1}, while the average observed by Vriend et al (2020) was 10–75 macroplastic particles.h^{-1}. This divergence is likely explained by the difference between examined abiotic compartments, water column and water surface, respectively. Another reason for the difference could be the influence of sampling and identification approaches, rather than just by the real quantity of plastic in the aquatic environment (Anderson et al., 2016). The average of macroplastic particles per sampled volume of 0.006 particles.m^{-3} in the water column of the Waal River was in accordance with preliminary results of the Scheldt River, Belgium (Teunkens et al. 2018). The average of macroplastic was determined to be 0.004 particles.m^{-3}. Studies conducted by Teunkens et al., (2018) in the Scheldt River were performed with the same sampling method of the current study, which possibly explains the similarity of the values.

According to statistical analyses, during low and very discharges a consistent pattern of macro- and mesoplastic abundance in the water column were observed between the two locations per month of sampling, that is, there was no significant difference among averages of particles.h-1 per location through time. Such results corroborate with the results obtained related to the hydrological effect on plastic particles abundance in the water column, which proved to be not directly related in the present study. However, studies conducted by Van Emmerik et al., (2019) showed evidence that floating plastic concentration and transport may depend on the hydrological flow regime. Here, once more this difference is likely explained by the different abiotic compartment investigated between studies. But also, sampling from current study were only performed at low and very low river discharges, where we expect to be a relation with higher discharges.

5. Conclusion

Macro- and mesoplastic collected in the water column of the river Waal, showed a large variety of plastic category, in different sectors and applications. Plastic categories and plastic types did not vary between sampling days and location. However, plastic signatures significantly differ between local riverbanks and water column. Results indicate the need of future research to draw strong conclusions about the correlation of plastic categories on the riverbank and in the water column. Difference in fluxes may impact plastic concentration and composition among abiotic compartments, where low discharges may influence plastic flowing through the water column and high discharges may influence plastic on riverbanks and floodplain areas.

The majority of plastic particles sampled in the water column of Waal River were fragments, restricting to accurately identify the items. Soft fragments (undefined soft plastics) were the dominant macroplastic as well as mesoplastic recorded.

The plastic abundance did not significantly differ between the main channel and shore channel, statistically proven by ANOVA. In the current study, macro- and mesoplastic concentrations in the water column of the Waal River were not influenced by the variation in the water discharge at the sampling date, during very low and low discharges. Differences in sampling methods and examined abiotic compartments among studies worldwide limited the comparison of plastic abundance in the freshwater systems.

The total amount of plastic in the river Waal is about 350 million particles per year. This is a baseflow at low and intermediate discharges, as we did not sample during flood events. High concentration of macro- and mesoplastic in the water column when compared with studies that only focus on floating plastic concentration underpin the concept that the majority of plastics is transported below the water surface, urging the need to accurately assess plastic concentrations below the surface water.

Identifying the sources and type of plastic is an important step in the development of mitigation and management strategies, e.g., environmental policies, educational strategies, among others. Conclusions point out to a continues need of research on plastic survey in freshwater systems to understand the riverine plastic concentration and transport.

6. References

Anderson, J. C., Park, B. J., and Palace, V. P. (2016). Microplastics in Aquatic Environments: Implications for Canadian Ecosystems. *Environmental pollution* (Barking, Essex: 1987), 218, pp. 269–280. doi: 10.1016/j.envpol.2016.06.074.

Andrady, A.L. and Neal, M.A. (2009). Applications and Societal Benefits of Plastics. Philosophical Transactions: *Biological Sciences*, 364(1526), pp. 1977–1984.

Arthur, C., Baker, J., and Bamford, H. (2009). Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Micro-plastic Marine Debris. Sept 9-11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Baldwin A. K., Corsi S. R and Mason S. A. (2016). Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. *Environmental science & technology*, 50(19), pp. 10377–10385.

Bergmann M., Gutow L. and K. M. (2015). Marine Anthropogenic Litter, *Springer International Publishing.*

Blair, R. M., Waldron, S., Phoenix, V. and Gauchotte-Lindsay, C. (2017). Micro- and Nanoplastic Pollution of Freshwater and Wastewater Treatment Systems. *Springer science reviews*, 5(1-2), pp. 19–30.

Blettler Martín C. M and Wantzen, K. M. (2019) "Threats Underestimated in Freshwater Plastic Pollution: Mini-Review," *Water, Air, & Soil Pollution: An International Journal of Environmental Pollution*, 230(7), pp. 1–11.

