Assessment of expanded and extruded polystyrene pollution on the North-East Atlantic coastline: abundance, distribution, composition, pathways and sources

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SUMMARY

Foamed polystyrenes which include expanded polystyrenes (EPS) and extruded polystyrene (XPS) have large variety of uses due to their numerous properties. They are also frequently found in the environment and in particular, in the marine environment.

In this context, the Atlantic Area Interreg project OceanWise aims at developing a set of long-term measures to reduce impact of foamed polystyrene products in the North-East Atlantic Ocean. Among OceanWise tasks, the present study aims at gathering knowledge about EPS and XPS pollution in the marine environment. It provides quantitative and qualitative assessments of EPS and XPS pollution in the North-East Atlantic, with a focus on pollution found on the coastline.

In this context, the study consists in:

- *Conducting a quantitative analysis of EPS/XPS pollution on the North-East Atlantic coastline based on existing beach litter data from either official monitoring programmes or citizen-science programmes,*
- *Providing information on EPS/XPS accumulations on coastlines based on a case study conducted in France in collaboration with the Interreg project CleanAtlantic,*
- *Providing a qualitative analysis of EPS/XPS pollution in the marine environment,*
- *Providing qualitative information on identified pathways and sources.*

Results of the study indicated that before 2018, data on EPS/XPS pollution were scarce in the North-East Atlantic since national and international monitoring programmes were not making distinction between foamed polystyrene items and other plastics.

Datasets identified and selected for the quantitative assessment of the EPS/XPS pollution were the OSPAR beach litter monitoring data (2018-2020, but with data available only for a limited number of countries), the HELCOM beach litter monitoring data (2013-2018) and datasets from three citizen science programmes: “Beachwatch” coordinated by the Marine Conservation Society for United Kingdom (2010-2016), “Oceans Initiatives” coordinated by Surfrider Foundation Europe (2015-2018) and “Plastique à la Loupe” coordinated by the Tara Océan Foundation for France (2020).

Among available data, OSPAR beach litter dataset represents the most extensive set of fit-for-purpose data. Over 2018-2020, in OSPAR countries monitoring foamed polystyrenes (Denmark, the Netherlands, Germany, France, Ireland and Portugal), EPS/XPS pollution represents 15% of total plastics and 13% of total litter found on beaches, with a median of 4 items/100m. Among litter types observed, the most frequent are non-identifiable fragments.

Overall, EPS/XPS pollution appears to be abundant, frequent and widespread on the North-East Atlantic coastline. However, the pollution distribution is highly heterogeneous with median abundances per survey site, ranging from 0 to 1270 items/100m.

The online survey launched in France to identify beach litter accumulations confirmed results obtained with the quantitative assessment. EPS/XPS pollution is abundant, frequent and widespread on the French coastline and 36 EPS/XPS accumulation sites were identified.

The qualitative assessment of EPS/XPS pollution indicated that EPS/XPS are easily broken, leading to the production of large amounts of lightweight fragments that float and can be transported and disseminated over long distances by winds and currents.

EPS/XPS pollution appears to be multisize going from very large items (several meters large) down to a few millimetres. It is mainly made of fragments that can be eroded due to mechanical processes or photo-oxidation.

EPS/XPS litter are known to interact with biota by being ingested by species like birds, by being colonised by species and transported them potentially over long distances, by constituting a new habitat for borer species leading to the release of large amounts of microplastics in the marine environment and by interacting with living plants.

River inputs, urban water inputs and extreme events are known pathways of discharge of EPS/XPS in the marine environment. Similarly to observations made on beaches, most of foamed polystyrenes collected in rivers and urban water systems are non-identifiable fragments, indicating fragmentation can occur before the entry in the marine environment.

Sources of EPS/XPS pollution are multiple and their contribution is difficult to assess due to the important degradation of EPS/XPS products in the environment making challenging their identification. Identified sources are fishing, aquaculture, fish transport and processing, food packaging and construction. Other sources exist such as agriculture or meteorological measurement but they probably contribute less to the pollution.

Abbreviation

EPS	Expanded Polystyrene
EU	European Union
GES	Good Environmental Status
HELCOM	Helsinki Convention for the Baltic marine environment protection
JRC	Joint Research Centre
MCS	Marine Conservation Society
MSFD	Marine Strategy Framework Directive
OSPAR	Oslo-Paris Convention for the protection and conservation of the North-East Atlantic and its resources
RAP ML	OSPAR Regional Action Plan for Marine Litter
RiLON network	Riverine Litter Observation Network
RIMMEL project	Riverine and Marine floating macro litter Monitoring and Modelling of Environmental Loading
TG ML	Technical Group on Marine Litter
UK	United Kingdom
UNEP	United Nations Environment Program
XPS	Extruded Polystyrene

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1. Introduction

In recent years, marine litter has been increasingly recognised as a serious problem with many environmental, economic and social impacts (Galgani et al., 2013; Werner et al., 2016). Marine litter is ubiquitous in the environment and comes from many different sources and origins. In the marine environment, marine litter can be observed in all compartments (*e.g.* surface, seawater column, sediment). To monitor this pollution and support the implementation of efficient reduction measures, different monitoring programs have been launched. Currently in Europe, marine litter is monitored on beaches, on the seafloor and in the surface layer of the water column.

