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**Abstract**

The present work was carried out to quantify microplastics (MP) from three sandy beaches along the Côte d'Opale coastline located in the Hauts-de-France region of northern France. Three different study sites located along the English Channel were investigated due to different levels of anthropopression and hydrodynamic conditions. Sediments were collected at three different tide lines: high tide line (HTL), middle of the intertidal zone (IZ), and low tide line (LTL) to investigate the effects of tide line on microplastic contamination. Particles and fibers were counted and colors were recorded; polymer identification was then performed using pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS). Particles and fibers abundance ranged from 23.4 ± 18.9 to 69.3 ± 30.6 items $kg^{-1}$ dry weight sediment, with a trend towards fiber predominance, were observed. No difference in particles and fibers abundance was found between the different beaches and tide lines, except for Boulogne-sur-Mer, where the particle number was significantly different between tide lines. Major polymers identified were polyethylene (36.6 %) and polypropylene (10.7 %). This citizen science project provided preliminary data about the abundance and polymeric nature of MP along the Côte d'Opale coastline.

**Keywords**

Microplastic, sediment, beach, tide line, identification, Py-GC/MS

## 1. Introduction

The production of plastics has grown continuously since the 1950s, with an increase of 37 % over the last decade (PlasticsEurope 2017). Most plastics are extremely durable and could persist from decades to centuries in their initial forms (Hopewell et al. 2009). Due to their physical properties, plastics are able to contaminate the environment on a global scale. Plastic particles smaller than 5 mm are defined as microplastics (MP) according to the United States National Oceanic and Atmospheric Administration (NOAA) (Arthur et al. 2009). The first record of MP, named spherules, in marine surface water dates back to the 1970s (Carpenter et al. 1972). The most prominent types of MP identified in the marine environment include beads, pellets, irregular fragments, and fibers. Large plastic debris can be fragmented by different degradation mechanisms such as physical, photolytic and chemical processes leading to secondary MP (Browne et al. 2007). Following these processes, MP are distributed throughout the sediment (Kedzierski et al. 2016), the water column (Bagaev et al. 2017; Chubarenko et al. 2016), and the deep-sea (Van Cauwenberghe et al. 2013b). Indeed, MP will tend to be present either on the sea surface or in the water column, depending on their densities. Nonetheless, beyond the theoretical repartition, some parameters like size and fouling can lead to the sink or oscillation of low-density polymers throughout the water column (Kooi et al. 2017). The presence of MP in sediments of various origins was highlighted many years ago (Thompson et al. 2004). Since this observation, numerous studies have demonstrated the abundance of MP in marine sediments worldwide (Besley et al. 2017; Lusher 2015; Van Cauwenberghe et al. 2015). However, few authors have been interested in MP occurrence in the sediments of beaches along the English Channel (Ashton et al. 2010; Browne et al. 2010; Browne et al. 2011; Endo et al. 2013; Holmes et al. 2012; Ogata et al. 2009).

The challenges of environmental protection have now led to greater communication between scientists and the local population. The general public can participate in scientific projects in order to discover the benefits of research, and this enables scientists to obtain large amounts of data. These projects are called “Citizen Science Projects” and involve volunteer participants from schoolchildren to adults, who participate in data collection, data processing, or even design of project protocols (Dickinson et al. 2012). These collaborative efforts have for example made it possible to study the MP in beach sediment across Europe (Lots et al. 2017), in an American mixed land-use river (Barrows et al. 2018), and in Atlantic cod (Liboiron et al. 2016). In the present collaborative framework, five students from the University Institute of Technology (Université du Littoral Côte d’Opale) located in Boulogne-sur-Mer (France) participated in an environmental project. As no data have been published about MP quantification and characterization along the Côte d’Opale coastline of the English Channel, this study was carried out in order to fill this gap. The aims of the present study were to (1) quantify and characterize for the first time MP abundance from three beaches along the Côte d'Opale coastline; (2) observe whether the hydrodynamic characteristics and human population of these sampling sites impacted this abundance; (3) study the influence of tide lines on MP accumulation, and (4) identify polymers using pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS).

## 2. Materials and Methods

### 2.1. Study Areas

Samples were collected from three beaches: Ambleteuse, Boulogne-sur-Mer and Berck, along the Côte d'Opale coastline in the Hauts-de-France region (Figure 1). These three locations are touristic beaches of the English Channel but Ambleteuse is very close to the mixture of waters between the North Sea and the English Channel. These three beaches presented different hydrodynamic and anthropopression conditions. Ambleteuse is a village of 1,807 inhabitants (INSEE 2015) near the North Sea and located in an environmental protection zone (Vérin et al. 2018). The mouth of the Slack River is located near the beach. This 21.8 km long river has an annually water flow of 0.646 $m^3.s^{-1}$ and its watershed surface is 156 $km^2$ (Ministère de l'écologie 2018c; Service Sandre Eau de France 2012b). Boulogne-sur-Mer is a town of 42,366 inhabitants (INSEE 2015) whose beach is close to an urban and industrial area, including the largest European center for seafood processing and is protected by a dike. A bathing ban, linked to microbiological contamination, is very common on this beach located near the mouth of the Liane River. This 38.2 km long river presents a watershed of 271 $km^2$ and an annual water flow of 2.99 $m^3.s^{-1}$ (Ministère de l'écologie 2018b; Service Sandre Eau de France 2012a). Berck is a city of 14,509 inhabitants (INSEE 2015) and its beach is close to a protected environment as a part of the Berck sand dunes and the north shores of Authie Bay, which are classified as protected areas by the Conservatory of the Coast (Inventaire National du Patrimoine Naturel 2018). Moreover, samples on this beach were collected near the estuary of the Authie, which is a 108.2 km long river with an annual water flow of 7.8 $m^3.s^{-1}$ and a watershed of 1,156 $km^2$ (Ministère de l'écologie 2018a; Service Sandre Eau de France 2012c).