Cable, R. N., Beletsky, D., Beletsky, R., Wigginton, K., Locke, B. W., Duhaime, M. B. (2017). Distribution and modeled transport of plastic pollution in the great lakes, the world's largest freshwater resource. *Environ. Sci*. 5, 45

Cheshire, A., Adler, E., Barbière, J., Cohen, Y., Evans, S., Jarayabhand, S., Jeftic, L., Jung, R.T., Kinsey, S., Kusui, E.T, Lavine, I., Manyara, P., Oosterbaan, L., Pereira, M.A., Sheavly, S., Tkalin, A., Varadarajan, S., Wenneker, B., and Westphalen, G. (2009). UNEP/IOC

Cole, M., Lindeque, P.; Fileman, E., Halsband, C., Goodhead, R., Moger, J., and Galloway, T. S. (2013). Microplastic ingestion by zooplankton. *Environ. Sci. Technol*., 47, 6646−6655.

Collas, F. P. L., Buijse, A. D., van den Heuvel, L.,. van Kessel, N.,. Schoor, M. M., Eerden, H., and . Leuven, R. S. E. W. (2018). Longitudinal training dams mitigate effects of shipping on environmental conditions and fish density in the littoral zones of the river Rhine. *Science of the Total Environment* 619–620:1183–1193.

de Ruijsscher, T., Naqshband, S., Hoitink, T. (2018). Flow Bifurcation at a Longitudinal Training Dam: Effects on Local Morphology. *E3s Web of Conferences 40*, 05020–20. https://doi-org.ru.idm.oclc.org/10.1051/e3sconf/20184005020.

Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, M., Tassin, B. (2015). Microplastic contamination in an urban area: a case study in Greater Paris. *Environmental Chemistry*, CSIRO Publishing, pp.2015.

Estahbanati S and Fahrenfeld N. L. (2016). Influence of Wastewater Treatment Plant Discharges on Microplastic Concentrations in Surface Water. *Chemosphere*, 162, pp. 277–84. doi: 10.1016/j.chemosphere.2016.07.083.

Ganita Mare. (2017). Available on: https://www.historischekringgente.nl/wp-content/uploads/2018/03/Ganita-mare-2017-1-optimized.pdf.

Gasperi, J., Dris, R., Bonin, T., Rocher, V. and Tassin, B. (2014). Assessment of Floating Plastic Debris in Surface Water along the Seine River. *Environmental Pollution*, 195, pp. 163–166. doi: 10.1016/j.envpol.2014.09.001.

González, D., Hanke,G., Tweehuysen, G., Bellert, B., Holzhauer, M., Palatinus, A., Hohenblum, P., Oosterbaan, 502 L. (2016). Riverine Litter Monitoring - Options and Recommendations. MSFD GES TG Marine Litter. Thematic Report; 503 JRC Technical Report; EUR 28307; doi:10.2788/461233

Gündoğdu, S., & Çevik, C. (2017). Micro- and mesoplastics inNortheast Levantine coast of Turkey: the preliminary resultsfrom surface samples. *Marine Pollution Bulletin*. https://doi.org/10.1016/j.marpolbul.2017.03.002.

Hartmann, N. B. Hüffer, T. R., Thompson, C., Hassellöv, M., Verschoor, A., Daugaard, A. E., . Rist, S., Karlsson, T., . Brennholt, N., Cole, M., Herrling, M. P., Hess, M.C., Ivleva, N. P., Lusher, A.L., Wagner, M. (2019). Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris. *Environ. Sci. Technol*., 53, pp. 1039-1047.

Hasselerharm, R. P. E., Falahudin, D. D., Peeters, E. T. H. M. and Koelmans, A. A. (2018). Microplastic Effect Thresholds for Freshwater Benthic Macroinvertebrates. *Environmental Science and Technology*, 52(4), pp. 2278–2286.

Hoek, P.P.C., (1888). Tijdschrift der Nederlandsche Dierkundige Vereeniging. Supplement deel ii bevattende een rapport over ankerkuil- en staalboomen-visscherij. E.J. Brill, Leiden.

IAWR- Internationale Arbeitsgemeinschaft der Wasserwerke im Rheineinzugsgebiet. (2020). Der Rhein. Available on: www.iawr.org.

Jambeck, J.R., Geyer. R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., and Law, K.L. (2015). Marine Pollution. Plastic Waste Inputs from Land into the Ocean. *Science* (New York, N.Y.), 347(6223), pp. 768–71. doi: 10.1126/science.1260352.

Lebreton, L. C. M., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., Reisser, J. (2017). River plastic emissions to the world's oceans. *Nat. Commun*. 8, 1–10.

Mani, T., Hauk, A., Walter, U. and Burkhardt-Holm, P. (2015). Microplastics profile along the Rhine *River. Sci.* Rep. 5, 17988 (2015).

