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# The largest estuary on the planet is not spared from plastic pollution: Case of the St. Lawrence River Estuary

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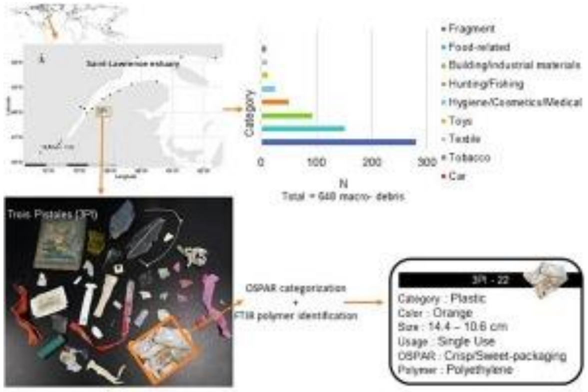
## Abstract :

The St. Lawrence River, one of the world's largest estuaries, drains >25 % of the world's freshwater reserves and is affected by various anthropogenic effluents. Although previous studies reported micro- and nanoplastics contamination in the Estuary and Gulf of St. Lawrence (EGSL), this study provides a first evaluation of macroplastic pollution along the north and south shores of the EGSL. Plastic debris categorization was performed according to the OSPAR protocol completed by polymer identification using Fourier-transform infrared spectroscopy. The EGSL appeared ubiquitously contaminated by plastic debris, dominated by single-use plastics primarily made of polypropylene (28 %), polyethylene (25 %) and polystyrene (17 %). The EGSL shores exhibited a mean contamination level of 0.17 ± 0.11 items/m2 and distance to Montreal significantly influenced the distribution of plastic debris. This study provides an essential baseline for implementing local waste reduction and management actions in the St. Lawrence watershed to reduce plastic pollution.

## Graphical abstract



Category : Plastic
Color : Orange
Size : 14.4 – 10.6 cm
Usage : Single Use
OSPAR : Crisp/Sweet-packaging
Polymer : Polyethylene

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**Highlights**

► The OSPAR protocol was used for the first time in Canada. ► Single use items (45 %) dominated plastic pollution in the St. Lawrence River. ► Distance to fishing ports and Montreal significantly affects contamination levels. ► Presence of hunting cartridges reflects local waterfowl hunting activities. ► This study provides a basis for improving local waste management.

**Keywords** : Macrolitter, Plastic pollution, Riverbank, St. Lawrence River, OSPAR, FTIR

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## 1. Introduction

A total of 390 million tons of plastics was produced in 2021, which is associated with complex waste management, leading to plastic pollution being one of the major concerns of the 21st century. This pollution is now recognized as a global contaminant with potential impacts on ecosystems, food security and human health [1–3]. Plastic production has increased over the last century due to its countless advantages (modularity, lightweight, insulation, resistance, barrier and hygienic functions) [4]. On the other hand, it is estimated that, only 9% of plastic waste is recycled worldwide, 12% is incinerated, and the remaining 79% accumulates in landfills or the environment [2]. It is currently estimated that every year 0.8 to 2.4 million metric tons of plastics end their lives in the environment [5]. Almost 50% of this production corresponds to single-use plastics (e.g. food packaging, cigarette butts), a category of plastic with a short useful life, resulting in rapid waste production [6]. These single-use items are most commonly found in the environment [7–9].

Estuaries are particularly affected by plastic pollution. Indeed, they represent a direct receptor for plastic waste issued from inland activities at the catchment area level [10, 11] and an important pathway for transport from land to ocean [12]. Coastal and estuarine areas have been identified as plastic pollution hotspots [13–15] with a large variability depending on the rivers. For instance, contamination of the river banks by plastic debris may vary from a low-level round 1 item/m$^2$ (a mean of 1.31 items/m$^2$ in three estuaries of the Cantabria region in Spain [16]) up to 3609 items/m$^2$ in the Seine estuary in France [17]. In these systems, the dispersion of macroplastic wastes (plastic debris > 2.5 cm) is highly variable in space and time, driven by environmental factors (e.g. hydrometeorological conditions, geomorphology, presence of tides, vegetation types) and by the physico-chemical characteristics of the plastics (e.g. size, shape, density) [18].

The hydrographic system of the St. Lawrence River, which includes the Great Lakes, is one of the largest in the world [19]. With a surface area of 1.6 million km$^2$ and a depth ranging from two meters in the fluvial section to 500 meters in the Gulf, it ranks third of the largest estuaries in North America. The St. Lawrence watershed drains more than 25% of the world's freshwater reserves and influences the environmental processes of the North American continent. More than 45 million people live in this basin, between Toronto, Ottawa, Detroit, Chicago, Montreal and Quebec City. The St. Lawrence River is, therefore, impacted by a variety of effluents from anthropogenic activities throughout its watershed, such as pharmaceuticals in the Montreal region [20], heavy metals in the Quebec City region [21], microplastics in the Great Lakes region [22], in sediment of Quebec City [23], in surface water of the Estuary and Gulf of St. Lawrence (EGSL) [24, 25] and nanoplastics in clams [26] and freshwater mussels [27] of the EGSL. Micro- and nanoplastics in the environment predominantly originate from the degradation of macroplastics due to environmental factors such as UV radiation, turbulence, and microorganisms [28]. In this context, the present study is the first to provide a comprehensive assessment of plastic pollution on the shores of the EGSL by targeting macroplastic debris beached on both shores at eighteen sites spread over 2000 km, from upstream to downstream of the river. The results of this study could serve as a basis for the implementation of local and global actions aimed at reducing macroplastic pollution of this system and, ultimately, micro- and nanoplastics. They will also be important for the scientific community in the context of long-term environmental monitoring of plastic pollution in the EGSL.

## 2. Materials and methods

### *2.1 Study area*

In order to provide a robust representation of the state of anthropogenic debris pollution along the EGSL, eighteen sites were sampled along the coast, nine on the north shore and nine on the south shore (Figure 1). These eighteen sites were chosen to cover the entire EGSL, encompassing different environments in terms of habitat (e.g. seagrass, foreshore, beach and seawall), accessibility and use (e.g. urban area, secluded beach, sandy beach, foreshore, boat launch) and anthropogenic activities in the vicinity of the sites (e.g. large towns, tourist sites, ports). The sites were selected to be approximately equidistant from each other on each shore, and mirroring each other between both shores.

### *2.2 Sampling and sample preparation*

Anthropogenic debris was sampled along the EGSL in 2022, from July to October. Given the diversity of landscape morphology (sandy beach, mudflat, foreshore, sloping riprap, boat ramp, small coves) along the EGSL, we adapted the sampling protocol to apply to these different sites. To do this, we chose to carry out sampling along a straight line parallel to the sea line behind the site in a fixed time of 15 min in each site. The GPS coordinates were recorded at the beginning and at the end of the 15-minutes period to calculate the distance covered by each sampling using QGIS v 3.28.9 software. All anthropogenic debris visible to the naked eye found along the transect was collected manually and stored in ®Ziploc bags. In the laboratory, samples were individually rinsed with milliQ water to remove coarse-grained debris covering the plastic samples (e.g. sand, leaves, wood debris) before being dried in a fume hood at room temperature for 24 hours and individually weighed.

### *2.3 Samples analyses*

#### *2.3.1 Visual characterization*

All debris from each site were photographed (one picture per site). Then, the debris were counted, and each feature was characterized. A visual characterization was carried out to record the size and the color of each debris. The size (maximal length and width) was measured using ImageJ (v. 1.53e). The dominant color was recorded following a grid of thirteen colors adapted from Martí *et al.* 2020; [29] (i.e. white, black, blue, yellow, red, green, pink, orange, purple, grey, brown, beige and colorless). The debris were then categorized according to the type of material involved (e.g. Paper/Cardboard, Plastic, Glass, Metal, Ceramic, Textile, Rubber, Cigarette-butt; [30]). Characterizing macrolitter based on the OSPAR categories (e.g. food packaging, butt, tires, expanded foam) help identifying the potential sources of plastic pollution. In our study, eight sources were identified: (i) food-related products, (ii) hygiene/cosmetics/medical products, (iii) tobacco products, (iv) building/industrial materials, (v) car parts, (vi) clothing/rags, (vii) hunting/fishing products and (viii) toys. The first six are those proposed by the Marine Strategy Framework Directive [31]. Here, we have added two categories (i.e. hunting and fishing products and toys) due to their prevalence in our survey. Finally, plastic items were categorized according to OSPAR classification, usually applied to marine environment and macroplastics > 2.5 cm [30] and their usage. Three criteria were used: Single-Use (SU), Long term-Use (LU) and Non-Identified (NI). The SU criterion covers items meant to be disposed of right after their use leading to a lifetime after use comprised between minutes and hours, such as food or hygiene packaging. The LU criterion covers items with a prolonged lifetime, such as building materials and textiles. Finally, the NI criterion covers debris for which it was impossible to determine their initial usage (e.g. unidentified fragments).

### *2.3.2 Chemical characterization*

A non-destructive analysis using an attenuated total reflection Fourier transformed infrared spectrometer (FTIR) was performed on 581 samples and 6 samples were discarded due to their lability (disintegrated paper sheets) or hazard in laboratory (cigarette lighters and neon party bracelets). Briefly, each debris was manually positioned using tweezers and placed on a diamond compression cell for analysis over a spectral range extending from 600 to 4000 $cm^{-1}$ (Thermo Scientific, OMNIC 9.3.32; ATR-Diamant (Golden gate DTGS); [32]). The obtained spectra were identified using a database Spectragryph© (v. 1.2.16.1) containing spectra references of the most common polymers, with a minimal correspondence of 70%. A widely used method for describing photodegradation and determining the degree of surface weathering and oxidation of polymers exposed to natural or artificial aging is the calculation of the carbonyl index ($I_{CO}$) [33, 34]. $I_{CO}$ were exclusively calculated for the most dominant polymers, PE and PP (i.e. n = 134 items), for which data are available in the literature to allow for comparison with our results. The $I_{CO}$ of each PE and PP debris was calculated from the ratio between the integrated band absorbance of the carbonyl (C=O) peak from 1,850 to 1,650 $cm^{-1}$ and that of the methylene ($CH_2$) scissoring peak from 1,500 to 1,420 $cm^{-1}$ as expressed in the following equation [34]:

$$ICO = \frac{Area\ under\ band\ 1{,}850\text{–}\ 1{,}650\ cm - 1}{Area\ under\ band\ 1{,}500\text{–}\ 1{,}420\ cm - 1}$$

## *2.4 Statistical analyses*

Statistical data processing was carried out using Rstudio software (version 2023.12.1) to check whether plastic debris concentrations at different sites varied according to environmental parameters. To answer this question, nine environmental variables were identified: (1) latitude and (2) longitude of the site; (3) site distance from Montreal; (4) site distance from Québec City; (5) site distance from the nearest city of at least 5000 inhabitants; (6) public access to the site (e.g. road, parking); (7) designation of each site (Urban/Frequented/Village/Rural); (8) soil type of each site (Silt/Sand/Shale); (9) site distance from the different ports (Marina/Fishing/Ferry/Commercial). The data table showing the variables in detail is available in supplementary data (SD0). The analyses were performed as follows: First, a hierarchical cluster analysis (package = “Cluster”, function = “Diana”) was performed to explore the relationship and magnitude of dissimilarity between sites based on measured plastic debris concentrations. Then, a canonical regression analysis (package = “Corrplot”, function = “cor.mtest”) and a simple linear regression (package = “Stat”, function = “lm”) were conducted to test whether the variation in waste concentration could be significantly explained by one or more of the nine environmental variables. The data did not require any transformations. The distribution and homogeneity of variances were checked.

Finally, a chi² residual test was carried out (package = “Stat”, function = “Chisq.test”) to highlight potential associations between OSPAR categories of waste and the different sites sampled, and thus, potential over-representation of OSPAR categories depending on the site.

## 3. Results

### *3.1 Diversity of anthropogenic debris*

The diversity of anthropogenic debris sampled during the campaign is illustrated in Figure 2 with easily identifiable items such as food packaging and other single use items (e.g. plastic straw, cup and lid, hunting cartridges, ropes, building materials) (Figure 2A; DES and B; MET) and numerous unidentifiable fragments of film and foam (Figure 2C; HSP). The debris collected at all sites are presented in supplementary data (SD1). In the EGSL, a total of 648 anthropogenic debris were collected, corresponding to 90.6% plastic items, followed by paper/cardboard (4.9%), cigarette butts (1.4%), rubber (1.2%), textiles (0.8%), metal (0.8%) and ceramics (0.3%). Plastic items were systematically dominant with more than 70% of the collected anthropogenic debris being plastics at each site, except for the MBA site, where plastic items represent only 54% of the collected debris (SD2).

### *3.2 Spatial distribution of plastic debris*

A total of 587 plastic debris were sampled with an average of 36 items per site. The minimum number of items sampled was N = 6 (ASE), and the maximum was N = 65 (ILO) (Table 1). The average concentration of plastic debris along the EGSL was 0.17 ± 0.11 items/m² with the highest concentration (0.40 items/m²) being recorded in 3RV, a densely populated area located in the fluvial part of SL between Montreal and Quebec City. The least contaminated site was ASE (0.02 items/m²), located in an area with little traffic as it is a cove in the Saguenay Fjord where access is difficult. The high standard deviation values show that the abundance of plastic waste varies widely in the EGSL. A significant gradient in plastic contamination levels appeared from upstream to downstream sites, as illustrated by the three clusters identified in the dendrogram analysis (Figure 3). Sites with low concentrations (<0.15 elements/m²; in yellow) were mainly located downstream of the EGSL. Sites with plastic debris concentrations between 0.15 and 0.24 items/m² (orange) were located upstream of the EGSL. Finally, the most polluted sites (≥0.25 items/m²; in red) are mostly located in the fluvial section of the St. Lawrence River, between Montreal and Quebec City, except for 3PI, which is located in the Upper Estuary, and KEG, which is the site furthest downstream from the EGSL.