### 2.2. Preparation of material and prevention of contamination

Water and 70 % ethanol were filtered once through a Whatmann GF/A, 1.6 µm glass microfiber filter (Velizy-Villacoublay, France). A fully saturated salt solution was prepared adding 1 L of filtered demineralized water with 360 g of Carlo Erba Reagents sodium chloride (NaCl) (Val de Reuil, France). The density of this saline solution was 1.2 g $cm^{-3}$. This NaCl solution was also filtered once through a GF/A, 1.6 µm glass microfiber filter. Glass jars and their metals lids were previously washed following three steps: 1) rinsing with filtered demineralized water, 2) washing with filtered 70 % ethanol, and 3) rinsing again with filtered demineralized water. Metal spoons used for sampling were also cleaned with the same process and packed in aluminum foils. Glass jars were prepared, weighed and the empty weights were recorded in order to subsequently obtain the sand weight. Four Petri dishes were put in different places in the laboratory during the extraction and counting processes in order to evaluate airborne contamination. In addition, cotton lab coats were worn during all steps of the analytical procedure (material preparation, filtration, counting, and isolation).

### 2.3. Sampling, extraction and quantification of particles and fibers

Five students supervised by a researcher collected the sediment samples on January 13th and 14th, 2017 corresponding to a period of limited tourist activity and a tidal coefficient of 102, in order to collect samples across the widest possible surface area along the beaches. For each site (see supporting information Table S1), sampling was done at three different tidal zones along the beach: the high tide line (HTL), the middle of the intertidal zone (IZ), and the low tide line (LTL). Metal spoons were used to scoop (0.25 x 0.25 m) approximately the top 3 cm of beach sediment, which was immediately stored in glass jars. The samples were collected in triplicate and two meters separated each replicate at each tide line. A total of nine sediment samples per beach were analyzed. Glass jars were stored one week at 50°C in a Heraeus Type T12 stove (Thermo Scientific, Germany) to dry the sediments. Before the extraction of particles and fibers, the glass jars were weighed using a 0.01 g Sartorius CP4202S sensitivity analytical balance (Göttingen, Germany) to obtain the exact weight of dry sediment. An average of 1.5 kg of dry sediments were obtained and analyzed for each replicate at each tide line. The sediment samples were then sieved with a Retsch, AS200 Basic column (Eragny-sur-Oise, France) with sieves of 5, 2 and 1 mm. In several samples, potential colored plastic particles, e.g. red or blue, were visually extracted from sieved sediments with tweezers and counted before the density separation. The MP density-based extraction from sediment was adapted from Laglbauer et al. (2014) and Lots et al. (2017). 500 mL of fully saturated salt solution (*cf.* 2.2) were added to 250 g of dry sediment and shaken by hand for 2 minutes. After a 24H decantation step, supernatants were filtered through GF/A, 1.6 µm glass microfiber filters with a ThermoFisher Scientific Nalgene Vacuum Manifold (Montigny-le-Bretonneux, France), equipped with a Merck glass filter holder assembly with a 250 mL funnel, fritted base, cap and clamp (Fontenay-sous-Bois, France). For each supernatant, several filters were used to avoid clogging and to facilitate the observation of particles. The extraction process was performed once for each sample. The different controls and filters from the 27 sediment samples were examined using a Motic SMZ 140 binocular loupe (Richmond, Canada) with x10 magnification.

When higher magnification was required, a Motic B1 Series stereomicroscope (Richmond, Canada) with up to x40 magnification was alternatively used to correctly differentiate the MP. They were counted and separated in two categories: 1) fibers, and 2) particles comprising: fragments, pellets, films, and foams. The colors were also recorded to display the proportions of the various observed colors. In addition, the colors of particles and fibers were compared between the controls and the samples. White, green, yellow, red and blue fibers were observed in controls, leading to the exclusion of these fiber colors in order to adjust the data for sample contamination. The abundance in a sediment sample was expressed as a number of items per kilogram dry weight sediment (items $kg^{-1}$ d.w.).

### 2.4. Polymer identification

A sub-sampling of MP, excluding fibers, was analyzed following the Py-GC/MS method described by Dehaut et al. (2016). Briefly, the analysis cup containing the plastic was placed on the AS-1020E autosampler of a Frontier Lab EGA/PY3030D (Fukushima, Japan), before being pyrolyzed at 600 or 700°C for 1 min. Pyrolysis products were directly injected, in split mode set at 40, 20 or 5 depending on item size, on a coupled Shimadzu GC-2010 device (Noisiel, France) and separated on a Restek RXi-5ms® column (60 m, 0.25 mm, 25 µm thickness) (Lisses, France). The temperatures of the transfer line and of the injection port were both fixed at 300°C. Helium was used as the carrier gas with a linear velocity of 40 $cm.s^{-1}$. The oven program was set as follows: 5 min at 40°C increasing to 320°C at $20°C.min^{-1}$, maintained for 14 min. Mass spectra were obtained by a Shimadzu QP2010-Plus mass spectrometer coupled to the GC. Interface temperature was fixed at 300°C, ion source temperature was set at 200°C, ionization voltage was set at 70 eV and a mass range extending from 33 to 500 m/z was analyzed with a 2000 Hz scan speed.

Polymer identification was performed using F-Search software 4.3. Each pyrogram was firstly identified, querying against Frontier Lab's database, and then a custom database containing pre-acquired pyrograms with reference plastic samples. Identification was established based on the similarity percentage between average mass spectra. As advised by the Py-GC/MS supplier, a minimal value of 80 % was necessary to certify proper identification. Secondly, if identification was not possible using F-Search and pyrolytic product was still present, the pyrogram was manually compared with the available literature (Tsuge et al. 2011), and characteristic compounds were searched in the pyrogram before being identified using the National Institute of Standards and Technology (NIST) 08 database.

### 2.5. Statistical analyses

All statistical analyses were performed using R software 3.4.2 (R Core Team 2017). Differences of item abundances were first assessed between beaches and then by zone for a given beach. For a given beach, the different abundances at the tide lines were compared considering the fibers, then the particles, and finally for all the items. The significance of the difference was studied using either one-way ANOVA or the Kruskal-Wallis test (KWT). ANOVA were solely carried out after careful control of residuals normality using a Shapiro-Wilks test and distribution homoscedasticity using Bartlett's test. When one of the hypotheses was not verified ($p$-value $< 0.05$), a non-parametric approach using a Kruskal-Wallis test was preferred. In a single case, a post-hoc test was performed after a Kruskal-Wallis test using the *kruskal()* function of the agricolae package 1.2.7 (De Mendiburu 2017), which is based on Fisher's least significant difference criterion and Bonferroni correction. Error bars indicated on bar charts represent the dispersion of data, illustrated by standard deviations. Bars tagged with different letters are significantly different with an error risk of 5%.