Nienhuis, P. H. (2008). Environmental history of the Rhine-Meuse delta: an ecological story on evolving human-environmental relations coping with climate change and sea-level rise. Dordrecht etc.: *Springer*

OSPAR Commission. (2010). Guideline for monitoring Marine Litter on the Beachers in the OSPAR Maritime Area

Parliament of Australia. (2016). Toxic tide: the threat of marine plastic. Environment and Communications References Committee. ISBN 978-1-76010-400-9

Phillips, M. B. and Bonner, T. H. (2015). Occurrence and Amount of Microplastic Ingested by Fishes in Watersheds of the Gulf of Mexico. *Marine Pollution Bulletin*, 100(1), pp. 264–269. doi: 10.1016/j.marpolbul.2015.08.041.

Pinheiro C, Oliveira U, and Vieira M (2017). Occurrence and Impacts of Microplastics in Freshwater Fish. *J Aquac Mar Biol*. 5(6): 00138 DOI: 10.15406/jamb.2017.05.00138

PlasticsEurope (2018). Plastics – the facts 2018, an analysis of European plastics production, demand and waste data. https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018.

PlasticsEurope (2019). Plastics – the facts 2019, an analysis of European plastics production, demand and waste data. https://www.plasticseurope.org/en/resources/publications/1804-plastics-facts-2019

R Core Team, 2019. R: A language and environment for statistical computing, version 3.5.3. https://doi.org/https://www.r-project.org/

Sanchez, W., Bender. C and Porcher J.M. (2014). Wild Gudgeons (gobio Gobio) from French Rivers Are Contaminated by Microplastics: Preliminary Study and First Evidence. *Environmental research*, 128, pp. 98–100. doi: 10.1016/j.envres.2013.11.004.

Schone Rivieren. (2017). Handleiding voor monitoring. Available on: https://schonerivieren.org/images/Onderzoek/DEF_Handleiding_monitoring_-_Schone_Rivieren_2018-2019.pdf

Spaink, P. A., Letswaart, T., and Roijackers, R. (1998). Plankton Dynamics in a Dead Arm of the River Waal: A Comparison with the Main Channel, *Journal of Plankton Research*, 20(10), pp. 1997–2007. doi: 10.1093/plankt/20.10.1997.

Ten Brinke, W. B. M., . Kruyt, N. M., Kroon, A., Van den Berg, J. H. (1999). Erosion of sediments between groynes in the River Waal as a result of navigation traffic. *Special Publications of the International Association of Sedimentologists*, 28 (1999), pp. 147-160

Teunkens, B., Maris, T., Blust, R., Damme, S., Meire, P. (2018). Quantification and characterization of the plastic fluxes in the Scheldt Basin, with the ultimate goal of setting-up an efficient remediation. Available on: https://wetland-ecology.nl/sites/cwe.nioo.knaw.nl/files/1.%20Bert%20Teunkens.pdf

Van Emmerik, T., Strady, E., Kieu-Le, T. C., Nguyen, L., & Gratiot, N. (2019). Seasonality of riverine macroplastic transport. *Scientific Reports*,9(1), 1–9

Van Emmerik, T., Romain, T., Van Calcar, C., Alligant, S., Treilles, R., Tassin, B., and Gasperi, J. (2019). Seine Plastic Debris Transport Tenfolded during Increased River Discharge. *Frontiers in Marine Science* 6.

Van Emmerik, T. and Schwarz, A. (2020). Plastic Debris in Rivers. *Wiley Interdisciplinary Reviews: Water 7* (1). https://doi-org.ru.idm.oclc.org/10.1002/wat2.1398.

Verbrugge, L. N. H., Ganzevoort, W., Fliervoet, J. M., Panten, K., and Van den Born, R. J. G. (2017). Implementing participatory monitoring in river management: the role of stakeholders' perspectives and incentives *J. Environ. Manag*., 19, pp. 62-69

Vriend, Paul, van, Caroline Calcar, Merel Kooi, Harm Landman, Remco Pikaar, and van, Tim Emmerik. 2020. “Rapid Assessment of Floating Macroplastic Transport in the Rhine.” *Frontiers in Marine Science* 7.

Wagner, M., Scherer, C., Alvarez-Munoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., Grosbois, C., Klasmeier, J., Marti, T., Rodriguez-Mozaz, S., Urbatzka, R., Vethaak, A.D., Winther-Nielsen, M., and Reifferscheid, G. (2014). Microplastics in freshwater ecosystems: what we know and what we need to know. *Environ. Sci.* 26, 12.

Worm, B., Lotze, H.K., Jubinville, I., Wilcox, C., and Jambeck, J., (2017). Plastic as a persistent marine pollutant. *Annu. Rev. Environ. Resour*. 42 (1). https://doi.org/10.1146/ annurev-environ-102016-060700. null.