Table 1: Distance (m) and plastic debris concentrations (items/m²) calculated from GPS coordinates (departure and arrival) along the transect, as well as the number of debris items sampled.

| **Site** | **Dep_Lat** | **Dep_Long** | **Arr_Lat** | **Arr_Long** | **Distance (m)** | **Samples** | **[N/m²]** |
|---|---|---|---|---|---|---|---|
| 3PI | 48.132929 | -69.185122 | 48.132456 | -69.186188 | 112 | 37 | 0,33 |
| 3RV | 46.373129 | -72.492410 | 46.373692 | -72.492082 | 068 | 27 | 0,40 |
| 7IL | 50.205034 | -66.297071 | 50.204928 | -66.302168 | 358 | 43 | 0,12 |
| AGR | 46.740502 | -71.296017 | 46.740053 | -71.296707 | 252 | 54 | 0,21 |
| ASE | 48.202779 | -69.905320 | 48.205219 | -69.905696 | 283 | 06 | 0,02 |
| CAB | 48.86778 | -67.453431 | 48.862549 | -67.456280 | 455 | 36 | 0,08 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CRO | 46.746956 | -71.339721 | 46.746617 | -71.337861 | 150 | 31 | 0,21 |
| DES | 46.651657 | -71.925258 | 46.651372 | -71.924888 | 141 | 41 | 0,29 |
| HSP | 50.204649 | -63.448869 | 50.206698 | -63.452090 | 320 | 14 | 0,04 |
| ILO | 46.846892 | -71.137922 | 46.848325 | -71.139676 | 217 | 65 | 0,30 |
| KEG | 50.177649 | -61.268985 | 50.177780 | -61.270513 | 135 | 34 | 0,25 |
| MBA | 48.149581 | -69.667015 | 48.148853 | -69.666904 | 089 | 08 | 0,09 |
| MET | 48.680612 | -68.033469 | 48.678717 | -68.035350 | 304 | 24 | 0,08 |
| PAP | 48.513580 | -68.470370 | 48.515483 | -68.468730 | 275 | 54 | 0,20 |
| PFR | 49.220494 | -65.036198 | 49.22091 | -65.039446 | 246 | 13 | 0,05 |
| RLO | 47.95035 | -69.495479 | 47.950186 | -69.497045 | 155 | 25 | 0,16 |
| SAM | 49.114157 | -66.645569 | 49.111891 | -66.640507 | 410 | 45 | 0,11 |
| TAD | 48.135411 | -69.699157 | 48.135729 | -69.696466 | 203 | 30 | 0,15 |

No statistical difference was observed in the number of debris items as a function of coastline (p-value = 0.1) even though a much lower number of anthropogenic debris came from the north shore (n = 266) in comparison with the south shore (n = 382), i.e. 18% more items from the south than from the north. The ANOVA performed on the canonical regression model (RDA) showed that plastic debris concentrations measured across the EGSL are dependent on latitude (p-value = 0.01**), distance to Montreal (p-value = 0.03*) and distance to fishing ports (p-value = 0.004**), with no significant (NS) influence of the distance to Quebec City (p-value = $0.08^{NS}$) (Figure 4). The outlier site above the correlation line in Figures 4B, C and D is the Kegaska (KEG) site, located at 950 km from Quebec City on the north coast. This site has one of the highest concentrations of plastic debris in our study, even though it is the most distant site in the EGSL. Running RDA without the KEG site led to much better correlation indices, as illustrated in supplementary data (SD3). The nature of the plastic litter collected in KEG may provide more information on its specificity as discussed below.

### *3.3 Plastic debris usage and color*

At the estuary scale, single-use items (SU) accounted for 43% (*i.e.* 250 items) of the total sample and were mainly represented by food and hygiene packaging. The proportion of single-use items varies from 12% (CRO, MET) to 67% (7IL) (SD4). Long-term use (LU) items account for 12% (*i.e.* 72 items) of the samples, mainly corresponding to expanding foam and, more anecdotally, toys, fishing tackle, reusable bags and textiles. For the SU and LU items, three anthropogenic sources account for 81% of the debris sampled: food-related products (42%), building/industrial materials (26%) and hunting/fishing products (14%). The remaining 45% (*i.e.* 265 items) correspond to debris for which it was impossible to determine the source or whether it was a single-use item (NI). This class includes all foam, film, fiber, soft and hard plastic fragments. Overall, plastic debris exhibited a wide variety of colors, the most dominant being white (32%), blue (17%) and transparent (14%) at the estuary scale. Inter-sites differences in color distribution can be observed as illustrated in supplementary data (SD5).

### *3.4 OSPAR classification of plastic debris*

Following the OSPAR classification protocol, 39 different plastic categories were encountered throughout the eighteen survey sites. Of these 39 categories, ten accounted for the vast majority of the collected debris (i.e. 84%; Figure 5). The two main categories are film/plastic fragments between 2.5 and 50 cm (24%) and those <2.5 cm (9%). Then come food packaging

(8%), hunting cartridges (7%), foam fragments (2,5-50 cm; 7%), insulating foam (6%), beverage cap/lid (6%), crisp/sweets packaging (6%), ribbon/tape/label/non-food packaging (6%) and foam fragment (<2.5 cm). The remaining 16% are composed of various categories, such as plastic cutlery, textile fragments or fishing lines, each accounting for less than 2%. Overall, 29 categories of less than 2% were identified.

Looking at the individual sites, the top ten categories remain the same, but there are differences in their proportions on a finer scale (Figure 6). For instance, the upstream sites of (3RV, DES) and those in the immediate vicinity of Quebec City (CRO, AGR, ILO) include numerous foam fragments (31-55%). In contrast, the 7IL site is predominantly represented by food packaging (54%), and the KEG site contains a significant proportion of hunting cartridges (38%). These results are illustrated by a Chi² test of conformity, which highlights the OSPAR categories that differ significantly from what is expected at each site (Figure 7). The null hypothesis is that there is no relationship between sites and OSPAR categories. In other words, waste is distributed independently of sites. Each OSPAR category is equally likely to be found at each site.

### *3.5 Chemical composition and oxidation degree of plastic debris*

Of the 581 plastic debris analyzed by FTIR spectrometry, 24 spectra (i.e. 4%) could not be identified (no exploitable signal, no correspondence in the database, or less than 70% of certitude). The results are thus presented for 557 identifiable plastic debris. Taking all sites together, the dominant polymers were polypropylene (PP = 27.7%), polyethylene (PE = 25.5%) and polystyrene (PS = 17.1%) (Figure 8A). Next come polyvinyl chloride (PVC = 8.1%), polyurethane (PUR = 6.8%), polyethylene terephthalate (PET = 4.7%), PE/PP copolymer (3.2%) and vinyl Chloride (VC = 2.7%). Nine other polymers were detected in less abundance, representing less than 2% each (Figure 8A). These are acrylonitrile butadiene styrene (ABS = 1.2%), polymethyl methacrylate (PMMA = 1.1%), polyoxymethylene (POM = 0.5%), polyvinyl alcohol (PVA = 0.3%), nylon (0.3%), polylactic acid (PLA = 0.2%), ethylene vinyl acetate (EVA = 0.2%), polyether ester (PEE = 0.2%) and polyvinyl butyral (PVB = 0.2%). The FTIR spectra of the 17 different polymers detected in this study can be seen in supplementary data (SD6). However, fine-scale spatial variations of polymer proportions were apparent at certain sites (Figure 8B). The 3PI site exhibited 41% of PET debris, PFR and SAM were dominated by PVC debris (73% and 32%, respectively), Anse Gingras (AGR) exhibited 33% of PUR and Kegaska (KEG) had only PE, PP and PE/PP.

The carbonyl index ($I_{CO}$) is used as an indicator of the presence of carbonyl groups, which may result from polymer degradation by environmental parameters [35]. The $I_{CO}$ was calculated for each debris of PE (N = 142), PP (N = 154) and copolymer PE/PP (N = 18) and ranged from 0 to 1.5 (SD7). No significant differences were observed in the $I_{CO}$ of PE (0.55 ± 0.31; p-value = 0.3), PP (0.47 ± 0.29; p-value = 0.1) and PE/PP copolymer (0.54 ± 0.16; p-value = 0.7) among the different sites.

## 4. Discussion

So far, the available data on plastic pollution in the EGSL focused on micro- and nanoplastics in water, sediment and mussels [23–27]. The present study provides for the first time an overview of macroplastics pollution on the banks of the EGSL, the world's largest estuary. Our study demonstrates that this ecosystem is ubiquitously contaminated by plastic debris, with an average of 0.17 ± 0.11 plastic debris/m².

### *4.1 The EGSL is ubiquitously affected by plastic pollution*

We observed a wide variety of debris, illustrating the omnipresence of anthropogenic materials in the environment, and more than 90% were plastic. This dominance of plastic is in accordance with other surveys performed on the shore of Mainland (Scotland), Adour River catchment (France) and Huveaune (France), demonstrating 77%, 95% and 83% of plastic debris, respectively [7, 11, 36]. This is due to the explosion of plastic production over the last century, associated with poor end-of-life management [2] and long persistence of this material in all environments. In addition, when not deposited directly by our uses, the positive buoyancy of most polymers makes them prone to beach on the sand banks, the shores of the rivers and beaches [10]. The level of macroplastics detected on the shore of the EGSL during our survey was relatively low compared to environmental data collected on other coastlines worldwide. Surveys carried out on beaches (Solomon and Vanuatu islands: 2.5 debris/m²; [37]), river shores (South Korea: 1 debris/m²; [38]), urban and rural areas (Philippines: 0.66 and 0.29 debris/m² respectively; [39]) demonstrated macroplastics levels that were 1.7 to 15 higher than the ones recorded in the present survey.

#### *4.1.1 Seasonal variations can partly explained the low concentrations of plastic debris on the shores of the EGSL*

Snow/ice melt and flooding are seasonal parameters that can influence the distribution of macro-waste on the shores of the St. Lawrence River. The coasts of the EGSL are snow-covered for almost six months of the year (generally from November to April), which limits recreational/touristic activities during the winter time. In addition, plastic debris trapped in the snow/ice for several months may be released into the waters of the EGSL during the spring snowmelt, then exported downstream and/or redeposited on the river banks depending on the hydrodynamic flow [18, 40, 41]. The mean annual flow of the St. Lawrence River measured at Quebec City (around 12.4 $m^3/s$ [42]) fluctuates widely due to seasonal variability and to the regulation of water inflows from Lake Ontario (variations of the order of tens of thousands of $m^3/s$ within a single year). Indeed, during spring floods, river flow is at least 40% higher than normal [43] and this substantial freshwater input plays a major role in the hydrodynamic processes of the Upper Estuary, the characteristics of the water masses and the transport of sediments. Floods, particularly in conjunction with precipitation and/or snowmelt, are also known to remobilize debris on the banks and transport it from land to sea [41, 44]. Seasonal variations in the concentration of macro-waste on European riverbanks have also been observed previously, with a spatially-averaged median litter density higher in spring (2.4 items/m) than in autumn (1.1 items/m) due to bank washout by precipitation during this period [45]. Snow/ice melt and seasonal flooding could partly explain the low concentrations of plastics observed on the banks of the EGSL, since our study was carried out a single time in summer, i.e. three months after the snowmelt and flood period.

#### *4.1.2 Hydrodynamics modeling is needed to understand spatial distribution of plastic debris on the shores of the EGSL*

There are two main currents in the St. Lawrence system, the Gaspe Current, which flows upstream and downstream along the south shore of the St. Lawrence River, and the Labrador Current, which flows down the Labrador coast and the east coast of the island of Newfoundland, then south-eastwards towards the coast of Nova Scotia [46, 47](SD8). A branch of this current enters the Gulf of St. Lawrence and flows up the Gulf along the north shore. Based on this hydrographic system, it was assumed that plastic debris from large anthropogenic centres would tend to follow the Gaspe current and accumulate on the south shore of the river system. However, our results, based on a single sampling, show no difference (p-value = 0.1) in the concentration of anthropogenic debris between the north and the south coasts of the EGSL. Long term and seasonal monitoring coupled with Lagrangian modeling of the distribution and fate of floating plastic debris in coastal ecosystems would be needed to better identify the influence of small-scale hydrodynamics and potential hot spots and/or sinks [48, 49]. In addition, the residence time of macroplastics in estuarine ecosystems can be increased by complex tidal dynamics or coastal topography, i.e. bidirectional flow with low export to the ocean, or by (temporary) storage of macroplastics on banks [18, 45]. In our study, the easily identifiable food and hygiene packaging debris was probably recent, with a short residence time in the river, as suggested by its low carbonyl index, around 0 (SD7). In contrast, other plastic debris such as some fragments showed higher carbonyl indices, close to 1, suggesting a more advanced state of degradation [50, 51]. The fragmented debris also appeared to have been subjected to environmental stresses (e.g. UV radiation, turbulence, salinity, microorganisms), suggesting a long residence time in the environment.