## 3. Results

### 3.1. Occurrence of particles and fibers in beach sediment

#### 3.1.1. Regional variability of particles and fibers

Overall, 184 filters were analyzed and 1692 items were detected from the sediments, which were separated in two categories: 185 particles and 1507 fibers. The average abundances of particles and fibers in beach sediments were 33.9 ± 24.9 items $kg^{-1}$ dry weight (d.w.), 46.5 ± 17.3 items $kg^{-1}$ d.w., and 48.1 ± 40.9 items $kg^{-1}$ d.w. at Ambleteuse, Boulogne-sur-Mer, and Berck, respectively (Table 1). Overall, the total particles and fibers abundance was not different (ANOVA, $p$>0.05) between the three sites (Figure 2). This similarity was also observed between the three sites (Figure 3) for the abundance of particles (KWT, $p$>0.05) and fibers (KWT, $p$>0.05).

#### 3.1.2. Line tide influence on particles and fibers variability

The particle abundance between the three tides lines at Boulogne-sur-Mer was significantly different (KWT, $p$=0.02) with no particles at the low tide line, while the number of particles increased with the proximity to the high tide line (Figure 3A). Moreover, 15.3 % of particles counted at the high tide line were black pellets (3.6 items $kg^{-1}$ d.w.) (Figure S1). Nonetheless, no significant difference was highlighted between the three tidal heights at the other studied sites concerning the total particles and fibers abundance (ANOVA or KWT, $p$>0.05), but also the abundances of particles (KWT, $p$>0.05) and fibers (ANOVA, $p$>0.05) (Figure 3B). Overall on the three sites, fibers were the dominant form (88.3 %).

### 3.2. Color considerations

Among the particles, a maximum of nine colors were counted at Boulogne-sur-Mer and Ambleteuse, while seven colors were found at Berck (Figure 4A). White, green, yellow, red and blue fibers were excluded in this study as they were also observed in controls. Despite this exclusion, the same fiber color profiles were observed in beach sediments with a majority of black fibers (range 74 to 80 %) followed by pink (9 to 11 %) (Figure 4B).

### 3.3. Particles identification

Among the 185 particles found in this study, only 93 particles were analyzed (50.3 %) and 68.8 % of these sub-sample particles (64 items) were successfully identified as plastic particles (Figure 5). One item (1.1 %) presented a pyrogram with peaks matching with rubber identification. Seven polymers were identified: polyethylene (PE; 34 items; 36.6 %), polypropylene (PP; 10 items; 10.7 %), polystyrene (PS; 7 items; 7.5 %), polyethylene terephthalate (PET; 3 items; 3.25 %), polyvinylchloride (PVC; 3 items, 3.25 %), PE/PP (6 items; 6.4 %), and acrylonitrile butadiene styrene (ABS; 1 item; 1.1 %).

## 4. Discussion

### 4.1. Occurrence of particles and fibers in beach sediment

This student-based citizen science project helped to gather evidence on MP contamination of three beaches along the Côte d'Opale coastline. The contribution of citizen science has, for example, already been reported to study marine litter (Hidalgo-Ruz and Thiel 2015; Nelms et al. 2017) and MP on the coasts of continental Chile and Easter Island (Hidalgo-Ruz and Thiel 2013), and on several European beaches (Lots et al. 2017).

The abundances found in the present study were consistent with other studies dealing with the MP contamination of sandy beaches (Table 1). Another recent study located along the English Channel revealed a concentration of 156 ± 29 MP $kg^{-1}$ d.w. and 143 ± 13 MP $kg^{-1}$ d.w. on two stations in Normandy (northwestern France) (Lots et al. 2017). The use of a single extraction step led to a potentially underestimated number of MP (Yu et al. 2016). However, due to the large variety of sampling and extraction techniques applied, comparison of reported MP concentrations between studies is difficult due to: (i) differences in the lower and upper size limit implemented, (ii) the sensitivity of the applied extraction technique, and (iii) differences in sampling techniques leading to a wide variety of reporting units (OSPAR 2017). Despite the different specifications for the three beaches, no significant differences in particle and fiber abundances were observed between these sites. Other authors have highlighted the same findings between their studied stations (Claessens et al. 2011; Dekiff et al. 2014; Lo et al. 2018).

### 4.2. Impact of tide lines on the occurrence of particles and fibers

The significance of sampling at several tidal heights was underlined by the European Union Technical Subgroup on Marine Litter (Galgani et al. 2013). The particle concentration on the beach of Boulogne-sur-Mer increased with the remoteness to the low tide line. This observation was consistent with a study conducted on the Belgian Coast, geographically close to the Côte d'Opale coastline (Van Cauwenberghe et al. 2013a). At Berck and Ambleteuse, no differences in particles and fibers concentrations were highlighted between tidal heights as observed by other authors. The abundance of MP was indeed identical between the upper and lower drift lines of three beaches of a German island (Dekiff et al. 2014). The shoreline and infralittoral zones from six beaches along the Slovenian coast exhibited the same MP content (Laglbauer et al. 2014). The impact of tidal height on total MP abundance was also insignificant among three Canadian beaches near Vancouver (Crichton et al. 2017), four beaches of the Baltic Sea Coast (Hengstmann et al. 2018), and ten beaches in Hong Kong (Lo et al. 2018). Overall, the present study and the literature demonstrate no clear trend in MP concentration related to tide lines.

### 4.3. Possible origins of particles and fibers on the Côte d'Opale coastline

The proportions of items observed in the present study could be linked to the possible MP origins, for example the water currents (Veerasingam et al. 2016). The trend towards a higher particle concentration at Boulogne-sur-Mer could be related to the presence of a dike that lessens the currents and probably promotes particle accumulation in the beach sediments. Moreover, the current of the Pas-de-Calais coast is directed northward and constitutes the culmination of the general circulation from the Atlantic to the North Sea (Lazure and Desmare 2012). The currents could also carry MP from netting used in benthic dredges and trawls, which have the potential to contribute to MP (Lusher et al. 2017). Ropes could also contribute to MP loading when they were lost in the sea or subject to abrasion from benthic sediments (Lusher et al. 2017). These degradations could lead to some MP reaching the beach sediment under the influence of the currents and the swell. MP presence could also arise from plastic wastes on the beaches following their degradation by UV and the swell. However, the particle and fiber abundance in the present study (Table 1) could not be clearly related to one of these degradation processes. Black pellets (Figure S1) found in the present study at the high tide line at Boulogne-sur-Mer could have been transported by these currents from other geographically close regions. Interestingly, these black pellets had already been observed along the English Channel from Normandy (France) to the Netherlands (Association SOS Mal de Seine 2011), but their origin is not yet understood.