Wright, S. L., Thompson, R. C. and Galloway, T. S. (2013). The Physical Impacts of Microplastics on Marine Organisms: A Review. Environmental Pollution, 178, pp. 483–492. doi: 10.1016/j.envpol.2013.02.031.

Yin, L., Jiang, C., Du, C., Zhong, W., Feng, Z., Long, Y., Ma, Y and Wen, X. (2019). Microplastic Pollution in Surface Water of Urban Lakes in Changsha, China. *International Journal of Environmental Research and Public Health*, 16(9). doi: 10.3390/ijerph16091650.

Yonkos, L., Friedel, E, A., Perez-Reyes, A, C., Ghosal, S., and Arthur, C, D. (2014). Microplastics in Four Estuarine Rivers in the Chesapeake Bay, U.S.A. *Environmental Science & Technology* 48 (24), 14195-14202. DOI: 10.1021/es5036317.

Appendix A

River-OSPAR plastic category checklist (Schone Rivieren, 2017).

SCHONE RIVIEREN

Naam rivier	
Provincie	
Gebiedscode (Vul hier ontvangen code van het tracé in)	
Oeverzijde	Linker/ rechter/ onbekend
Datum monitoring	
Naam onderzoeker 1	
E-mail onderzoeker 1	
Naam onderzoeker 1	
E-mail onderzoeker 2	

Kon de meting worden uitgevoerd? Ja/ nee	Ja/Nee
Zo nee, beschrijf hier waarom	

Is er afgeweken van de voorafbepaalde 100 meter? Geef lengte en breedte aan.	Ja/Nee
Zo ja, beschrijf hier waarom	

Waren er nog bijzonderheden? Noteer hier ook herkenbare items die niet op de lijst staan. (gelieve omschrijving per gevonden item en hoeveelheid)	

Ospar ID	Plastic en piepschuim	Aantal
15	Doppen en deksels	
4.2	Drankflessen >< 1/2 liter	
4.1	Drankflessen > 1/2 liter	
40	Industriele verpakkingsmaterialen (o.a. plastic zeil, bouwplastic, landbouwplastic)	
3	Kleine plastic tasjes	
117.1	Ondefinieerbare plastic stukjes 0 - 2,5 cm (hard plastic)	
46.1	Ondefinieerbare plastic stukjes 2,5 - 50 cm (hard plastic)	
47.2	Plastic stukken > 50cm (hard plastic)	
1172	Ondefinieerbare stukjes piepschuim 0 - 2,5cm (schatting)	
462	Ondefinieerbare stukjes piepschuim 2,5cm - 50 cm	
472	Piepschuim > 50 cm	
6.1	Piepschuim voedselverpakkingen (o.a. hamburger)	
212	Piepschuim bekers of delen daarvan	
21	Plastic bekers of delen daarvan	
117.2	Plastic folies of stukken daarvan 0 - 2,5 cm (zacht plastic)	
46.2	Plastic folies of stukken daarvan 2,5 - 50cm (zacht plastic)	
47.1	Plastic folies of stukken daarvan > 50cm (zacht plastic)	

SCHONE RIVIEREN

22.1	Rietjes	
22.2	Roerstaafjes	
19	Snoep, snack en chipsverpakkingen	
6	Voedselverpakkingen (o.a. yoghurt, ketchup, boter, frietbakjes etc.)	
4.3	Wikkels van drankflessen	
5	Verpakking van schoonmaakmiddelen (o.a. afwasmiddel, allesreiniger etc.)	
1	6-pack ringen	
16	Aanstekers	
14	Auto onderdelen	
22	Bestek	
22.1	Plastic borden	
481	Biofilm/waterfiltertjes	
36	Breekstaafjes	
38	Emmers of stukken daarvan	
38.1	Plastic bloem/plant potten, plantentrays of stukken daarvan	
43	Geweerpatronen en hulzen	
25	Handschoenen huishoudelijk (zacht plastic)	
113	Handschoenen professioneel (dikker plastic)	
42	Helmen	
10	Jerry cans	
11	Kitspuiten	
13	Kratten of stukken daarvan	
39	Plastic band en tie-wraps	
39.1	Plakband/ schilders- ducttape of stukken daarvan	
19.1.	Plastic lolly stokjes (let op: met gaatje aan de bovenkant)	
8	Motorolie verpakkingen < 50 cm	
9	Motorolie verpakkingen > 50 cm	
24	Netzakken (o.a. voor uien/fruit)	
2.1.	Plastic vuilniszakken of stukken daarvan	
17	Schrijfwaren (o.a. pennen)	
20	Speelgoed	
35	Sportvisspullen (o.a. dobbers, aasbakjes, verpakkingen van sportvisproducten)	
2	Tassen	
31	Touw diameter > 1 cm	
32	Touw en koord diameter < 1 cm	
35.1	Visdraad (van nylon of gevlochten lijn)	
43.1	Vuurwerk of resten daarvan (alleen plastic of gecombineerd met karton)	
48	Overige plastics (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Rubber	Aantal
49	Ballonnen of resten van ballonnen (incl sierlinten)	
52	Banden (o.a. auto/fiets)	