#### *4.1.3 Local anthropogenic activities influence plastic debris distribution on the shores of the EGSL*

Latitude (pv = 0.01**) and distance from Montreal (pv = 0.03*) were shown to significantly influence the distribution of plastic debris as demonstrated by the canonical regression analysis. However, latitude and proximity to major cities are closely related in the present study. Indeed, the higher the latitude, the further away from the major anthropogenic centers represented here by Montreal and Quebec City, and the lower the concentration of plastic debris. Proximity to urban centers is suggested as one of the most important factors contributing to plastic pollution [52]. This hypothesis has been confirmed in several studies, where measured concentrations of plastic particles were higher in the immediate vicinity of urban centers in Portugal [53], Iran [54], South Africa [55] and the Great Lakes [56]. In our survey, an exception was detected with the high concentration of plastic debris retrieved at KEG (0.25 items/m$^2$), the furthest site from Montreal and Quebec Cities. This site is characterized by an over-representation of hunting cartridges (Figure 7), which thus increased the debris concentration, as discussed below.

Our correlation analysis also showed that the further away from a fishing port, the higher the concentration of plastic debris. This result seems surprising given the impact that fishing-related waste can have on plastic pollution. Indeed, it is estimated that around 10% of plastics in aquatic environments come from fishing and aquaculture activities [57, 58]. These debris can be accidentally lost at sea or deliberately thrown overboard [59]. The authors specify that the 10% of debris related to fishing includes both macro- and micro-sized debris (e.g. fragments of fishing nets), whereas in our study, only macro-sized debris is taken into account. Here, the negative correlation observed between plastic debris concentrations and distances to fishing ports may be explained by the fact that the EGSL is characterized by many fishing ports in its marine section, which is not the case in its river section [60] where the highest plastic debris levels were recorded in the Vicinity of Quebec and Montreal cities.

Local and recreational activities may also influence the composition of plastic debris [61]. The protocol established by the OSPAR Convention provides a replicable and comparable framework for monitoring anthropogenic litter pollution at the studied sites [30], which may help to identifying the sources of anthropic debris. Initially developed for the North-East Atlantic, it was recently used in other coastal regions, such as the Caribbean [62], Oman [63] and Vanuatu [37] and was used for the first time in Canada in the present study. The litter present at a given site may come from a local source, at sea or in land, or from distant sources and be transported by rivers or ocean currents. The composition of coastal litter indicates the scale and dimension of the problem and the level of threat to the marine environment. Spatial differences in the abundance and composition of litter from one site to another can highlight areas where regulatory measures could be implemented to tackle local sources of plastic pollution. The majority of debris collected in the EGSL was represented by fragments of hard plastic, film and foam, which is in line with studies carried out on the coastal shores, where the authors found from 20 to 80% of plastic fragments (hard, film, foam) [8, 36, 64–66]. The presence of hard fragments of aged plastic at all sites attests to their persistence and ability to be transported along river basins. In addition, the dominance of foam fragments that were found mainly in the fluvial section of the St. Lawrence, from Trois-Rivières (3RV) to Île d'Orléans (ILO) can be explained by the immediate proximity of two major cities (e.g. Trois-Rivières and Quebec City). These foam fragments may come from food packaging or building materials. A study carried out in Lake Ontario has shown that bromine, used as a flame retardant, can be used to differentiate between foams from packaging or construction [67]. The river section of the St. Lawrence is characterized by the presence of numerous construction plants and shipbuilding factories. A bromine assay could confirm the origin of the foam fragments. In general, urban beaches have more users than other types of beach due to their attractive nature and accessibility, and are therefore more exposed to anthropogenic debris [54]. Site 7IL, located on an urban beach, is characterized by a high proportion (54%) of food packaging (Figure 7) that is linked with tourism as suggested in other tourist sites in Zanzibar [68], the Seychelles [69], the Solomon Islands [37] and on various Western European coasts [70]. The large number of single-use items (such as bottles and cutlery) and, the relatively low levels of oxidation suggest that a significant proportion of this waste is deposited directly on the shore by users.

### *4.2 Predominance of food packaging: the culture of single-use*

Food packaging were found at 14 of the 18 sites sampled, with higher proportions at recreational sites (i.e. sandy beaches and tourist sites). This can be explained by the fact that 40% of the world's plastic production is dedicated to single-use packaging [2, 3, 71]. The single-use plastics are defined as products that have a life cycle of less than a few hours, are non-biodegradable under domestic composting or landfill conditions, are non-recoverable and lose more than 95% of their economic value after single use [72]. Because of our "one-use culture", this category generates an overproduction of waste [71]. Canada is no exception, since most plastic waste comes from single-use packaging. The amount of waste generated by this category has been recognized as an environmental problem [73]. To address this issue, Canada was to ban many items (e.g. plastic grocery bags, straws, sticks, six-pack rings, cutlery and food containers) by the end of 2021 [74]. Despite these regulatory actions, our study demonstrated the ubiquity of single-use items in the EGSL, which may be underestimated since 43% of the debris sampled was too degraded to determine whether it was single-use or durable. The spatial variations in the presence and proportions of SU packaging among sites may suggest a link with recreational use and better accessibility of specific sites (7IL, 67%) compared with others (MET, 13% ; TAD, 23%). Site 7IL is a vast and touristic sand beach, unlike PAP, represented by a foreshore and TAD, only accessible via a private road. These results highlight the importance of limiting the production of single-use plastics and improving waste recovery and management systems, which have been inadequate to accommodate the increasing quantities of waste produced over the last decades.

### *4.3 The importance of identifying plastic waste to help local decision-making*

The ubiquitous presence of hunting cartridges along the coast and mostly at KEG could be explained by the fact that the St. Lawrence River is a privileged migration zone for emblematic species such as the Canadian goose (*Brenda canadensis*)[75]. Waterfowl hunting is popular in this area, and hunters may target species such as ducks (e.g., mallards, black ducks, and teal) and geese (e.g., Canada geese) that are present in large colonies during the migration period (end of winter/spring). Hunting cartridges may be irretrievably ejected into the sea and/or may not be picked up by the hunter who fired them, which make them a significant source of plastic waste in the aquatic environment of such hunting areas [76]. Hunting cartridges are a local, point source of pollution, as they are linked to a specific population and come from places such as coastal game reserves, river affluents and wetlands, but they represent a non-negligible contribution to overall marine pollution. They are made up of several materials that can release toxic molecules into the environment for flora and fauna [77]. By removing the KEG site, identified as an outlier in the correlation analysis, from the data set, we obtained better correlation coefficients between debris concentration and the various variables measured. This is an important result, since it highlights the importance of local activity in plastic pollution. At present, there is little data on the global contribution of hunting cartridges to environmental pollution, but local studies have provided some estimates. Based on annual usage data for hunting cartridges in Europe, it was estimated that at least 2,100 tonnes of cartridges are dispersed into natural systems each year [76]. In a pollution survey carried out in 2016 on 276 European beaches, hunting cartridges ranked 27th out of a total of 238 objects identified [78]. Another study carried out on the Californian coast identified hunting cartridges as among the four most frequently found items on local beaches [79]. This source of pollution could be significantly reduced by educating users about the environmental impact of hunting cartridges through the installation of signs, and by encouraging them to collect cartridges by installing collectors at the various sites identified as hunting areas.

## 5. Conclusion and perspectives for improving plastic litter monitoring and management in the EGSL ecosystem

The present study represents an initial assessment of macro-waste pollution along the estuary and Gulf of St. Lawrence. The sites were chosen to give a representative overview of macroplastic pollution along the EGSL, depending on nearby land use (i.e. urban, tourist, isolated, natural) but also site accessibility. For some sites, access to the shore was difficult (e.g. boat ramps, seawalls, sloping rocks) and the OSPAR protocol was adapted to the landscape, which limited strict comparisons among sites of different nature (substrate and landscape). Moreover, given their morphology and slope, these environments are less conducive than sandy beaches to plastic debris strandings [80]. In order to ensure monitoring over time and a robust inter-site comparison, it is therefore advisable to select sites along the EGSL that are conducive to the implementation of the OSPAR protocol, such as sandy beaches. In addition, while the OSPAR protocol includes sampling for microplastics, we only focused on macrometric-sized debris in the present study. This led to an underestimation of the plastic contamination levels in the EGSL as the proportion of microplastics in the environment is known to be much higher than that of macroplastics along river shores [81].

This study also aims to serve as a basis of reflection for legal bodies such as Fisheries and Ocean Canada to implement local and global actions in managing the St. Lawrence watershed to reduce plastic pollution. Our study revealed three main sources of plastic debris related to food packaging, construction and hunting activities. This debris corresponds to accidental escapes (debris carried by the wind and rainwater) but also to voluntary and/or accidental discharges by users directly on the sites. Voluntary dumping could be reduced by improving communication and raising user awareness. This could be achieved by posting notices around sensitive/recreational sites, installing waste collectors and, better still, asking everyone to take all their waste home.

Finally, the OSPAR method provides data on the density and categorization of macro and micro litter. These data, particularly when collected over extended periods, can be used to identify waste sources, sinks and transport mechanisms, giving an overview of waste distribution in time and space. This one-off study provides a snapshot of macroplastic pollution along the EGSL at a given time. It could be refined by a temporal investigation of plastic pollution over several seasons and years. Such long-term series acquisition would allow measuring the influence of seasons and weather events (flood, drought, snowmelt) and site frequentation. The OSPAR protocol is available to all users and can be used by anyone wishing to get involved in monitoring plastic pollution on coasts and shorelines. Thus, the organization of multi-year collections by local authorities, associations, schools and users, in line with the OSPAR protocol, would enable the acquisition of data for spatio-temporal monitoring and large-scale comparison of results, while involving users in the preservation of their environment [30]. Providing training and guidance on the OSPAR protocol to local environmental agencies or associations would allow it to acquire large-scale data to track macro/micro debris along the EGSL over time and could even be extended to the main tributaries of the St. Lawrence River, such as the Saguenay and Ottawa rivers.

[74]

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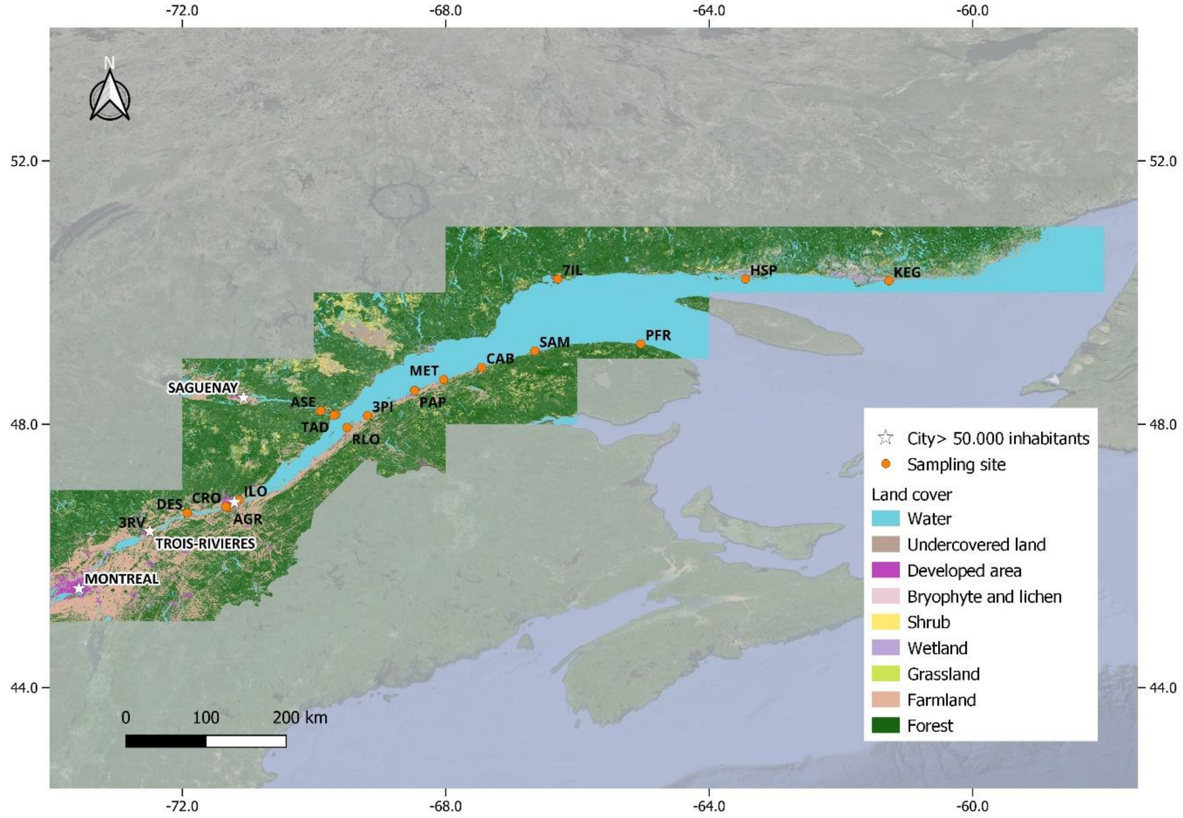


Figure 1: Sampling map of the St. Lawrence coastline (Canada) in summer 2022. The eighteen sites are, from upstream to downstream, for the north shore: Trois-Rivières (3RV), Deschambault (DES), Cap-Rouge (CRO), Anse Saint-Etienne (ASE), Tadoussac (TAD), Moulin à Baude (MBA), Sept-Îles (7IL), Havre Saint-Pierre (HSP), Kegaska (KEG); and for the south shore: Anse Gingras (AGR), Île d'Orléans (ILO), Rivière du Loup (RLO), Trois Pistoles (3PI), Pointe aux Pères (PAP), Métis (MET), Sainte-Anne des Monts (SAM), Cap à la Baleine (CAB) and Pointe à la Frégate (PFR).