In most studies, no differentiation is made between particle and fiber concentrations (Table 1). The high fiber proportion in the present study corroborated the global trend to a predominance of fibers as observed on beaches in Belgium (Claessens et al. 2011; Van Cauwenberghe et al. 2013a), France (Bosker et al. 2018), Germany

(Dekiff et al. 2014; Hengstmann et al. 2018; Stolte et al. 2015), Iran (Naji et al. 2017), Mexico (Pinon-Colin et al. 2018), Poland (Graca et al. 2017), and the United States (Yu et al. 2018). Moreover, sewage treatment plants are present on the three studied sites (Ministère de la Transition écologique et solidaire 2016) and a large proportion of MP fibers found in the marine environment may be derived from sewage as a consequence of washing clothes (Browne et al. 2011; Henry et al. 2018). In addition, MP concentrations could be linked to human population densities, as suggested by Browne et al. (2011). Boulogne-sur-Mer has a population density three times higher than Berck and Ambleteuse, which have less than 2,000 inhabitants in winter (INSEE 2015). Despite these different numbers of inhabitants, particles and fibers abundance observed between the three sites was not different.

### 4.4. Color considerations

All sediment samples collected on the Côte d'Opale coastline contained colored particles and fibers. The observed panel of color strengthened the strong anthropogenic influx assumption of synthetic materials on these tourist beaches, as mentioned by a German study (Stolte et al. 2015). Blue fragments were already found in sediments on other beaches (Graca et al. 2017; Stolte et al. 2015). Five fiber colors were excluded from the count of the present study as they were also observed in the controls. This background contamination by fibers was already considered by other authors (Nuelle et al. 2014). Despite this exclusion of five colors, the results of the present study were consistent with the colors observed on two other French beaches where fibers were predominantly blue/black (78 to 92 %) and red (5 to 12 %) (Lots et al. 2017). The pink color observed in the present study could originate from red color degradation caused by biofilms or UV radiation (Browne et al. 2011).

### 4.5. Particles identification

MP identification using spectroscopic or thermal techniques remains an essential step in studies dealing with plastic pollution (Table 1). Among the analyzed particles, 68.8 % were successfully identified by Py-GC/MS. The comparison of identification success rates between studies remained complicated as the number of analyzed MP and the identification methods were different. The rate of successful identification may be for example 57.5 % in a New Zealand study (Clunies-Ross et al. 2016) or 4.5 % in a European study (Lots et al. 2017).

Black pellets from the high tide line at Boulogne-sur-Mer were made of PE/PP. They could correspond to black pellets observed in a previous study on the MP contamination of beaches along the French coastline (Association SOS Mal de Seine 2011). However, they were identified as PE using FTIR. The majority of the polymers identified in the present study have a low density (< 1 $g.cm^{-3}$), which was already observed in beach sediment on the southern Baltic Sea (Graca et al. 2017) and corresponded to the extraction method of MP. The density of fully saturated salt solution (1.2 g $cm^{-3}$) was indeed higher than the density of several polymers such as PP (0.85-0.92 g $cm^{-3}$), PE (0.89-0.98 g $cm^{-3}$), ABS (1.03 – 1.21 g $cm^{-3}$) and PS (0.01 – 1.06 g $cm^{-3}$) (Frias et al. 2018). Denser polymers like PET (1.38 – 1.41 g $cm^{-3}$) and PVC (1.38 – 1.41 g $cm^{-3}$) have not been extracted from sediment by flotation using this salt solution. Particles of PET and PVC were identified and corresponded to colored plastic particles (e.g. blue or red) collected and extracted visually before flotation treatment. PE was the main identified polymer at the three study sites along the Côte d'Opale coastline, which is not surprising as this is the main resin produced in Europe (PlasticsEurope 2017). These results provided preliminary characterization of MP found on three beaches located in the eastern area of the English Channel.

## 5. Conclusion

This student-based citizen science project provides initial data about MP abundance on the Côte d'Opale coastline located in Northern France. Particles and fibers concentration ranged from 23.4 ± 18.9 to 69.3 ± 30.6 items $kg^{-1}$ d.w. No significant differences in overall particles and fibers abundances were highlighted between the three beaches despite their different hydrodynamic characteristics. However, an influence of tide lines was shown on particle abundance only at Boulogne-sur-Mer, probably due to the high proportion of black pellets at this tide line. The MP analysis by Py-GC/MS identified 68.8 % of the analyzed particles, polyethylene being the major polymer. Other polymers include namely PP, PS, PET, PVC, PE/PP, ABS and rubber. Further investigations using citizen science would make it possible to diversify the sample locations to assess MP abundances and identification along the Côte d'Opale coastline or along the English Channel coastline, including samples along the Kent coast (United Kingdom). Moreover, the use of standardized protocols for collection and extraction of MP, as mentioned by Frias et al. (2018), could improve the understanding of MP pollution worldwide.

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Table 1: Overview of microplastics studies in beach sediments, where expression of abundance is on a dry weight basis (i.e. items $kg^{-1}$ d.w.) (NC is noted when abundances were not communicated)

Figure 1: Location map showing the geographical position of the Côte d'Opale coastline within France (A) and the position of the three sampling sites, namely: Ambleteuse (B); Boulogne-sur-Mer (C); Berck (D). The samples were collected at three different tide lines: HTL = high tide line; IZ = middle of the intertidal zone; LTL= low tide line.

Figure 2: Average number of particles (in white), fibers (in grey) and particles + fibers (in black) expressed as $kg^{-1}$ d.w. for each station. Bars represents the standard deviation for each station (n=9).

Figure 3: Mean number of particles (A) and fibers (B) $kg^{-1}$ d.w. at each tide line from the three stations. Bars represents the standard deviation from n = 3 for each sampling. Bars with different letters are statistically different ($p<0.05$).

Figure 4: Proportion of particles (A) and fibers (B) per color at each station.

Figure 5: Relative abundance (%) of identified polymers.