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53	Overig rubber (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Textiel	Aantal
54	Kleding	
57/44	Schoenen, laarzen en slippers	
55	Vloerbedekking	
59	Overig textiel (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Papier	Aantal
62.1	Drankkartons (o.a sap, melk, yoghurtdrink)	
67.1.	Ondefinieerbare stukjes papier 0 > 50cm	
64	Sigarettenfilters	
63	Sigarettenverpakking of delen daarvan (plastic verpakking hier ook turven)	
61	Karton (o.a. delen van verpakking)	
65	Kartonnen bekers	
66	Kranten	
60	Tassen	
67	Overig papier (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Hout	Aantal
72	Ijsstokjes	
68	Kurken	
73	Kwasten	
69	Pallets	
74	Overig hout < 50 cm (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	
75	Overig hout > 50 cm (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Metaal	Aantal
81	Aluminium folies en verpakkingen	
81.1.	Capsules (o.a. koffie/ chocomel)	
78	Drankblikjes	
79	Electriciteitsdraden	
83	Industrieel oud ijzer (o.a. kabels, pijp etc.)	
77	Kroonkurken & metalen doppen (o.a. bierdoppen)	
84	Oliedrums	
88	Omheingsdraad, prikkeldraad	
76	Spuitbussen	
86	Verfblikken	
80	Vislood	
82	Voedselblikken	

SCHONE RIVIEREN

120	Wegwerp BBQs	
89	Overig metaal < 50 cm (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	
90	Overig metaal > 50 cm (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Glas	Aantal
91	Flessen, potten of stukken daarvan	
92	Lampen en TL lampen	
93	Overig glas (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Sanitair	Aantal
7	Cosmetica verpakkingen (o.a. shampoo, deodorant, zonnebrand)	
98	Plastic wattenstaafjes (let op: ribbels aan beide zijden)	
982	Kartonnen wattenstaafjes	
102.2	Sanitaire/vochtige doekjes	
97	Condooms	
99	Maandverbanden, inlegkruisjes of verpakkingen ervan	
18	Plastic kam of borstel	
100	Tampons, tampon applicators of verpakkingen ervan	
102.3	Toiletpapier of stukken daarvan	
101	Toilet verfrissers	
102	Overig sanitair (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Medisch	Aantal
103	Verpakkingen (van o.a. pillen, lenzen- en vloeistof)	
104	Injectiespuiten	
105	Overig medisch (indien herkenbaar, noteer omschrijving per gevonden item in opmerkingen veld)	

Ospar ID	Granulaat	Aantal granulaatkorrels
	Detailmeting 50x50 cm x strooisellaag	

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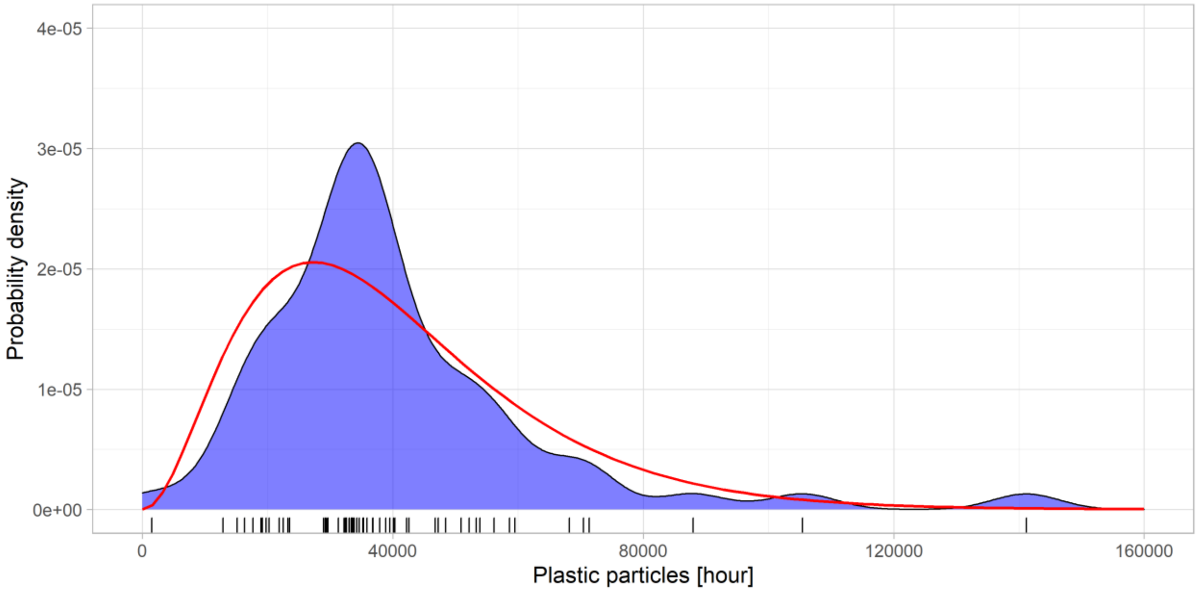
Appendix B