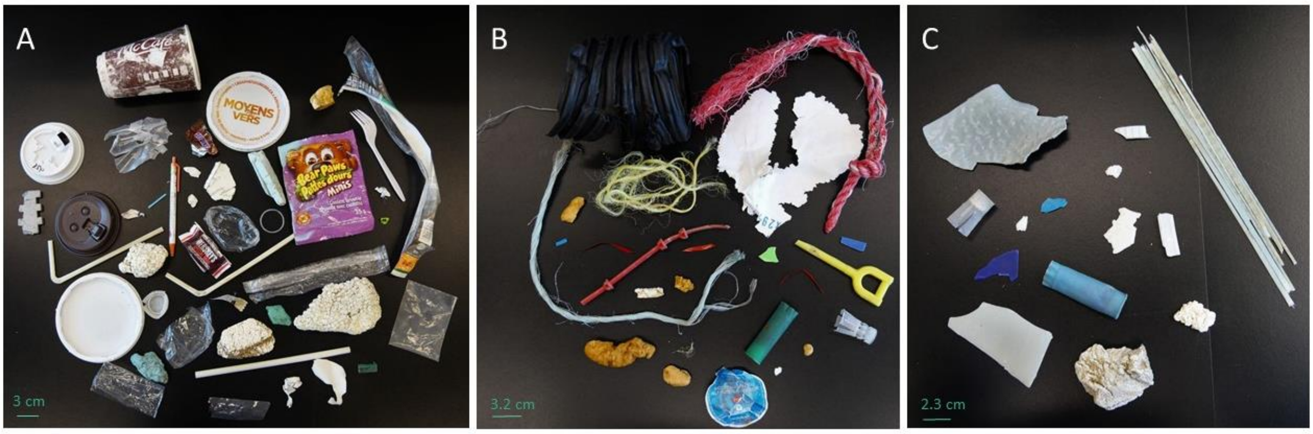


Figure 2: Diversity of anthropogenic debris sampled from the seashore at DES (A), MET (B) and HSP (C) sites along a linear transect.

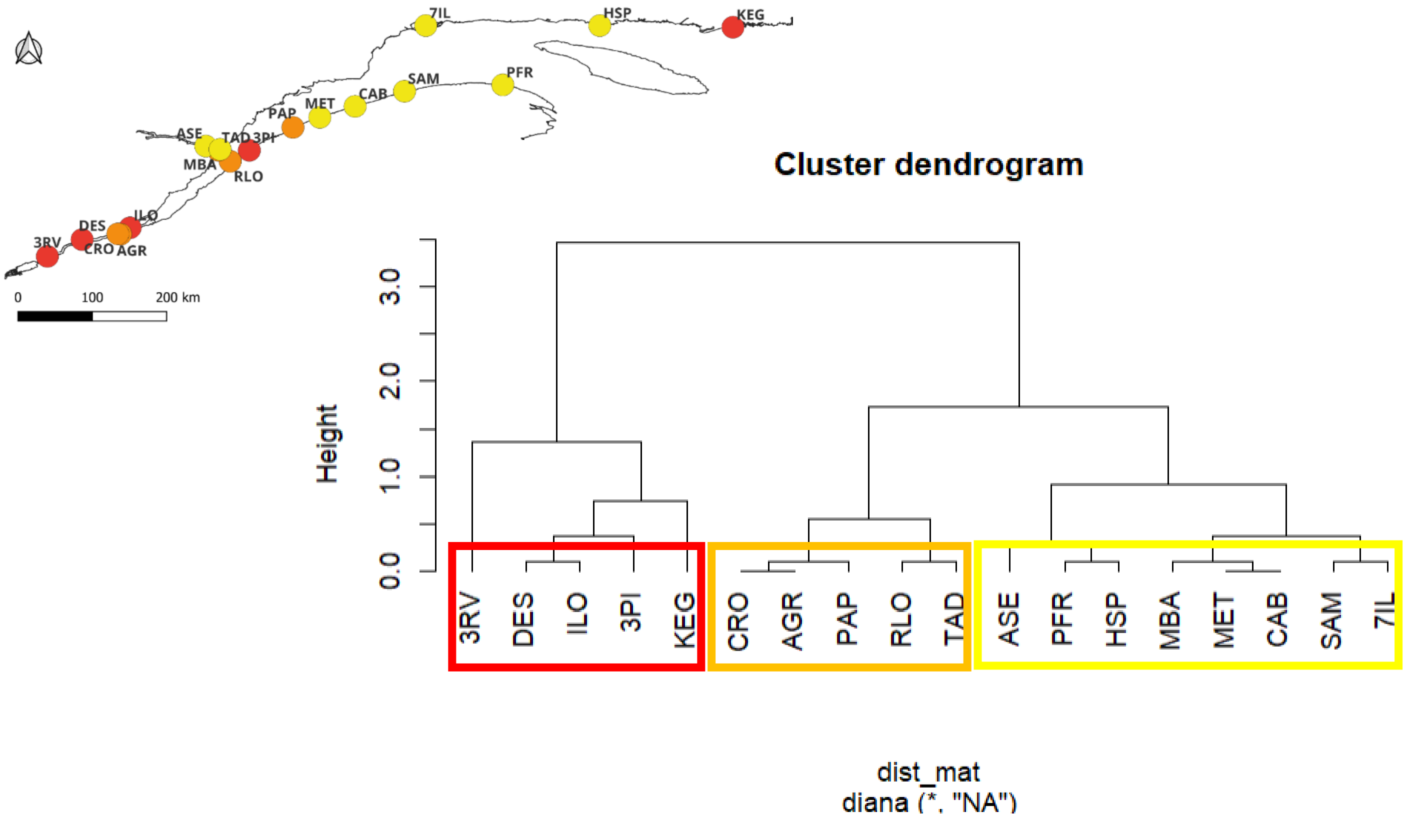


Figure 3: Hierarchical cluster analysis dendrogram indicating the proximity and significance of the relationship between the plastic debris concentrations at each site.

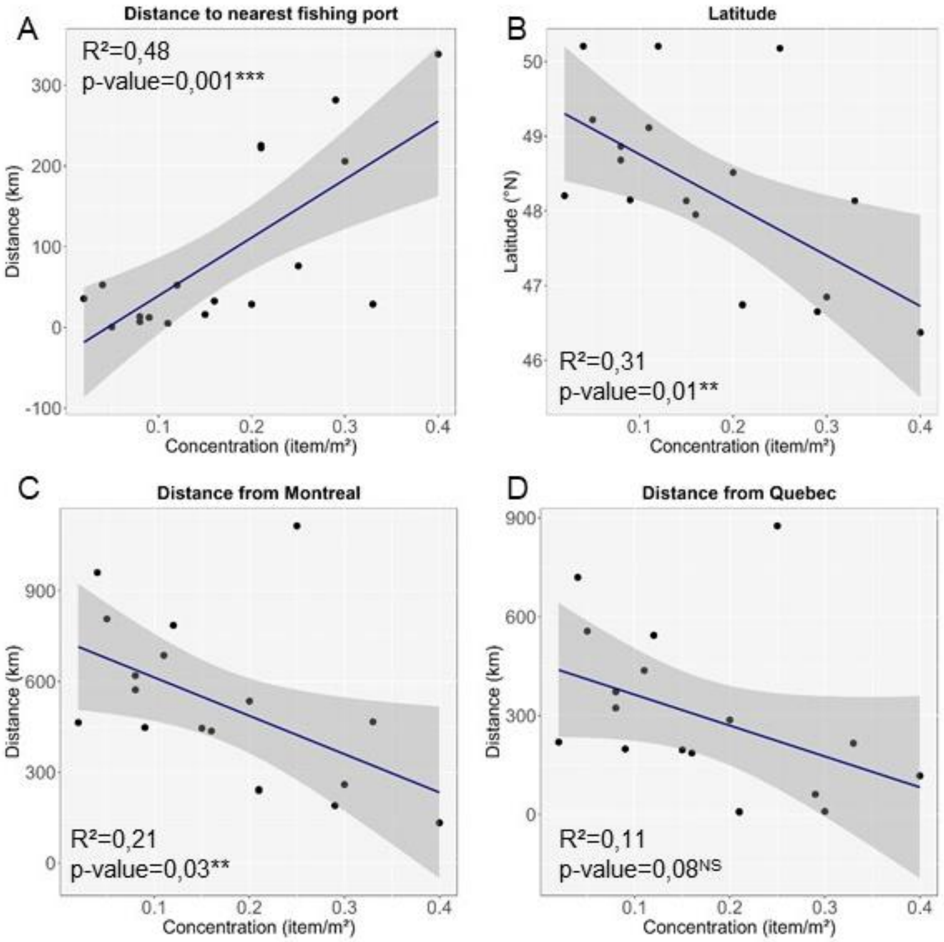


Figure 4: Linear regression lines of plastic debris concentration as a function of various environmental variables: distance to nearest fishing port (A), latitude (B), distance from Montreal (C) and Quebec City (D). The * represent the degree of significance of the p-value, and NS indicates that the p-value is not significant.

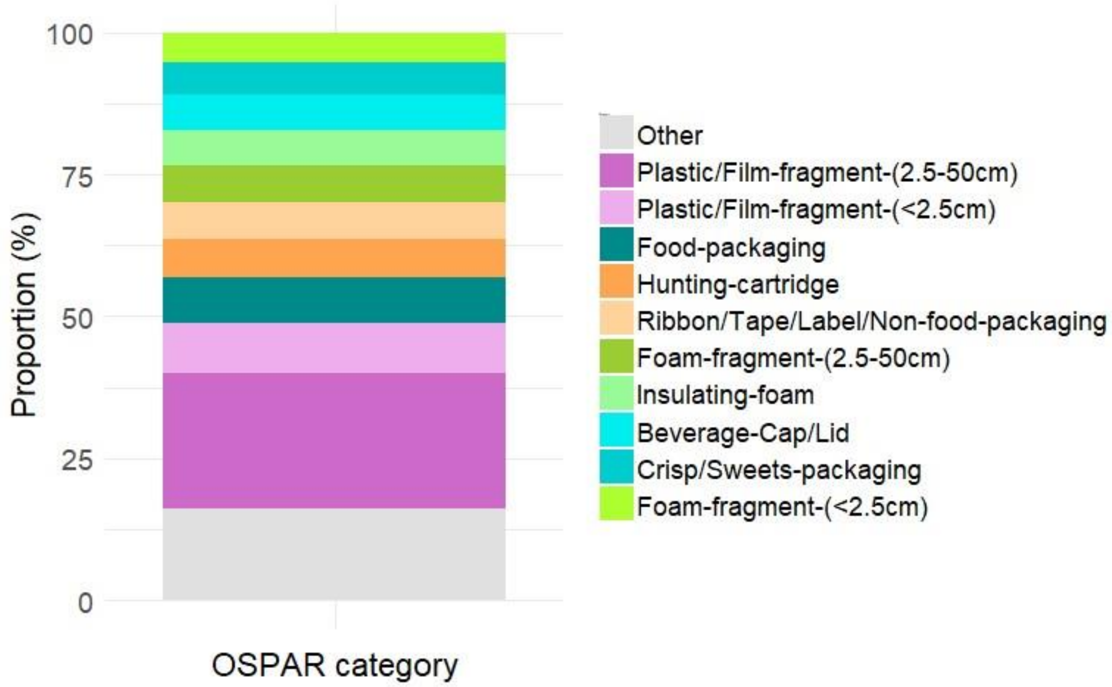


Figure 5. Plastic debris abundance (number, y-axis) and OSPAR category at global scale.

Figure 6. Plastic debris abundance (number, y-axis) and OSPAR category at sites scale. The sites are ordered from upstream to downstream (x-axis).

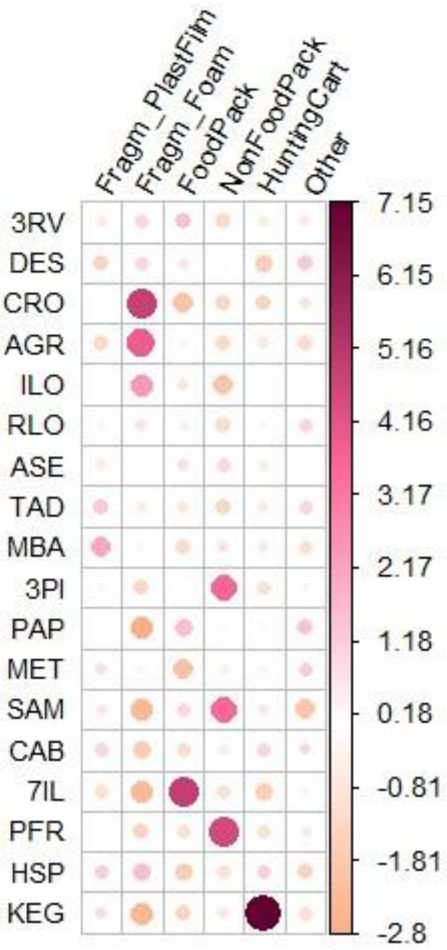


Figure 7: Chi² test of conformity for the different OSPAR categories at each site. This graph of standardized residues allows us to identify which OSPAR categories are over- or under-represented at which sites.