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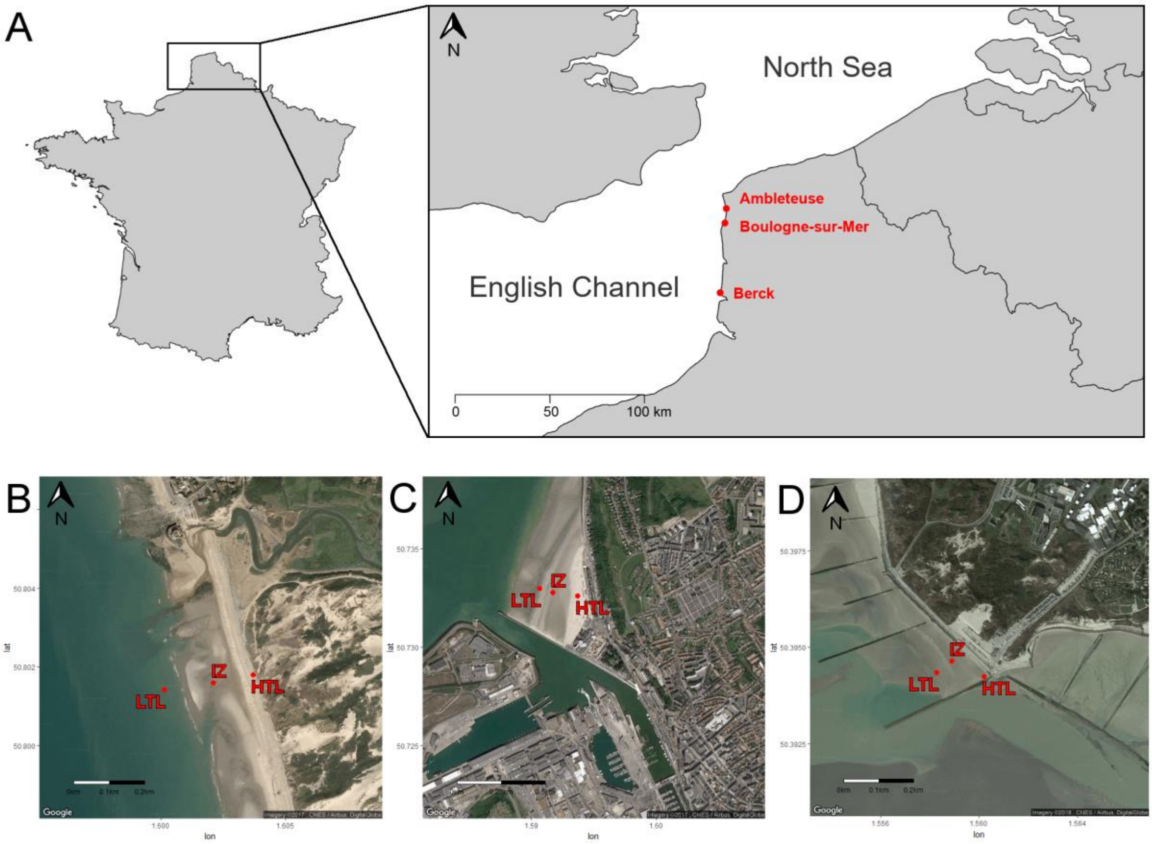
| | Country | Location | | Abundance (items $kg^{-1}$ d.w) particles | fibers | Total | Size (mm) | Method of identification | Reference |
|---|---|---|---|---|---|---|---|---|---|
| European zone | France | Ambleteuse | mean ± SD | 2.5 ± 3.8 | 31.4 ± 21.7 | 33.9 ± 24.9 | < 5 | Py-GC/MS | This study |
| | | | min - max | 0 – 9.5 | 4.36 – 62.98 | 4.36 – 71.38 | | | |
| | | Boulogne-sur-Mer | mean ± SD | 9 ± 13.1 | 37.5 ± 15.5 | 46.5 ± 17.3 | | | |
| | | | min - max | 0 – 39.55 | 13.54 – 62.11 | 16.10 – 65.35 | | | |
| | | Berck | mean ± SD | 3.5 ± 5.3 | 44.6 ± 41 | 48.1 ± 40.9 | | | |
| | | | min - max | 0 – 16.86 | 6.78 – 120.03 | 6.78 – 122.12 | | | |
| | Belgium | 3 beaches along the Belgian coast | mean ± SEM | 6.3 ± 2.5 | 81 ± 37.2 | 92.8 ± 37.2 | 0.038 – 1 | FTIR | Claessens et al. (2011) |
| | Belgium | 4 beaches along the Belgian coast | mean ± SD | NC | NC | 13 ± 9 | < 1 | *none* | Van Cauwenberghe et al. (2013a) |
| | Several countries | 23 beaches across 13 countries | range of mean ± SEM | NC | NC | 72 ± 24 - 1512 ± 187 | 0.3 – 5 | Raman | Lots et al. (2017) |
| | France | 2 sites of the western Gulf of Lion | range of mean ± SD | NC | NC | 58 ± 53-166 ± 205 | 0.063-5 | FTIR | Constant et al. (2019) |
| | Frisian Island | 2 transects in Kachelotplate &Spiekeroog islands | min - max | 0 – 62,100[a] | 100 – 1,400[a] | NC | < 5 | *none* | Liebezeit and Dubaish (2012) |
| | Germany | One beach of an eastern Frisian island | min - max | NC | NC | 1 – 2 | < 1 | Py-GC/MS | Nuelle et al. (2014) |
| | Germany | 3 beaches of Norderney island | min - max | NC | NC | 1,3 – 2,3 | < 1 | TD-Py-GC/MS | Dekiff et al. (2014) |
| | Germany | 4 beaches of the Rostock area | min - max | 0 - 4 | 42 - 532 | NC | 0.055 – 1 | *none* | Stolte et al. (2015) |
| | Germany | 4 beaches of the Baltic Sea Coast | median | 22.96 | 54.37 | 88.1 | 0.063 – 5 | *none* | Hengstmann et al. (2018) |
| | Greece | 3 beaches in northern Crete | Range of number and of mean ± SD | 0-64.2 | 2.5-22.3 | 5±5 - 85± 141 | < 5 | FTIR | Piperagkas et al. (2019) |
| | Poland | 2 beaches of the Gulf of Gdansk | mean ± SD | NC | NC | 39 ± 10 | ≤ 5 | Micro-FTIR | Graca et al. (2017) |
| | Slovenia | 6 beaches along the Slovenian coast | median | NC | NC | 133.3 | 0.25 – 5 | *none* | Laglbauer et al. (2014) |
| | | 9 beaches along the Slovenian coast in march | range of mean ± SD | NC | NC | 0.5 ± 0.5 - 1 ± 0.8 | | ATR-FTIR | Korez et al. (2019) |
| | The Netherlands | Meijendel beach | min-max | NC | NC | 200-1500 | < 5 | *none* | Besley et al. (2017) |
| Outside European zone | Canada | 4 beaches of Vancouver Island | mean± SD | NC | NC | 60.2 ± 63.4 | 0.1 – 5 | *none* | Collicutt et al. (2019) |
| | China | 5 beaches along the South Sea coast | min - max | NC | NC | 5020 - 8720 | < 5 | Micro-FTIR | Qiu et al. (2015) |
| | China | 3 beaches in the north of the Bohai Sea | min - max | NC | NC | 102.9 – 163.3 | 0.01 – 5 | FTIR | Yu et al. (2016) |
| | China | 4 beaches in the Qinzhou Bay | mean± SD | NC | NC | 3266 ± 6390.8 | < 5 | FTIR | Li et al. (2018) |
| | India | 5 beaches along the coast of Tamil Nadu | range of mean± SD | NC | NC | 33±30 - 439± 172 | | FTIR | Sathish et al. (2019) |
| | Iran | 5 beaches along the Strait of Hormuz in the Persian Gulf | range of mean± SD | NC | NC | 2±1 -1258±291 | < 4.75 | FTIR | Naji et al. (2017) |
| | Japan | 6 beaches of Hiroshima Bay | min - max | NC | NC | 5 - 1245 | 0.3 – 5 | FE-SEM and X-ray | Sagawa et al. (2018) |
| | Lesser Antilles | 21 beaches over four volcanic islands | mean ± SEM | NC | NC | 261 ± 6 | 0.3 – 5 | *none* | Bosker et al. (2018) |
| | Mexico | 9 beaches in Huatculco bay | min-max | NC | 0 – 2300[b] | NC | < 5 | *none* | Retama et al. (2016) |
| | Mexico | 21 beaches of the Baja California Peninsula | mean ± SD | NC | NC | 135 ± 92 | < 5 | FTIR | Pinon-Colin et al. (2018) |
| | New Zealand | 5 beaches in the Canterbury region | mean ± SD | NC | NC | 21.2 ± 16.5 | < 5 | Micro-Raman spectroscopy | Clunies-Ross et al. (2016) |
| | Russia | 13 beaches in the Kaliningrad region | min - max | NC | NC | 1.3 – 36.3 | 0.5 – 5 | *none* | Esiukova (2017) |
| | Russia | 3 beaches of the south-eastern part of the Baltic sea (6 sampling at wrack lines) | min - max | 31 - 365 | 5 - 335 | 53 - 572 | 0.5 – 5 | *none* | Chubarenko et al. (2018) |
| | Singapore | 5 beaches Singapore’s coastline | min - max | NC | NC | 2 – 8 | 0.0016-5 | IR spectroscopy | Ng and Obbard (2006) |
| | Taiwan | Xialiao Beach | mean | NC | NC | 17.7 | 1 – 5 | FTIR or Raman | Bancin et al. (2019) |
| | Tunisia | 4 beaches in the lagoon of Bizerte | min-max | NC | NC | 3000-18000 | 0.3 – 5 | *none* | Abidli et al. (2017) |
| | Turkey | 4 beaches in the Datça Peninsula | mean ± SD | 3313±545 | 585±110 | 1154.4±700.3 | < 5 | ATR-FTIR | Yabanlı et al. (2019) |
| | United States | 37 beaches in national parks | range of mean ± SEM | NC | NC | 21±4.3 – 221.3±28.8 | < 2 | *none* | Whitmire and Bloem (2017) |
| | United States | 18 national park beaches in the Southeastern US | min - max | NC | NC | 43 - 443 | 0.01 – 5 | FTIR | Yu et al. (2018) |