Overview of each plastic category, plastic type per location and plastic sizes, included in the current study.

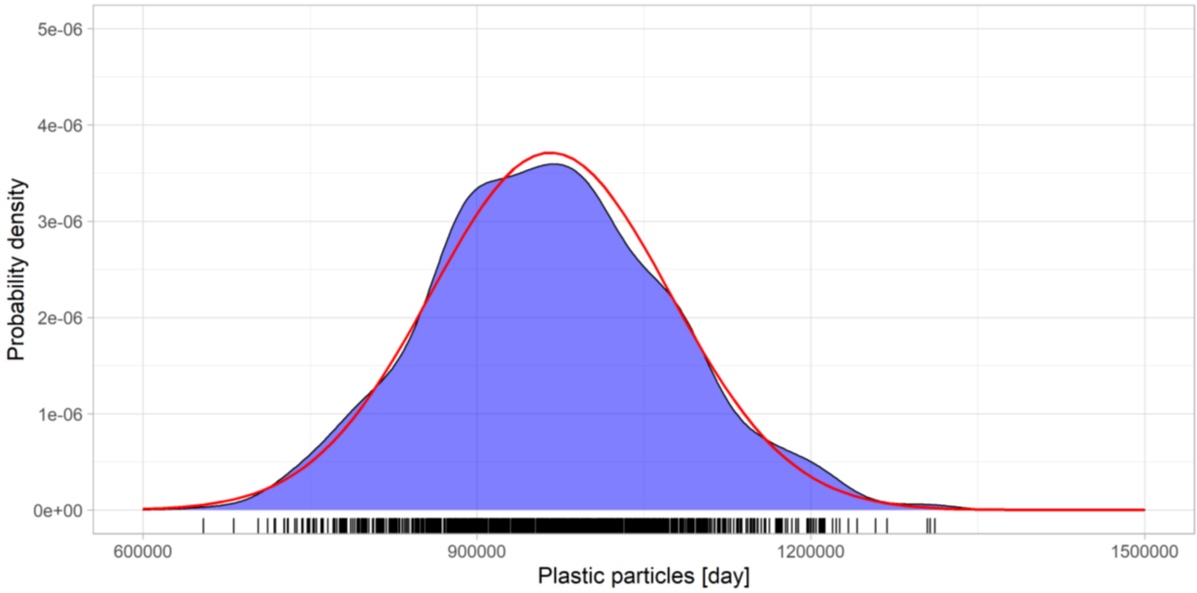
			Main channel		Shore channel	
			% Items		% Items	
Plastic category	Type	% Total	Macroplastic	Mesoplastic	Macroplastic	Mesoplastic
Caps and lids	Hard	0,37%	0,10%	0,00%	0,67%	0,41%
Drink bottles ≤1/2	Hard	0,03%	0,00%	0,00%	0,07%	0,00%
Drink bottles >1/2	Hard	0,07%	0,05%	0,00%	0,13%	0,00%
Industrial packaging materials	Hard	0,04%	0,00%	0,00%	0,10%	0,00%
Small plastic bags	Soft	0,54%	0,84%	0,00%	0,74%	0,00%
Undefined plastic pieces 0 - 2.5 cm (hard plastic)	Hard	1,97%	0,00%	3,30%	0,00%	8,87%
Undefined plastic pieces 2.5 cm - 50cm (hard plastic)	Hard	1,90%	1,34%	0,00%	3,75%	0,00%
Plastic pieces> 50cm (hard plastic)	Hard	0,01%	0,05%	0,00%	0,00%	0,00%
Indefinable pieces of styrofoam 0 - 2.5cm	Foam	0,19%	0,00%	0,38%	0,07%	0,66%
Indefinable pieces of styrofoam 2.5 cm - 50 cm	Foam	0,01%	0,00%	0,00%	0,03%	0,00%
Styrofoam> 50 cm	Foam	0,00%	0,00%	0,00%	0,00%	0,00%
Styrofoam food packaging	Foam	0,00%	0,00%	0,00%	0,00%	0,00%
Styrofoam cups	Foam	0,00%	0,00%	0,00%	0,00%	0,00%
Plastic cups	Hard	1,41%	0,25%	0,00%	3,24%	0,08%
Plastic film 0 - 2.5 cm (soft plastic)	Soft	28,07%	0,00%	93,60%	0,00%	85,62%
Plastic film 2.5 - 50 cm (soft plastic)	Soft	39,37%	65,57%	0,00%	51,84%	0,00%
Plastic film >50cm (soft plastic)	Soft	0,21%	0,40%	0,00%	0,24%	0,00%
Straws	Hard	0,08%	0,05%	0,00%	0,17%	0,00%
Stirrers	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Candy- snack- and chips packaging	Soft	6,67%	7,65%	0,19%	11,00%	0,16%
Food packaging	Hard	0,70%	0,15%	0,00%	1,62%	0,00%
Food packaging (soft)	Soft	1,03%	0,84%	0,00%	1,92%	0,08%
Beverage bottle wrappers	Soft	1,32%	0,40%	0,19%	2,80%	0,25%
Cleaner bottles & containers	Hard	0,04%	0,05%	0,00%	0,07%	0,00%
6-pack ring	Soft	0,00%	0,00%	0,00%	0,00%	0,00%
Cigarette lighters	Hard	0,04%	0,05%	0,00%	0,07%	0,00%
Car parts	Hard	0,01%	0,00%	0,00%	0,03%	0,00%
Cutlery	Hard	0,08%	0,00%	0,00%	0,20%	0,00%
Plastic plates	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Biofilm / water filters	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Light sticks	Hard	0,03%	0,05%	0,00%	0,03%	0,00%