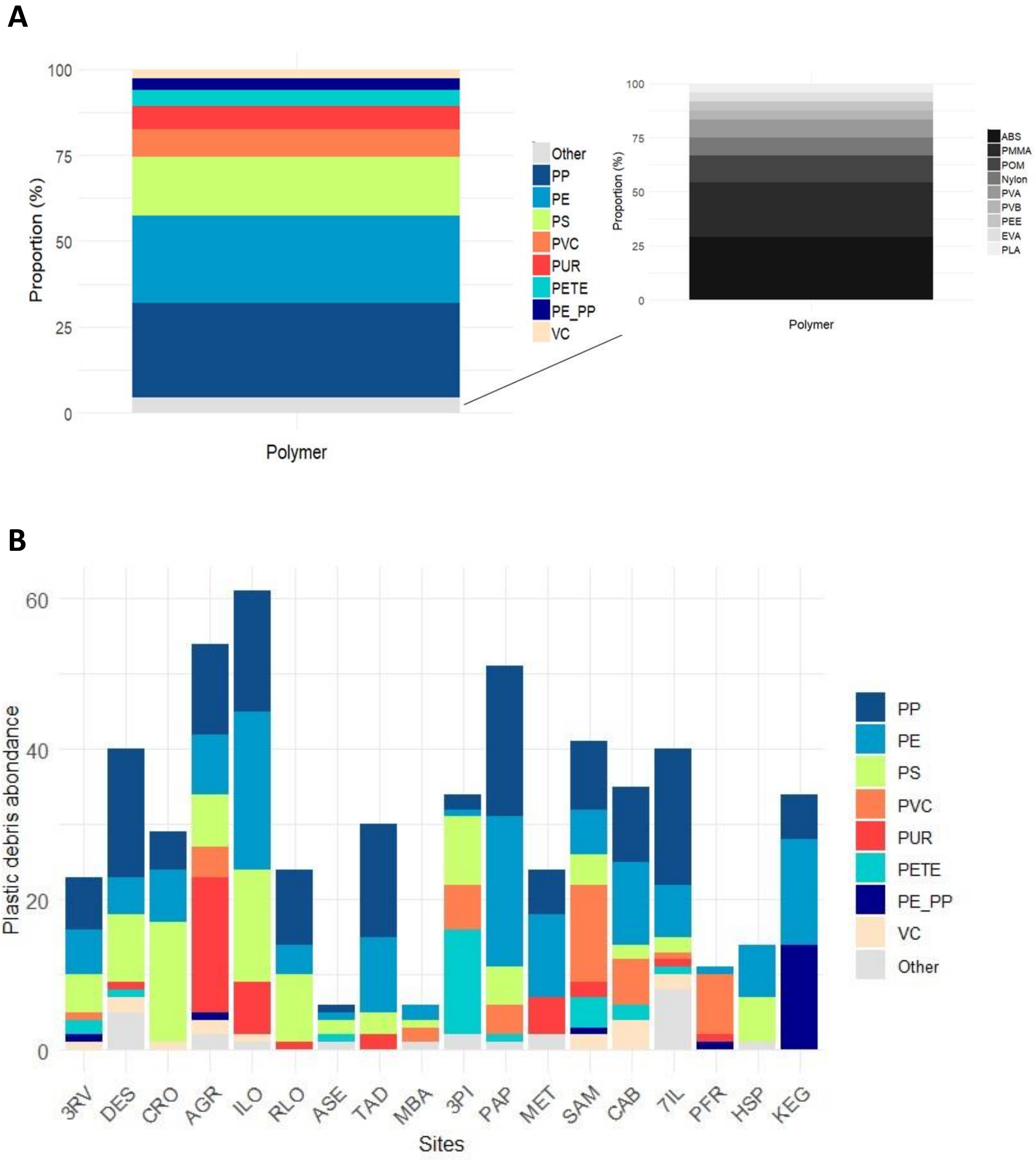


Figure 8. Plastic debris abundance (number, y-axis) and polymer distribution at global (A) and site (B) scales. The sites are ordered from upstream to downstream (x-axis).

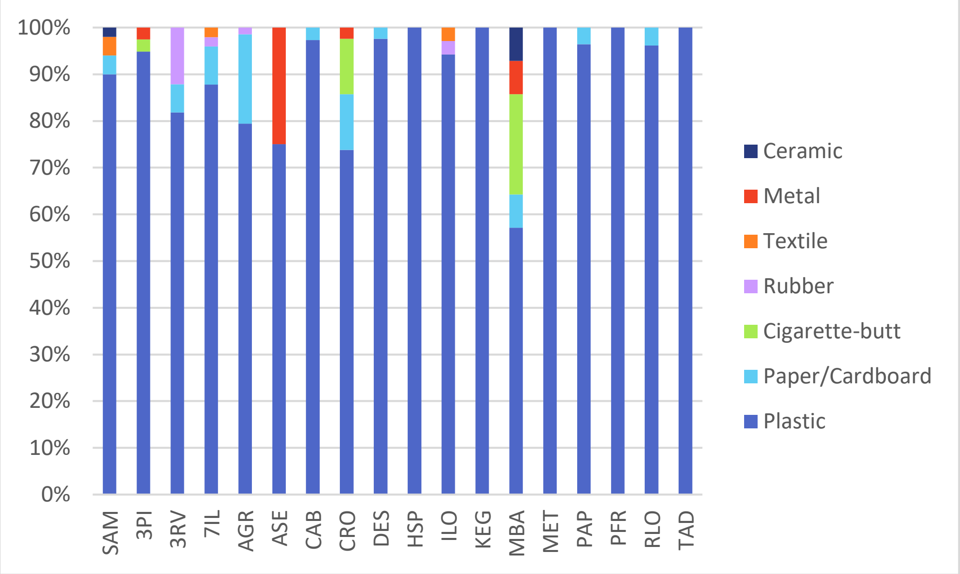
## SUPPLEMENTARY DATA

**SD0: Data table of environmental variables used to explain measured plastic debris concentrations. The "Concentration" variable is in items/$m^2$. Distance from Montreal "Dist-MTRL" and distance from Quebec City "Dist-QC" are in km. Public accessibility "PUBLIC_ACCESS" was measured according to 0 = difficult access (long walk without marked path or access via private property) and 1 = easy access (car park, road, public domain). The "CITY-dist_km" variable corresponds to the distance between the site and a town with more than 5000 inhabitants. The designation was measured according to the site's distance from a town with a population of more than 5000 inhabitants. "D_urban" = 1 for sites less than 10 km from a town with at least 5000 inhabitants. "D-frequented" = 1 for sites located between 11 and 50 km from a town with at least 5000 inhabitants. "D-village" = 1 for sites located between 51 and 100 km from a town with at least 5000 inhabitants. "D-rural" = 1 for sites located more than 101 km from a town with at least 5000 inhabitants. "S_Silt/Sand/Shale" according to soil type. Site distances from various ports are in km.**

| Site | Latitude | Longitude | Conc | Dist-Mtrl | Dist-QC | CITY-dist_km | Public-access | D-urban | D-frequented | D-village | D-rural | S-Silt | S-Sand | S-Shale | Marina-P_km | Fishing-P_km | Commercial-P_km | Ferry-P_km |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3RV | 46.373029 | -72.492483 | 0.40 | 133 | 117 | 7.8 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2.8 | 338 | 7.3 | 127 |
| DES | 46.651483 | -71.92498 | 0.29 | 190 | 61 | 20 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 4.7 | 281 | 46 | 70 |
| CRO | 46.7467 | -71.338893 | 0.21 | 239 | 8.7 | 8.7 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 6.1 | 225 | 12 | 14 |
| AGR | 46.740392 | -71.295891 | 0.21 | 242 | 7.3 | 7.3 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1.9 | 222 | 8.7 | 11 |
| ILO | 46.847621 | -71.13838 | 0.30 | 259 | 9.1 | 4.4 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 6.6 | 205 | 1.2 | 5.6 |
| RLO | 47.95099 | -69.49908 | 0.16 | 436 | 186 | 12 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 13 | 32 | 2.5 | 12 |
| ASE | 48.203731 | -69.899254 | 0.02 | 464 | 219 | 51 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 19 | 35 | 45 | 16 |
| TAD | 48.135196 | -69.698524 | 0.15 | 445 | 195 | 33 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1.6 | 16 | 27 | 2.8 |
| MBA | 48.148972 | -69.665817 | 0.09 | 448 | 198 | 35 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 5.5 | 12 | 27 | 6.5 |
| 3PI | 48.13345 | -69.186791 | 0.33 | 466 | 215 | 43 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0.4 | 28 | 33 | 0.6 |
| PAP | 48.514573 | -68.472955 | 0.20 | 535 | 286 | 11 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 5.1 | 28 | 5.1 | 55 |
| MET | 48.681011 | -68.032258 | 0.08 | 572 | 323 | 18 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 45 | 13 | 42 | 80 |
| SAM | 49.114406 | -66.646038 | 0.11 | 686 | 436 | 16 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 5.1 | 5.1 | 16 | 86 |
| CAB | 48.864213 | -67.455127 | 0.08 | 619 | 372 | 6.9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 7.1 | 7.1 | 11 | 53 |
| 7IL | 50.204777 | -66.297467 | 0.12 | 786 | 543 | 3.9 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 8.2 | 52 | 7.9 | 150 |
| PFR | 49.220558 | -65.037743 | 0.05 | 806 | 556 | 111 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 23 | 0.5 | 85 | 233 |
| HSP | 50.204864 | -63.449443 | 0.04 | 960 | 719 | 261 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 14 | 53 | 14 | 353 |
| KEG | 50.177349 | -61.26939 | 0.25 | 1114 | 875 | 458 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 211 | 76 | 1.2 | 154 |

**SD1: Anthropogenic debris sampled from the seashore at 3RV (A), CRO (B), TAD (C), ASE (D), MBA (E), 7IL (F), KEG (G), AGR (H), ILO (I), RLO (J), 3PI (K), PAP (L), CAB (M), SAM (N) and PFR (O) sites along a linear transect.**

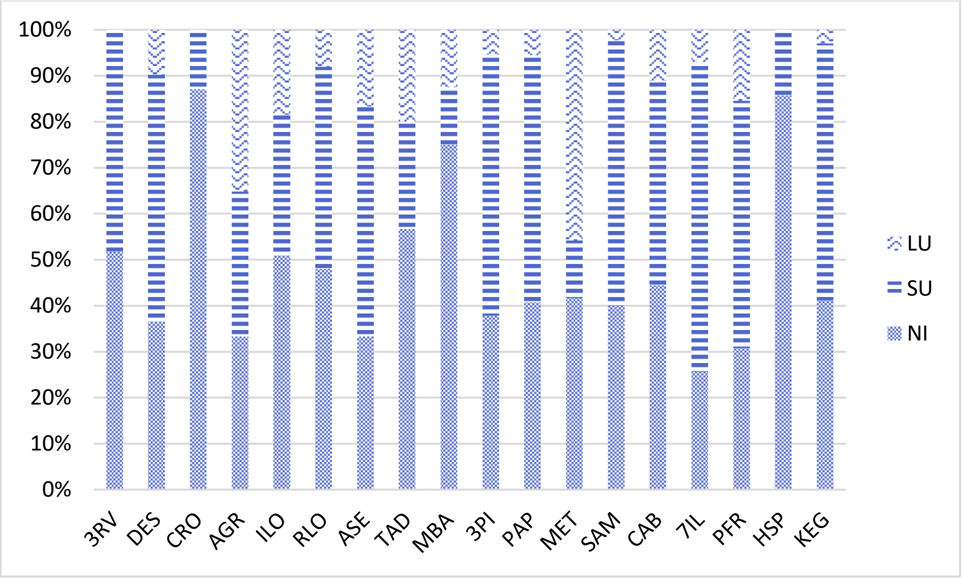
**SD2: Categories of anthropogenic debris sampled from the seashore at 3RV (A), CRO (B), TAD (C), ASE (D), MBA (E), 7IL (F), KEG (G), AGR (H), ILO (I), RLO (J), 3PI (K), PAP (L), CAB (M), SAM (N) and PFR (O).**