SD : Standard Deviation; SEM: Standard Error of the Mean; Py-GC/MS: pyrolysis-gas chromatography-mass spectrometry; TD-Py-GC/MS: thermal desorption-Py-GC/MS; FTIR: Fourier transform infrared spectroscopy; ATR-FTIR: attenuated total reflectance-FTIR; FE-SEM: field emission scanning electron microscopy; SEM-EDS: scanning electron microscopy (SEM) with energy-dispersive-X-ray spectroscopy (EDS)

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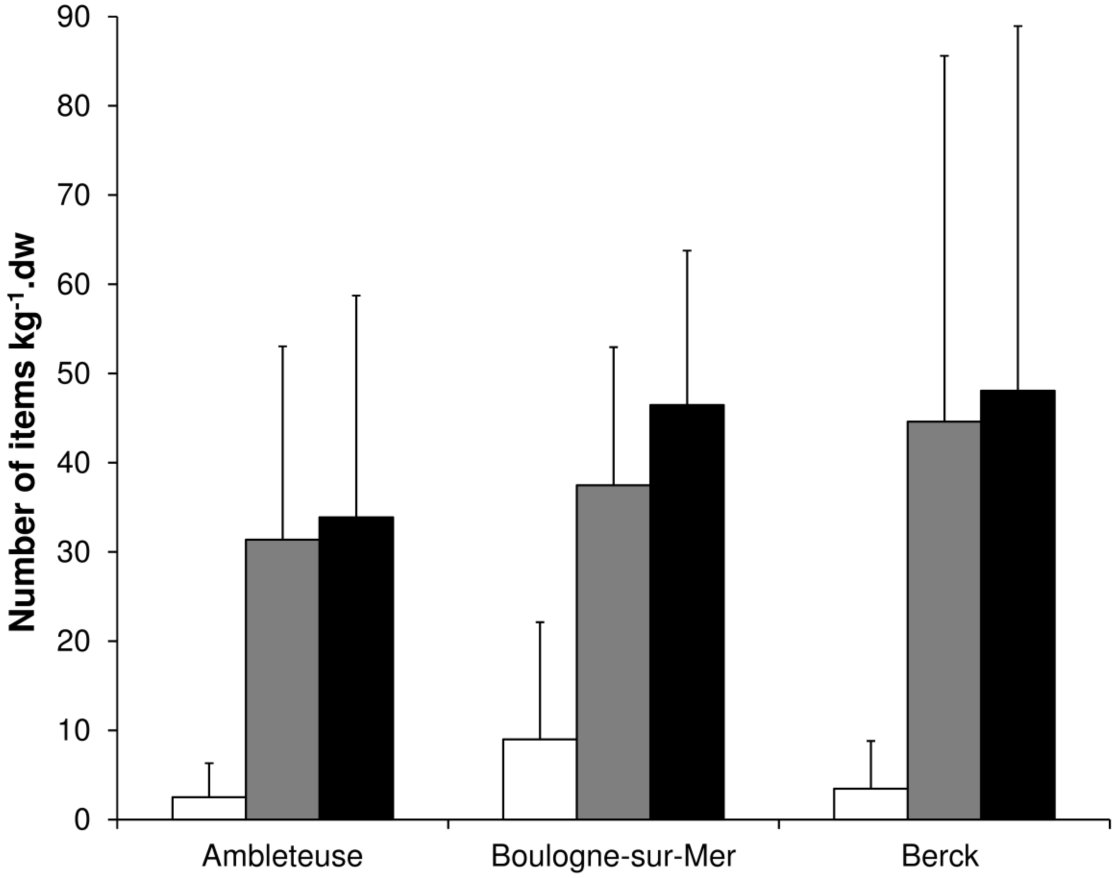