Beach litter is defined as any anthropogenic, persistent, solid material longer than 5 mm, discarded, disposed of, abandoned or lost in the marine and coastal environment and encountered on coastlines. As beach litter is abundant in European waters (OSPAR, 2019; Hanke et al., 2019), the monitoring of beach litter pollution is necessary in order to assess the status and evolution of its abundance and composition. The only way to obtain comprehensive data on beach litter is to perform monitoring surveys with a sufficient frequency through the years. In addition, methodologies need to be harmonised across regions and countries to study the pollution at a large scale to implement global regulations. In that sense, regional and EU-wide public policies, such as Oslo-Paris Convention (OSPAR Convention; OSPAR, 1992) and the Marine Strategy Framework Directive (MSFD; EU, 2008; EU, 2010) have been elaborated to protect the marine environment, notably by reducing the abundance of marine litter. The final aim of these policies is to achieve or maintain Good Environmental Status (GES) of marine waters. Within the MSFD, marine litter is one of the descriptor (Descriptor n°10) that is used to assess GES, which is defined for this descriptor as: "Properties and quantities of marine litter do not cause harm to the coastal and marine environment".

Nowadays, studies and reports agree that litter types made out of plastic accounts for the majority of beach litter pollution, representing more than 80% of the pollution (OSPAR, 2019; Hanke et al., 2020). Among plastic litter types found on the coastline, foamed polystyrene products, which include expanded polystyrenes (EPS) and extruded polystyrenes (XPS), are of concern. These materials have numerous qualities as they are lightweight, low cost, mouldable and have great insulating and protective properties. It is therefore not a surprise to find these products in our daily lives in the form of cups, lids, food containers or hidden inside helmets or surf boards. EPS/XPS are also used for building insulation, food packaging (*e.g.* fish box, meat trays) and product protection during transport (Figure 1).

Figure 1: Examples of foamed polystyrene products: an EPS fish box (left) and an XPS food box (right) (source: Cedre).

As foamed polystyrenes are lightweight, they represent a low mass of plastic produced per inhabitant (500 g/inhabitant/year). However, they are among the most produced plastics in terms of volume. EPS/XPS constitute 60% in volume of plastic production in Europe yearly (OceanWise WP5.2, Godet et al., 2018), and they are frequently found in the environment, in particular in the marine environment.

Figure 2: Examples of foamed polystyrene pollution in the environment: EPS observed on the coastline of the town of Agde, France (left) and EPS observed on banks of the Bidassoa river, France (right) (source: Cedre).

In this context, the Atlantic Area Interreg project OceanWise aims at developing a set of long-term measures to reduce impact of foamed polystyrene products in the North-East Atlantic Ocean. Thirteen partners from five Atlantic Area countries – France, Ireland, Portugal, Spain and the United Kingdom – have joined forces to find solutions to the growing environmental problem of foamed polystyrenes by considering the entire life-cycle of these products to achieve transnational sound management of EPS/XPS marine litter in the Atlantic Area. Based on resource-efficiency, participatory methods and circular economy principles, the OceanWise project plans to generate new and best practice within sectors using, manufacturing or recycling foamed polystyrenes. In particular the project has several objectives:

- Identify EPS/XPS products and their source that are more likely to reach the marine environment and impact ecosystems;
- Propose and test plausible options (reduce, reuse, recycle, recover) to achieve better environment outcomes within different sectors;
- Engage producer and designer communities on the sustainability of specific applications and to explore more circular models;
- Develop circular-economy-oriented methodologies to assess new opportunities, barriers and policy options.

The project is directly linked to Action 49 of the first Regional Action Plan for Marine Litter (RAP ML) of the OSPAR Convention, aiming at "investigating the prevalence and impact of foamed polystyrenes in the marine environment, and engaging with industry to make proposals for alternative materials and/or how to reduce its impacts".

Among OceanWise tasks, the Work Package (WP) 5 "Knowledge hub" aims to deliver the knowledge base on foamed polystyrenes and their alternatives – such as their usage, applications, production and presence in the marine environment – and on stakeholders and existing policies, incentives and producer responsibility schemes. In this work package, the present study aims at gathering knowledge about EPS and XPS pollution in the marine environment. It provides quantitative and qualitative assessments of EPS and XPS pollution in the North-East Atlantic with a focus on pollution found on coastlines.

2. Presentation of the study

This study aims to provide an assessment of EPS/XPS pollution on the North-East Atlantic coastline. In this context, the study consists in:

- Conducting a quantitative analysis of EPS/XPS pollution on the North-East Atlantic coastline based on existing beach litter data,
- Providing information on EPS/XPS accumulations on coastlines based on a case study conducted in France,
- Providing a qualitative analysis of EPS/XPS pollution in the marine environment,
- Providing qualitative information on identified pathways and sources.