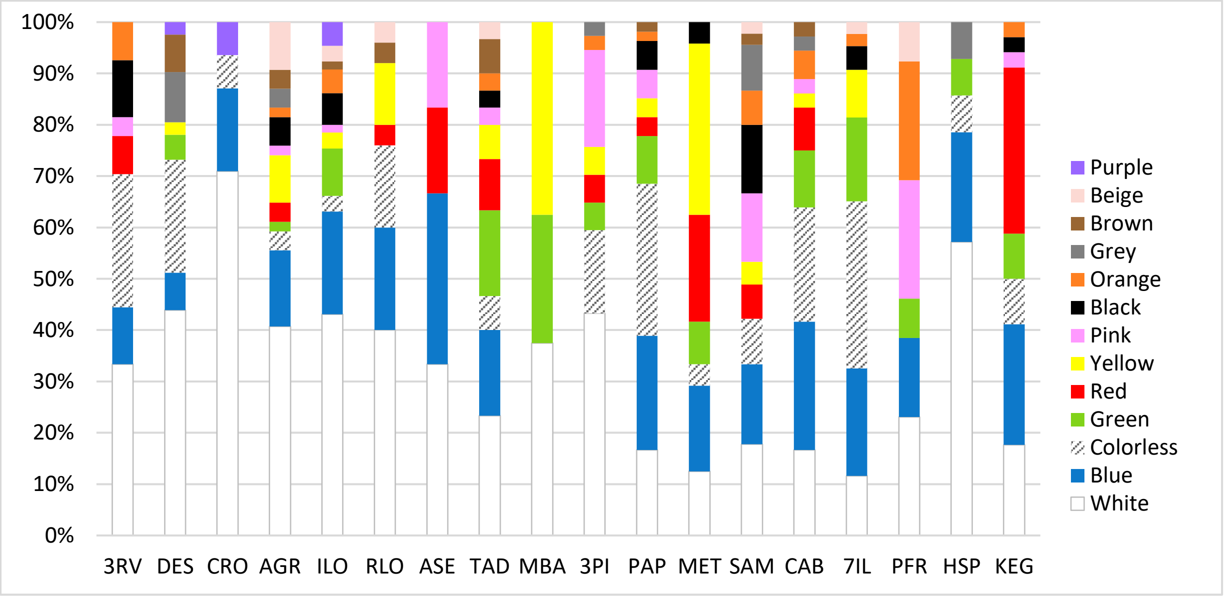
**SD3: Results (p-value and R²) of the simple linear regression on plastic debris concentration as a function of environmental variables: distance to the nearest fishing port, latitude, distance from Montreal and Quebec City. The analysis was performed on the dataset with and without the KEG site. The * represent the degree of significance of the p-value, and NS indicates that the p-value is not significant.**

| | ALL SITES | | WITHOUT KEG | |
|---|---|---|---|---|
| | p-value | $R^2$ | p-value | $R^2$ |
| **NEAREST FISHING PORT** | $0.004^{**}$ | 0.48 | $0.001^{***}$ | 0.51 |
| **LATITUDE** | $0.01^{**}$ | 0.31 | $0.001^{***}$ | 0.50 |
| **DISTANCE FROM MONTREAL** | $0.03^{**}$ | 0.21 | $0.001^{***}$ | 0.51 |
| **DISTANCE FROM QUEBEC CITY** | $0.08^{NS}$ | 0.11 | $0.01^{*}$ | 0.38 |

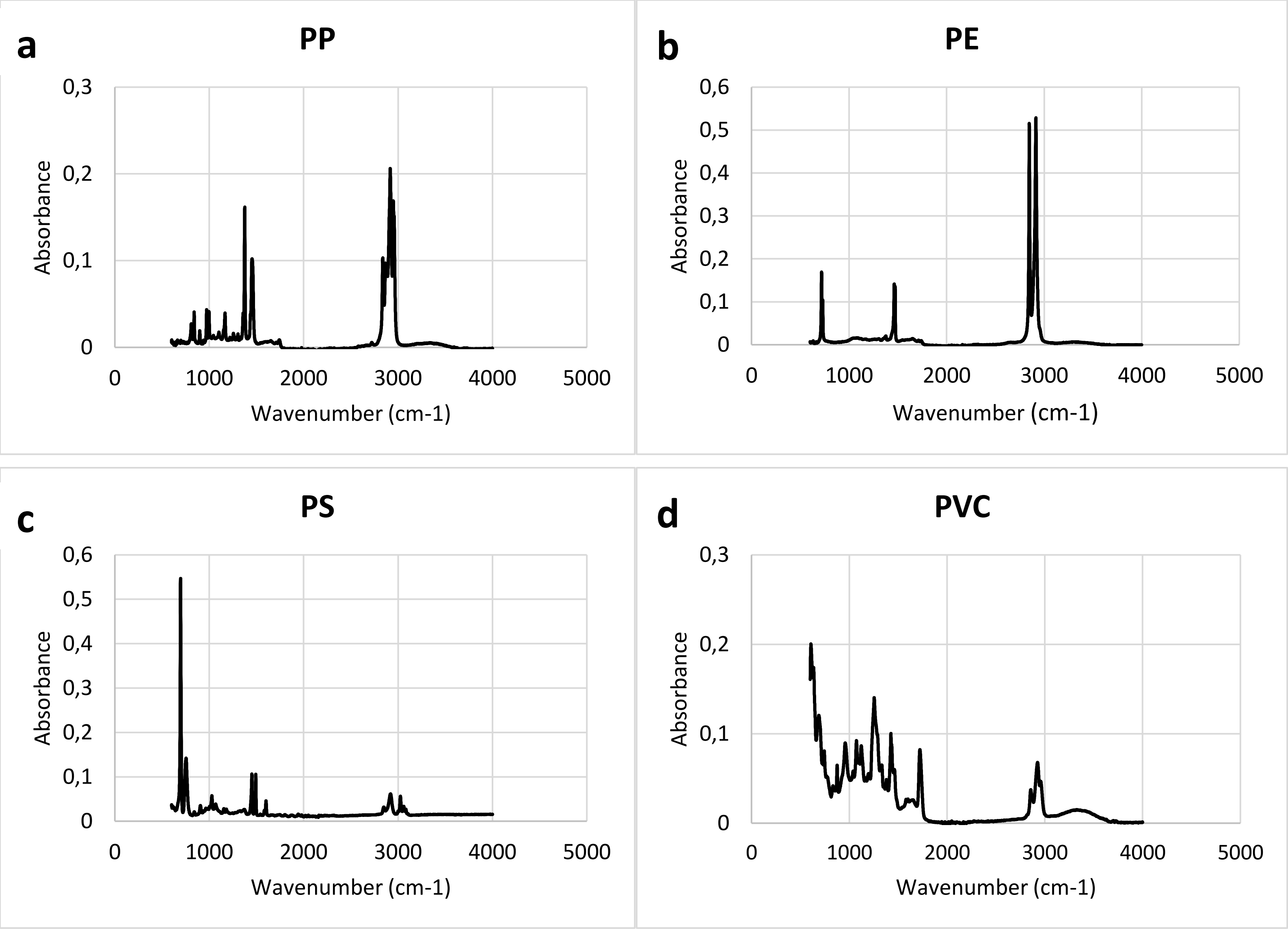
**SD4: Usage of plastic debris collected in each site of St. Lawrence River.**

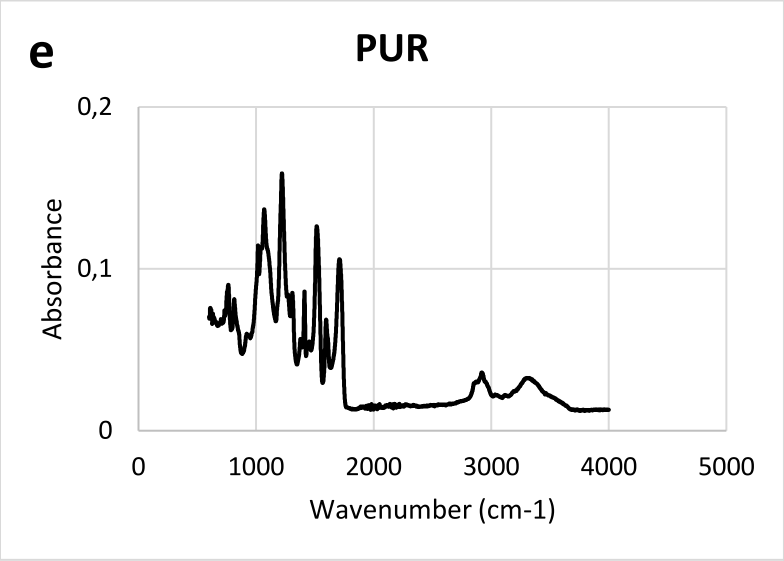


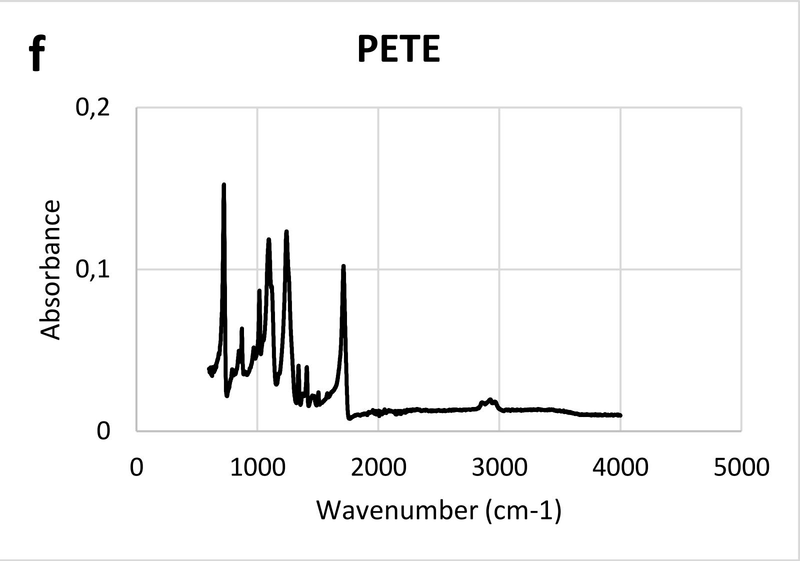
**SD5: Color of plastic debris collected in each site of St. Lawrence River.**

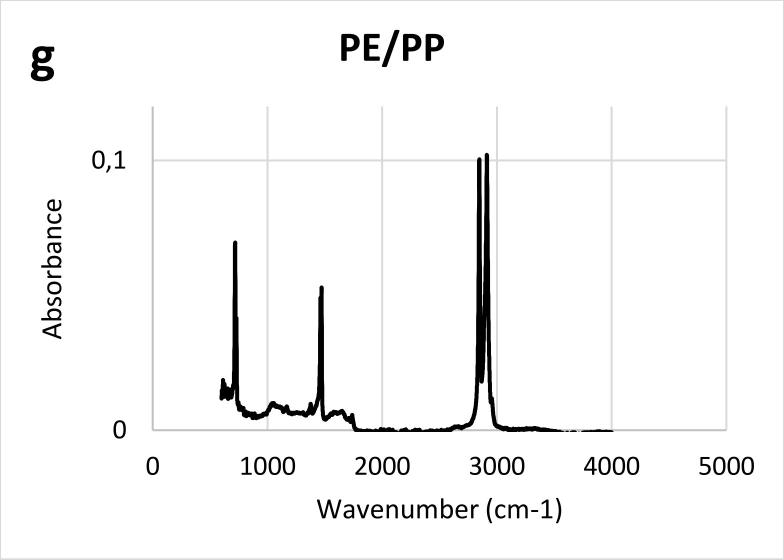


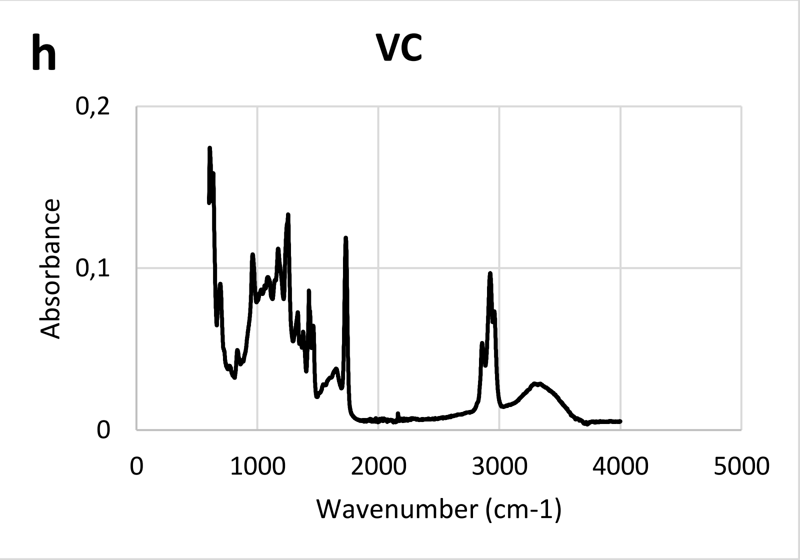
**SD6: Spectra obtained from different plastic debris of St. Lawrence River with polymers using ATR FT-IR. The spectra obtained were identified using a Spectragryph© database (v. 1.2.16.1) containing references to spectra of the most common polymers, with a minimum match of 70%. The names of the items presented, and the matches obtained for each polymer, are as follows: (a) SAM-48: polypropylene (PP) = 99%, (b) 3RV-32: polyethylene (PE) = 99%, (c) CRO-14: polystyrene (PS) = 97%, (d) SAM-04: polyvinyl chloride (PVC) = 87%, (e) MET-10: polyurethane (PUR) = 85%, (f) 3PI-28: polyethylene terephthalate (PET) = 97%, (g) KEG-18: polyethylene/polypropylene copolymer (PE/PP) = 95%, (h) 3RV-08: vinyl Chloride (VC) = 90%, (i) AGR-22: acrylonitrile butadiene styrene (ABS) = 97%, (j) 7IL-48: polymethyl methacrylate (PMMA) = 98%, (k) ILO-64: polyoxymethylene (POM) = 99%, (l) MET-06: nylon = 98%, (m) MBA-06: polyvinyl alcohol (PVA) = 92%, (n) 3PI-29: polyvinyl butyral (PVB) = 76%, (o) ASE-07: polyether ester (PEE) = 79%, (p) 7IL-45: ethylene vinyl acetate (EVA) = 87%, (q) 7IL-37: polylactic acid (PLA) = 95%.**