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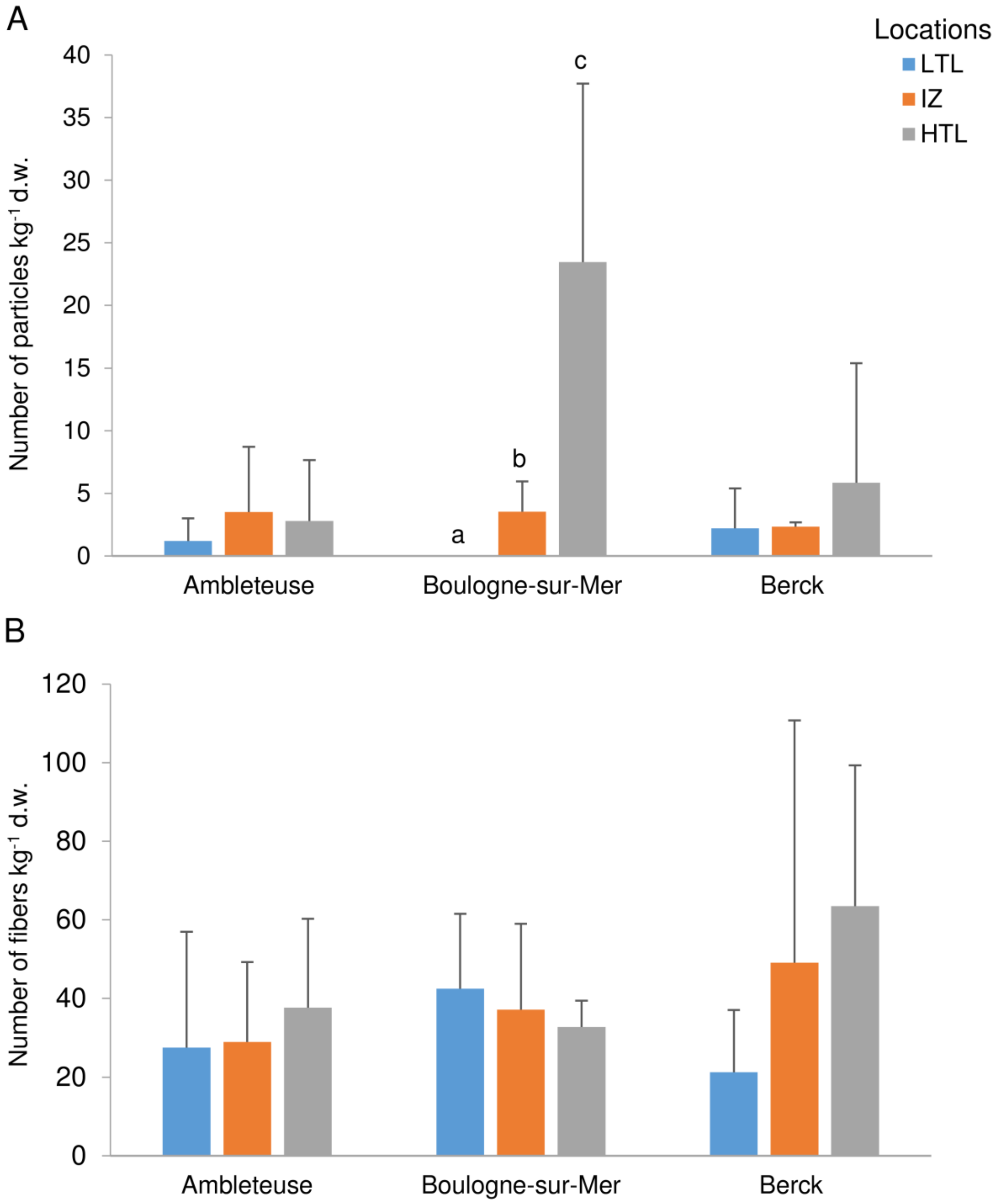