Buckets	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Plastic flower / plant pots	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Shotgun cartridges	Hard	0,03%	0,00%	0,00%	0,07%	0,00%
Gloves (washing up)	Soft	0,12%	0,00%	0,00%	0,30%	0,00%
Gloves (industrial/ professional)	Soft	0,04%	0,00%	0,00%	0,10%	0,00%
Hard hats/ Helmets	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Jerry cans	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Injection gun containers	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Crates and baskets	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Strapping bands	Hard	0,08%	0,10%	0,00%	0,13%	0,00%
Duct tape	Soft	1,39%	0,94%	0,09%	2,60%	0,33%
Lolly sticks	Hard	0,01%	0,00%	0,00%	0,03%	0,00%
Engine oil bottles & containers < 50 cm	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Engine oil bottles & containers >50 cm	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Mesh vegetable bags	Soft	0,01%	0,05%	0,00%	0,00%	0,00%
Plastic garbage bags	Soft	0,06%	0,15%	0,00%	0,03%	0,00%
Pens and pen lids	Hard	0,01%	0,05%	0,00%	0,00%	0,00%
Toys	Hard	0,12%	0,00%	0,00%	0,30%	0,00%
Sport fishing equipment	Foam	0,15%	0,10%	0,00%	0,30%	0,00%
Shopping bags	Soft	0,17%	0,25%	0,00%	0,24%	0,00%
Rope (diameter > 1 cm)	Filament	0,03%	0,00%	0,00%	0,07%	0,00%
String and cord (diameter < 1 cm)	Filament	4,85%	9,99%	0,66%	4,42%	1,07%
Fishing line/ monofilament (angling)	Filament	2,12%	4,07%	0,09%	2,16%	0,58%
Fireworks cartridges	Hard	0,17%	0,00%	0,00%	0,40%	0,00%
Cosmetic bottles & containers	Hard	0,01%	0,00%	0,00%	0,03%	0,00%
Plastic cotton swabs	Hard	0,22%	0,10%	0,00%	0,47%	0,00%
Combs and hair brushes	Hard	0,00%	0,00%	0,00%	0,00%	0,00%
Tampons and tampons packages	Soft	3,79%	3,43%	0,94%	5,80%	1,64%
Medical Packaging	Hard	0,10%	0,00%	0,38%	0,20%	0,08%
Other plastics items	-	2,29%	2,88%	0,09%	3,48%	0,16%

Appendix C

Generated Probability distributions of plastic particles per hour and plastic particles per day calculated in the bootstrapping procedure.



Original PDF — Modelled PDF



Original PDF — Modelled PDF

Appendix D

Figures for comparison between filaments included in the "String and cord (diameter < 1 cm)" category and geotextile material observed in the groyne fields.