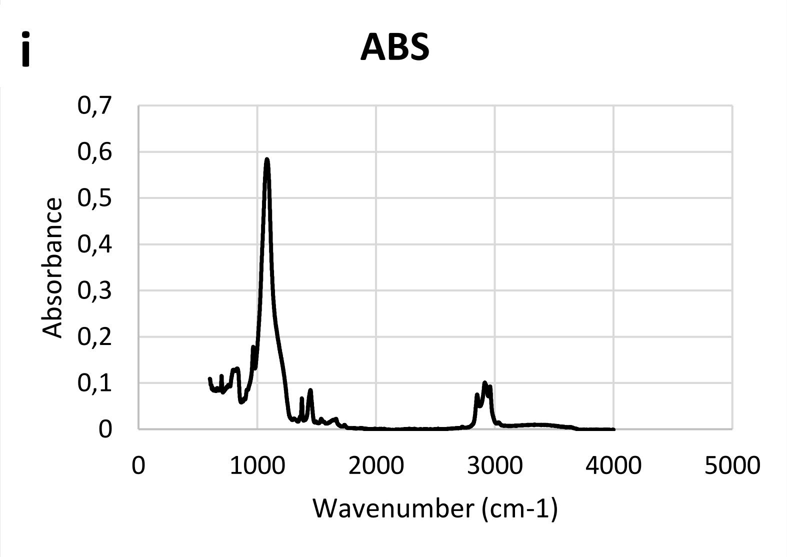


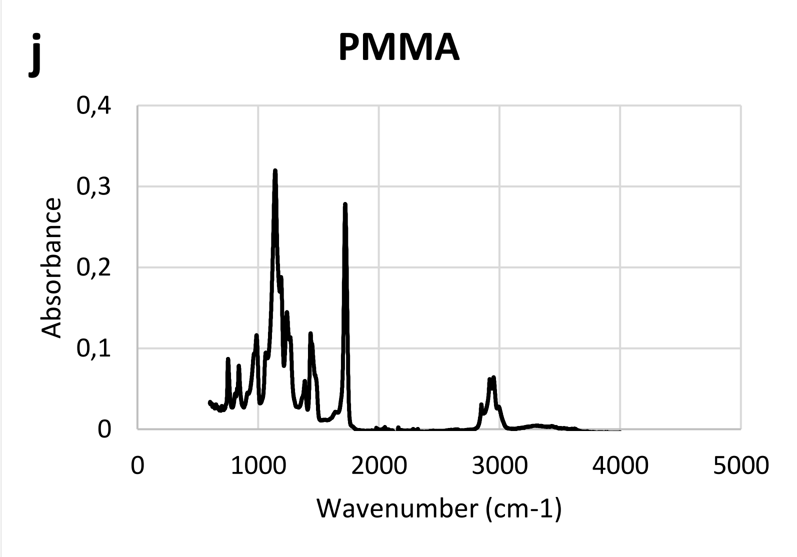

e
PUR
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

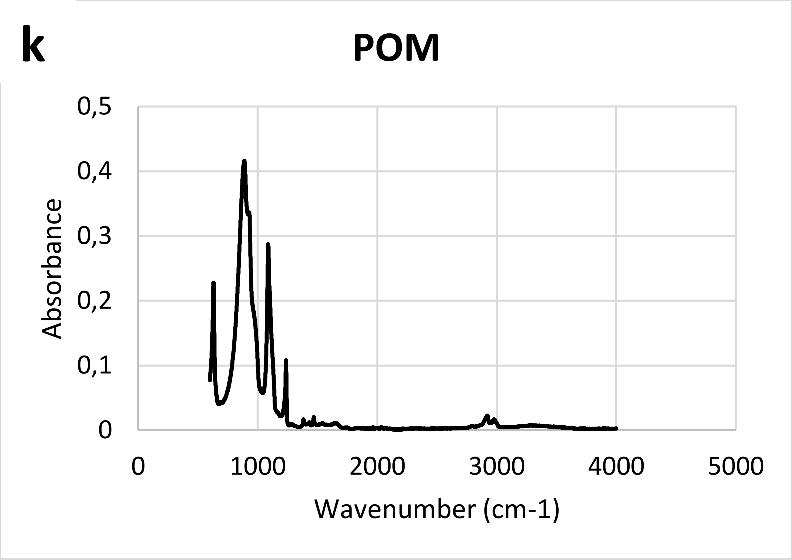

f
PETE
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

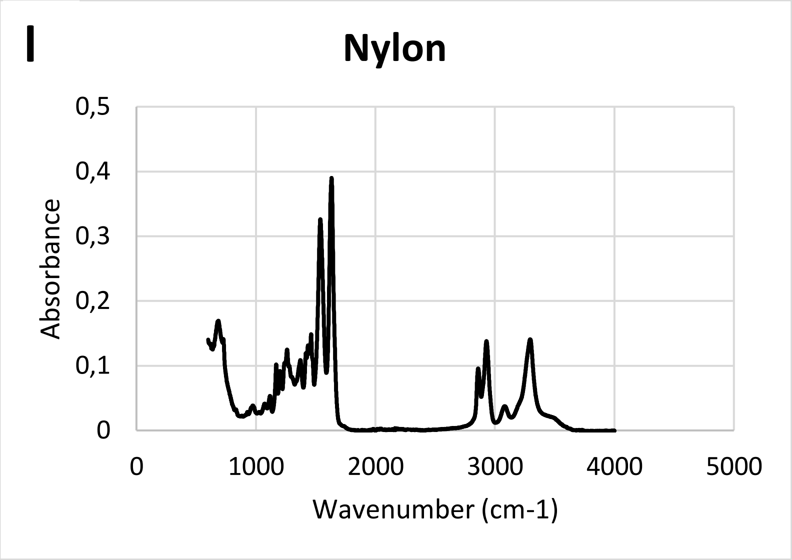

g
PE/PP
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

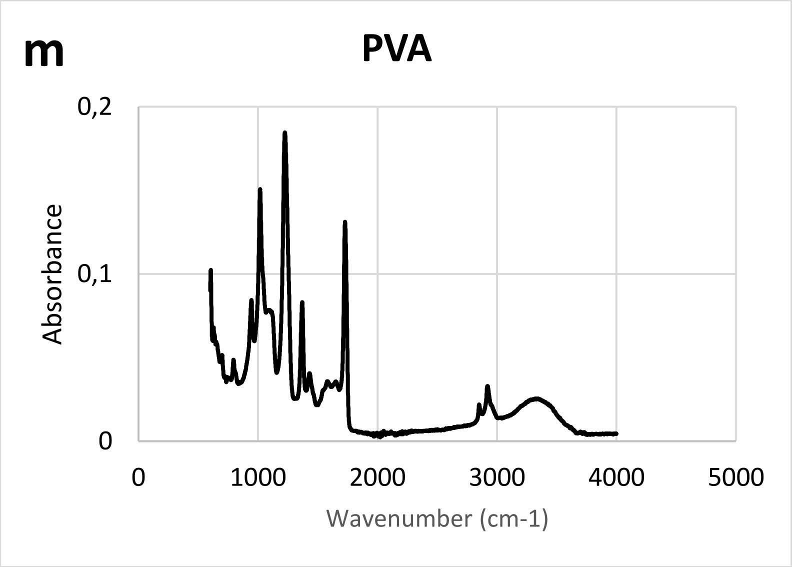

h
VC
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

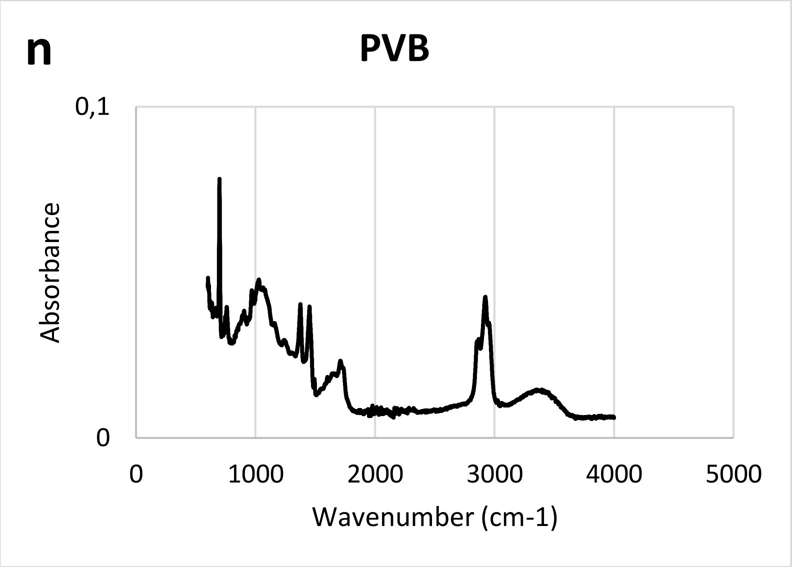

i
ABS
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

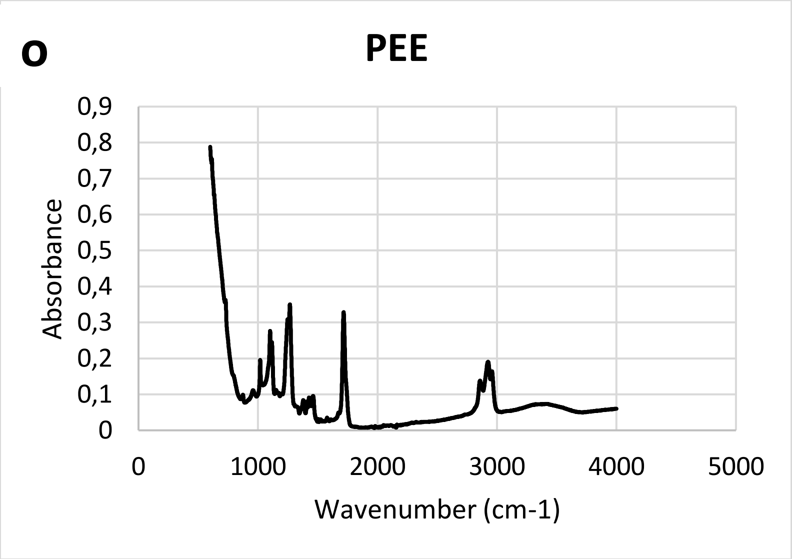

j
PMMA
0,4
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

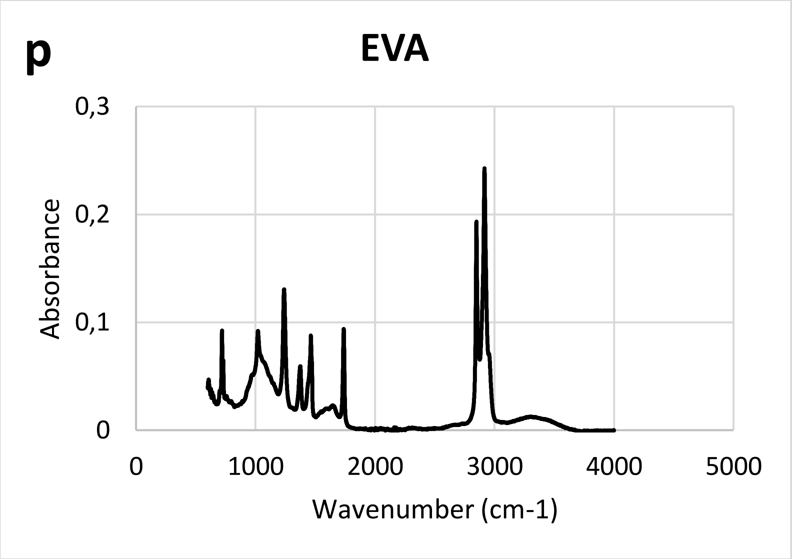

k
POM
0,5
0,4
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)

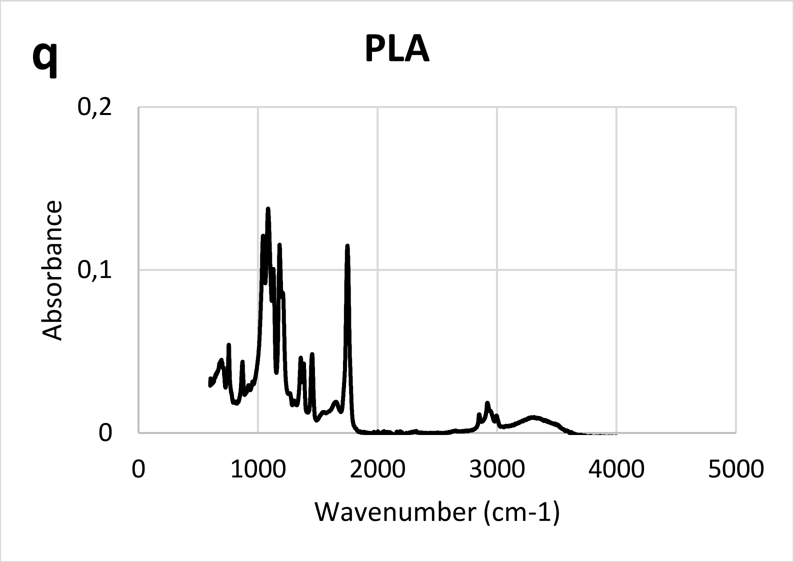

l
Nylon
0,5
0,4
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)


m
PVA
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)


n
PVB
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)


o
PEE
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)


p
EVA
0,3
0,2
0,1
0
Absorbance
0
1000
2000
3000
4000
5000
Wavenumber (cm-1)