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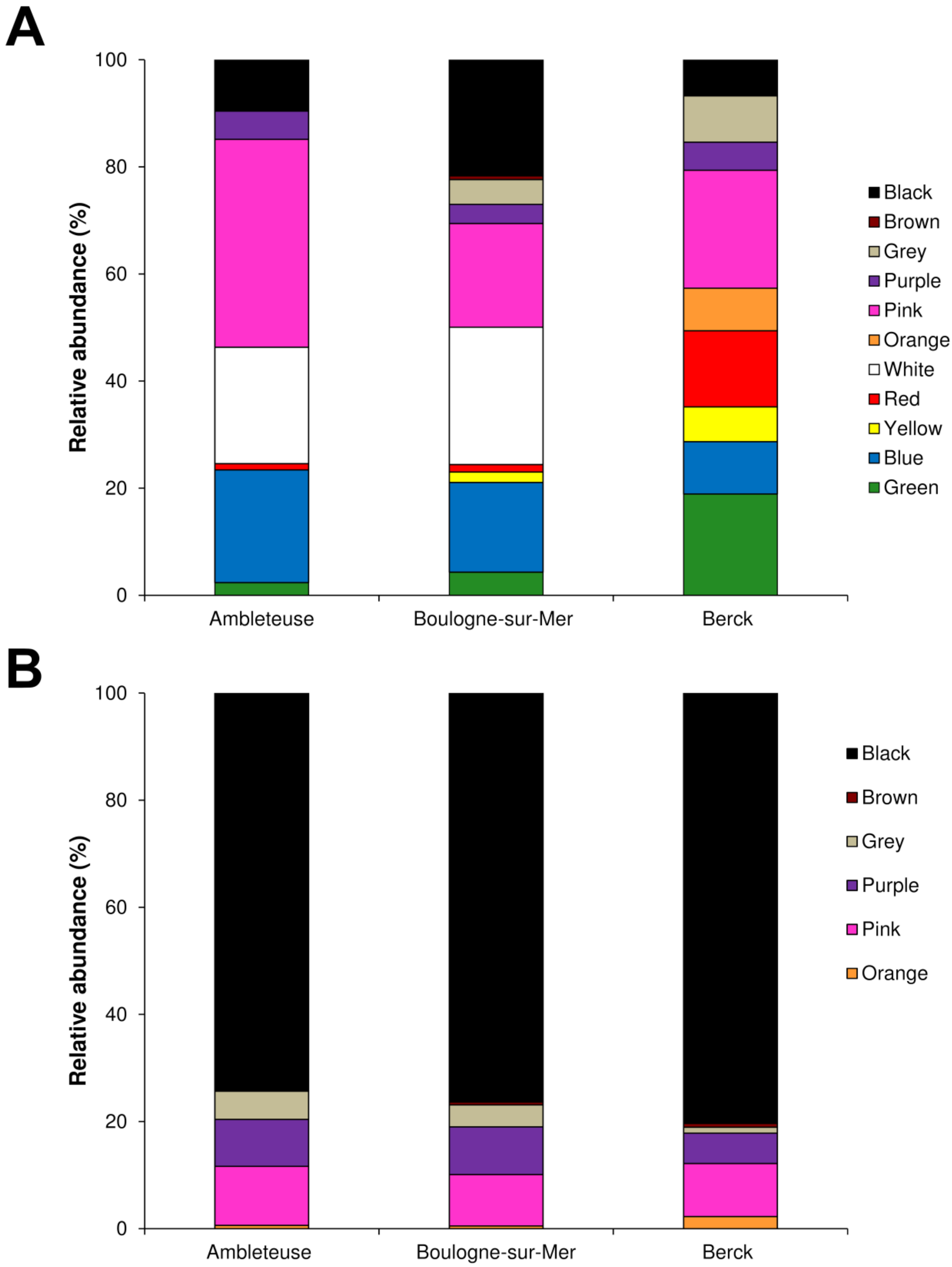


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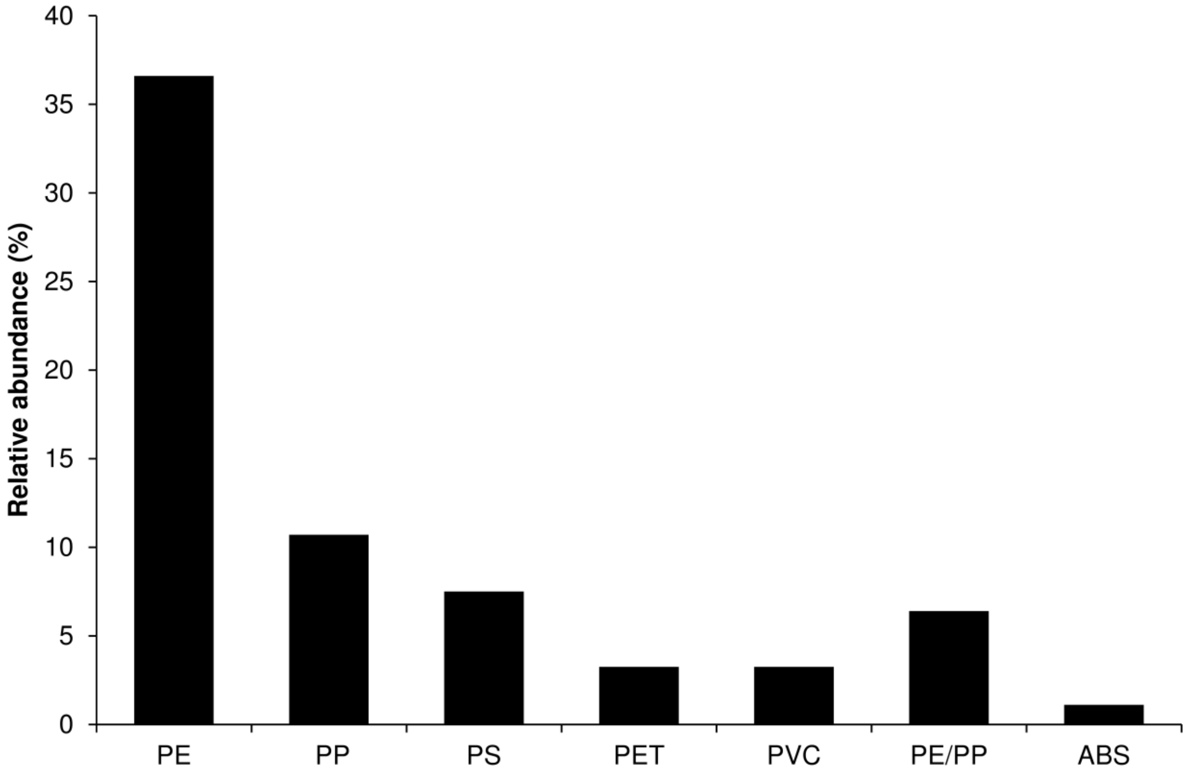


Figure 5: Relative abundance (%) of identified polymers.

**Occurrence and identification of microplastics in beach sediments from the Hauts-de-France region**

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Supplementary data

| | Ambleteuse | Boulogne-sur-Mer | Berck |
|---|---|---|---|
| HTL | 50°48'6.47" N<br>1°36'13.4"E | 50°43'57.41"N<br>1°35'13.4"E | 50°23'39.3"N<br>1°33'36.7"E |
| IZ | 50°48'5.75"N<br>1°36'7.63"E | 50°43'58.05"N<br>1°35'30.11"E | 50°23'40.7"N<br>1°33'32.0"E |
| LTL | 50°48'5.12"N<br>1°36'0.51"E | 50°43'58.72"N<br>1°35'26.39"E | 50°23'39.7"N<br>1°33'29.8"E |

Table S1: GPS coordinates of the sampling sites at the different tide line: HTL = high tide line; IZ = middle of the intertidal zone; LTL = low tide line, located in the three stations.


Figure S1: Black pellets found at the high tide line at Boulogne-sur-Mer.