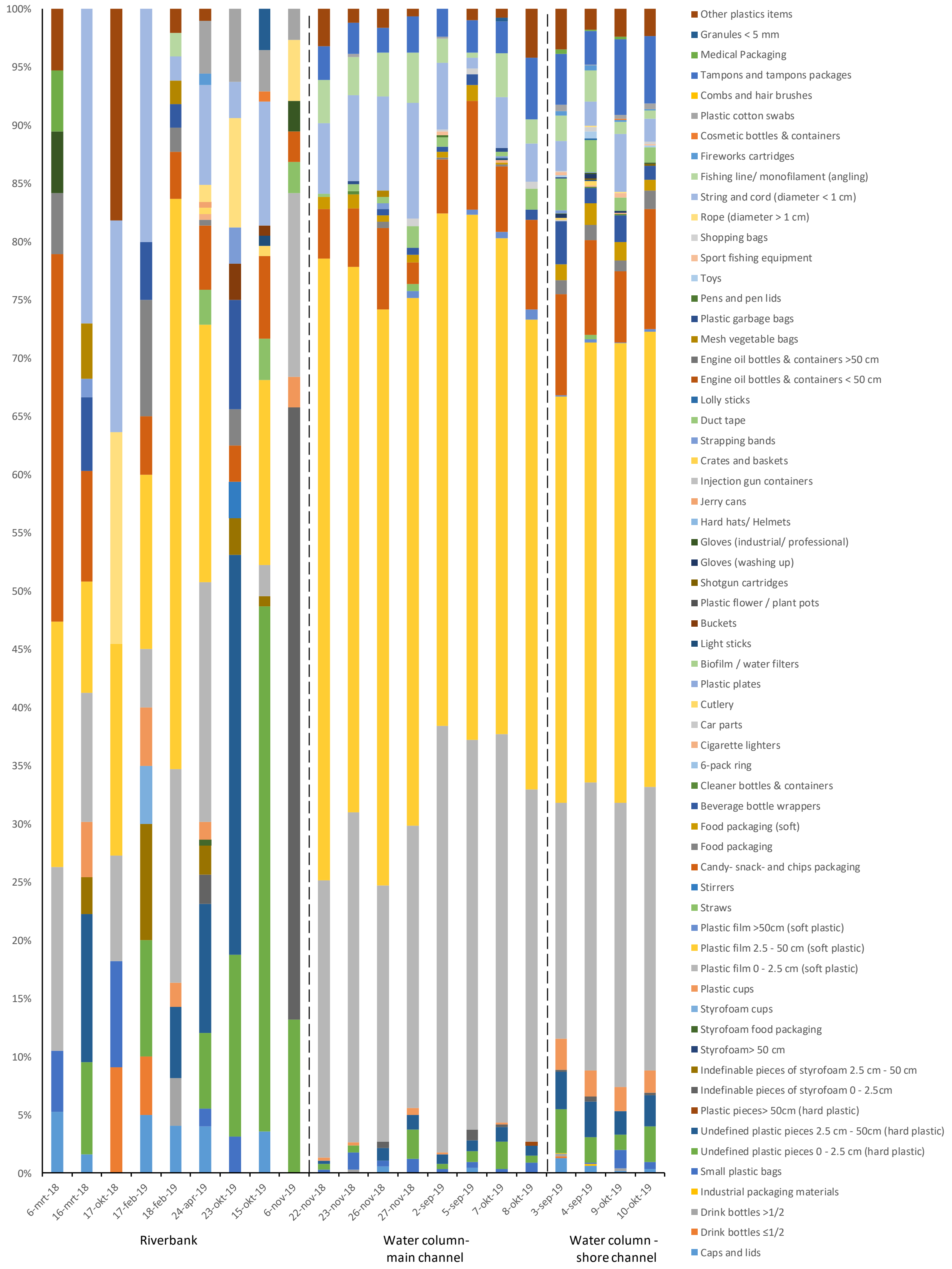
Appendix E

Overview of water discharge ($m^3.s^{-1}$) and flow velocity ($m.s^{-1}$) from model calculations, per sampling day and location.

Location	Sampling day	Daily mean water level Tiel	Water discharge Waal (m3.s^{-1})	Flow velocity ($m.s^{-1}$)
Main channel	22-nov-18	1,85	537	0,51
	23-nov-18	1,83	537	0,51
	26-nov-18	1,80	537	0,51
	27-nov-18	1,82	537	0,51
	2-sep-19	3,51	1164	0,73
	5-sep-19	3,35	1108	0,72
	7-okt-19	2,94	937	0,69
	8-okt-19	3,06	990	0,70
Shore channel	3-sep-19	3,47	1151	0,82
	4-sep-19	3,42	1134	0,81
	9-okt-19	3,22	1066	0,77
	10-okt-19	3,40	1134	0,81

Appendix F

Proportions of River-OSPAR plastic categories per day at local riverbank, water column in the main and shore channel.



Appendix G

Proportions of plastic types in the main channel and local riverbanks, according classification method used by Gündoğdu and Çevik (2017)