### SD7: ICO calculated for plastic debris in PE, PP and copolymer PE/PP

| ID | Polymer | $I_{CO}$ |
|---|---|---|
| 3PI22 | PE | 0.64 |
| 3RV04 | PE | 0.85 |
| 3RV12 | PE | 0.48 |
| 3RV21 | PE | 0.33 |
| 3RV31 | PE | 0.65 |
| 3RV32 | PE | 0.27 |
| 3RV33 | PE | 1.08 |
| 7IL02 | PE | 0.73 |
| 7IL05 | PE | 0.59 |
| 7IL06 | PE | 1.04 |
| 7IL14 | PE | 0.45 |
| 7IL15 | PE | 0.25 |
| 7IL19 | PE | 0.48 |
| 7IL26 | PE | 0.50 |
| AGR13 | PE | 0.19 |
| AGR19 | PE | 0.68 |
| AGR23 | PE | 0.28 |
| AGR24 | PE | 0.35 |
| AGR35 | PE | 0.32 |
| AGR55 | PE | 0.00 |
| AGR60 | PE | 0.29 |
| AGR62 | PE | 0.40 |
| ASE08 | PE | 0.00 |
| CAB01 | PE | 0.45 |
| CAB03 | PE | 0.75 |
| CAB07 | PE | 0.69 |

| | | |
|---|---|---|
| CAB14 | PE | 0.46 |
| CAB16 | PE | 0.92 |
| CAB17 | PE | 0.57 |
| CAB22 | PE | 0.93 |
| CAB26 | PE | 0.00 |
| CAB28 | PE | 0.71 |
| CAB29 | PE | 0.69 |
| CAB33 | PE | 0.54 |
| CRO03 | PE | 0.14 |
| CRO08 | PE | 0.19 |
| CRO16 | PE | 1.11 |
| CRO19 | PE | 0.68 |
| CRO29 | PE | 0.47 |
| CRO38 | PE | 1.28 |
| CRO42 | PE | 1.13 |
| DES01 | PE | 0.00 |
| DES03 | PE | 0.78 |
| DES09 | PE | 0.20 |
| DES30 | PE | 0.52 |
| DES37 | PE | 0.02 |
| HSP01 | PE | 0.50 |
| HSP02 | PE | 0.56 |
| HSP05 | PE | 0.17 |
| HSP06 | PE | 0.18 |
| HSP09 | PE | 0.50 |
| HSP11 | PE | 0.33 |
| HSP13 | PE | 0.24 |
| ILO02 | PE | 0.25 |
| ILO08 | PE | 0.46 |
| ILO12 | PE | 0.52 |
| ILO21 | PE | 0.82 |
| ILO22 | PE | 0.93 |
| ILO24 | PE | 1.33 |
| ILO28 | PE | 0.66 |
| ILO29 | PE | 0.70 |
| ILO33 | PE | 0.43 |
| ILO34 | PE | 0.72 |
| ILO37 | PE | 0.31 |
| ILO38 | PE | 0.02 |
| ILO48 | PE | 0.29 |
| ILO54 | PE | 0.42 |
| ILO55 | PE | 0.55 |
| ILO56 | PE | 0.07 |
| ILO58 | PE | 0.50 |

| | | |
|---|---|---|
| ILO60 | PE | 0.14 |
| ILO65 | PE | 0.51 |
| ILO66 | PE | 1.00 |
| ILO69 | PE | 0.63 |
| KEG14 | PE | 0.41 |
| KEG15 | PE | 0.61 |
| KEG16 | PE | 0.20 |
| KEG17 | PE | 0.93 |
| KEG19 | PE | 1.18 |
| KEG20 | PE | 1.14 |
| KEG21 | PE | 0.33 |
| KEG22 | PE | 0.49 |
| KEG23 | PE | 0.89 |
| KEG25 | PE | 0.94 |
| KEG26 | PE | 0.13 |
| KEG27 | PE | 0.34 |
| KEG28 | PE | 0.82 |
| KEG31 | PE | 0.70 |
| MBA05 | PE | 0.54 |
| MBA09 | PE | 0.60 |
| MET01 | PE | 1.43 |
| MET05 | PE | 1.08 |
| MET07 | PE | 0.54 |
| MET13 | PE | 0.46 |
| MET14 | PE | 0.46 |
| MET16 | PE | 0.17 |
| MET17 | PE | 0.00 |
| MET18 | PE | 1.10 |
| MET19 | PE | 0.84 |
| MET21 | PE | 0.68 |
| MET24 | PE | 0.39 |
| PAP06 | PE | 0.40 |
| PAP09 | PE | 0.29 |
| PAP11 | PE | 0.59 |
| PAP16 | PE | 0.71 |
| PAP19 | PE | 0.44 |
| PAP23 | PE | 0.92 |
| PAP25 | PE | 0.67 |
| PAP26 | PE | 0.67 |
| PAP33 | PE | 0.38 |
| PAP36 | PE | 0.90 |
| PAP37 | PE | 0.63 |
| PAP38 | PE | 0.42 |
| PAP39 | PE | 0.43 |

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|---|---|---|
| PAP40 | PE | 0.48 |
| PAP41 | PE | 0.39 |
| PAP42 | PE | 0.25 |
| PAP47 | PE | 0.17 |
| PAP48 | PE | 0.65 |
| PAP51 | PE | 0.85 |
| PAP52 | PE | 0.88 |
| PFR12 | PE | 0.61 |
| RLO07 | PE | 0.31 |
| RLO08 | PE | 0.68 |
| RLO23 | PE | 0.42 |
| RLO26 | PE | 0.38 |
| SAM22 | PE | 0.44 |
| SAM30 | PE | 1.34 |
| SAM43 | PE | 0.18 |
| SAM44 | PE | 0.44 |
| SAM45 | PE | 0.71 |
| SAM50 | PE | 0.43 |
| TAD01 | PE | 0.61 |
| TAD02 | PE | 1.11 |
| TAD03 | PE | 1.00 |
| TAD07 | PE | 0.36 |
| TAD09 | PE | 1.03 |
| TAD16 | PE | 0.51 |
| TAD17 | PE | 0.39 |
| TAD22 | PE | 0.38 |
| TAD25 | PE | 0.26 |
| TAD30 | PE | 0.68 |
| 3RV07 | PE/PP | 0.44 |
| AGR30 | PE/PP | 0.52 |
| KEG02 | PE/PP | 0.59 |
| KEG03 | PE/PP | 0.62 |
| KEG04 | PE/PP | 0.29 |
| KEG05 | PE/PP | 0.52 |
| KEG06 | PE/PP | 0.59 |
| KEG07 | PE/PP | 0.72 |
| KEG09 | PE/PP | 0.36 |
| KEG10 | PE/PP | 0.59 |
| KEG18 | PE/PP | 0.34 |
| KEG29 | PE/PP | 0.43 |
| KEG30 | PE/PP | 0.67 |
| KEG32 | PE/PP | 0.56 |
| KEG33 | PE/PP | 0.66 |
| KEG34 | PE/PP | 0.93 |

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|---|---|---|
| PFR03 | PE/PP | 0.33 |
| SAM25 | PE/PP | 0.53 |
| 3PI12 | PP | 0.60 |
| 3PI39 | PP | 0.18 |
| 3RV01 | PP | 0.47 |
| 3RV02 | PP | 0.07 |
| 3RV03 | PP | 0.64 |
| 3RV05 | PP | 0.75 |
| 3RV10 | PP | 0.67 |
| 3RV14 | PP | 0.16 |
| 3RV19 | PP | 0.35 |
| 7IL01 | PP | 0.80 |
| 7IL04 | PP | 0.81 |
| 7IL07 | PP | 0.41 |
| 7IL08 | PP | 0.46 |
| 7IL09 | PP | 0.00 |
| 7IL17 | PP | 0.22 |
| 7IL21 | PP | 0.55 |
| 7IL24 | PP | 0.43 |
| 7IL27 | PP | 0.59 |
| 7IL29 | PP | 0.41 |
| 7IL32 | PP | 0.10 |
| 7IL35 | PP | 0.34 |
| 7IL36 | PP | 0.00 |
| 7IL38 | PP | 0.53 |
| 7IL40 | PP | 0.23 |
| 7IL41 | PP | 0.40 |
| 7IL44 | PP | 0.46 |
| 7IL49 | PP | 0.13 |
| AGR09 | PP | 0.85 |
| AGR12 | PP | 0.53 |
| AGR20 | PP | 0.00 |
| AGR31 | PP | 0.65 |
| AGR32 | PP | 0.30 |
| AGR33 | PP | 0.00 |
| AGR38 | PP | 0.64 |
| AGR43 | PP | 0.26 |
| AGR46 | PP | 0.14 |
| AGR49 | PP | 0.40 |
| AGR51 | PP | 0.11 |
| AGR56 | PP | 0.74 |
| ASE05 | PP | 0.46 |
| CAB02 | PP | 0.52 |
| CAB04 | PP | 0.95 |

| | | |
|---|---|---|
| CAB11 | PP | 0.42 |
| CAB12 | PP | 0.00 |
| CAB23 | PP | 0.68 |
| CAB24 | PP | 0.47 |
| CAB30 | PP | 0.51 |
| CAB31 | PP | 0.79 |
| CAB32 | PP | 0.66 |
| CAB35 | PP | 0.23 |
| CRO01 | PP | 1.52 |
| CRO11 | PP | 0.00 |
| CRO12 | PP | 0.00 |
| CRO28 | PP | 0.64 |
| CRO40 | PP | 0.05 |
| DES02 | PP | 0.00 |
| DES05 | PP | 0.21 |
| DES06 | PP | 0.04 |
| DES07 | PP | 0.78 |
| DES12 | PP | 0.82 |
| DES13 | PP | 0.95 |
| DES15 | PP | 0.61 |
| DES18 | PP | 0.40 |
| DES20 | PP | 0.47 |
| DES21 | PP | 0.74 |
| DES22 | PP | 0.44 |
| DES23 | PP | 0.52 |
| DES24 | PP | 0.99 |
| DES26 | PP | 0.14 |
| DES33 | PP | 0.75 |
| DES34 | PP | 0.00 |
| DES36 | PP | 0.54 |
| ILO04 | PP | 0.79 |
| ILO14 | PP | 0.24 |
| ILO18 | PP | 0.00 |
| ILO19 | PP | 0.00 |
| ILO20 | PP | 0.00 |
| ILO31 | PP | 0.16 |
| ILO35 | PP | 0.45 |
| ILO36 | PP | 0.30 |
| ILO40 | PP | 0.22 |
| ILO41 | PP | 0.00 |
| ILO43 | PP | 0.43 |
| ILO44 | PP | 0.49 |
| ILO51 | PP | 0.41 |
| ILO52 | PP | 0.00 |

| | | |
|---|---|---|
| ILO53 | PP | 0.34 |
| ILO67 | PP | 0.51 |
| KEG01 | PP | 0.59 |
| KEG08 | PP | 0.43 |
| KEG11 | PP | 0.57 |
| KEG12 | PP | 0.34 |
| KEG13 | PP | 0.35 |
| KEG24 | PP | 0.36 |
| MET02 | PP | 0.26 |
| MET04 | PP | 0.93 |
| MET11 | PP | 0.75 |
| MET20 | PP | 0.40 |
| MET22 | PP | 0.35 |
| MET23 | PP | 0.38 |
| PAP01 | PP | 0.35 |
| PAP02 | PP | 0.97 |
| PAP03 | PP | 0.57 |
| PAP07 | PP | 0.32 |
| PAP10 | PP | 0.44 |
| PAP13 | PP | 0.33 |
| PAP15 | PP | 0.81 |
| PAP20 | PP | 0.14 |
| PAP21 | PP | 0.63 |
| PAP27 | PP | 0.75 |
| PAP28 | PP | 0.75 |
| PAP29 | PP | 0.68 |
| PAP30 | PP | 0.38 |
| PAP31 | PP | 0.66 |
| PAP32 | PP | 0.64 |
| PAP43 | PP | 1.19 |
| PAP44 | PP | 0.75 |
| PAP45 | PP | 1.02 |
| PAP46 | PP | 0.81 |
| PAP49 | PP | 0.56 |
| RLO01 | PP | 0.62 |
| RLO02 | PP | 0.90 |
| RLO03 | PP | 0.70 |
| RLO10 | PP | 0.64 |
| RLO12 | PP | 0.53 |
| RLO13 | PP | 0.64 |
| RLO14 | PP | 0.67 |
| RLO15 | PP | 0.51 |
| RLO16 | PP | 0.41 |
| RLO19 | PP | 0.48 |

| | | |
|---|---|---|
| SAM17 | PP | 0.33 |
| SAM19 | PP | 0.44 |
| SAM31 | PP | 0.27 |
| SAM33 | PP | 0.52 |
| SAM35 | PP | 0.61 |
| SAM40 | PP | 0.99 |
| SAM42 | PP | 0.00 |
| SAM48 | PP | 0.16 |
| SAM49 | PP | 0.32 |
| TAD04 | PP | 0.77 |
| TAD05 | PP | 0.39 |
| TAD06 | PP | 0.28 |
| TAD08 | PP | 0.06 |
| TAD10 | PP | 0.20 |
| TAD11 | PP | 0.67 |
| TAD12 | PP | 0.38 |
| TAD13 | PP | 0.28 |
| TAD15 | PP | 0.90 |
| TAD20 | PP | 0.06 |
| TAD24 | PP | 0.39 |
| TAD26 | PP | 0.74 |
| TAD27 | PP | 1.04 |
| TAD28 | PP | 0.56 |
| TAD29 | PP | 1.09 |

**SD8: Location and general circulation patterns for Eastern Canada. The Gaspe current originates in the Upper Estuary and flows along the south shore of the St. Lawrence, followed by the Labrador counter-current, which enters the estuary along the north shore** [82]**.**