3. Methodology

3.1. Quantitative analysis of beach litter monitoring data

For the quantitative analysis of EPS/XPS pollution on the North-East Atlantic coastline, the first step was to identify existing datasets. Once identified, datasets were analysed using the method detailed below.

3.1.1. Data sources

The identification of data sources was conducted by considering firstly datasets generated by international monitoring programs. As these data were scarce, datasets provided by national or international citizen science programmes were also considered. The identification of datasets was facilitated by the sharing of information within the OceanWise consortium.

Existing datasets providing information on EPS/XPS beach litter pollution in the North-East Atlantic were identified. The datasets selected for the present study are listed below.

- **OSPAR beach litter monitoring data (North-East Atlantic)**

The OSPAR beach litter dataset, which comes from the OSPAR beach litter monitoring program, initiated in 2010, provides the most extensive set of fit-for-purpose beach litter monitoring data in the North-East Atlantic. Data are collected from regular dedicated surveys carried out according to a standardized methodology described in OSPAR Guidelines (OSPAR, 2010). Four times a year (once per season), OSPAR countries monitor litter pollution on survey beaches (OSPAR, 2017) which are selected according to specific criteria. The monitoring consists in collecting and identifying, in terms of number and types of litter, all the litter items larger than 0.5 cm present within the same sampling unit of 100 m stretch of beach, from the water's edge to the back of the beach. All surveys are carried out in compliance with a defined quality assurance procedure and, once controlled and validated by OSPAR national coordinators, data are stored in the dedicated OSPAR beach litter database (https://beachlitter.ospar.org/).

Although very complete for the assessment of beach litter pollution, this dataset has limitations for the analysis of EPS/XPS. Indeed, foamed polystyrenes were not differentiated from other plastics before 2018 and the introduction of "*test items*" in the OSPAR survey list that include several EPS/XPS litter types. From 2018, it was possible for the national operators to differentiate between foamed polystyrenes and other plastics for fragments and other products such as tableware or food packaging. However, this differentiation was optional and was not made in all OSPAR countries, limiting the data collection on EPS/XPS abundance, distribution and composition on the OSPAR maritime area coastline.

NB: the monitoring of EPS/XPS litter types became compulsory in 2021 for all OSPAR countries implementing a beach litter monitoring, so more data will be available in the future to assess foamed polystyrene pollution on the OSPAR maritime area coastline.

- **HELCOM beach litter monitoring data (Baltic Sea)**

Though not strictly speaking in the North-East Atlantic, It appeared interesting to consider the Baltic Sea in the present study since a dedicated assessment of foamed polystyrene pollution has been recently conducted in this region, in the framework of the Baltic Marine Environment Protection Commission, also known as the Helsinki Commission (HELCOM; Lassen et al, 2019). This assessment covered several countries around the Baltic Sea using different protocols for monitoring of beach litter:

- The OSPAR protocol proposed by the OSPAR Commission (OSPAR, 2010);
- The modified technical protocol for marine beach litter assessment (MARLIN/UNEP) based on the United Nations Environment Program (UNEP) standard method during the MARLIN project (2011-2013);
- The protocol of the Technical Group on Marine Litter (TG ML) and the associated Master List for the categorization of litter items recommended for use during MSFD monitoring (Galgani et al, 2013).

In these monitoring protocols, foamed polystyrenes are not usually distinguished from other plastic materials. In order to obtain data on foamed polystyrenes, a questionnaire regarding the results of beach litter monitoring was specifically prepared by Lassen et al (2019). Nevertheless, the study mainly focused on data acquired by Denmark from 2018 which distinguish foamed polystyrenes from other plastic polymer items for the categories containing mixes of the plastic materials, such as unidentifiable pieces and some specific categories (food containers, cups, fish boxes, floats and buoys). In this context, quantitative data on EPS/XPS pollution appear to be limited in the Baltic Sea.

- **Datasets obtained from citizen science programmes**

As only a limited number of quantitative data on EPS/XPS pollution is available at the scale of regional sea conventions, datasets obtained by citizen science programmes have also been considered in the present study.

The first dataset considered is data acquired in United Kingdom (UK) within the framework of the *Beachwatch* programme of the Marine Conservation Society (MCS), covering the period 2010-2016 (MCS UK, 2021). Within this programme, the monitoring is carried out by any volunteers wishing to conduct cleaning operations, preferably on sites of 100 m long (but not only) in order to record comparable data. Beyond the collection, marine litter is identified according to litter types close to international reference lists. In this programme, foamed polystyrenes are differentiated from other types of plastic since 2010. Although comprehensive and well fed, it should be noted that this dataset only covers the UK coastline.

The second dataset considered was provided by *Ocean Initiatives* coordinated by Surfrider Foundation Europe (Surfrider Foundation Europe, 2021). In this programme, data are also acquired by volunteers who collect marine litter during beach, lake, river and seabed clean-ups. The dataset generated by these surveys is then compiled year by year and presented in the form of environmental reports. In the present study, beach litter data from 2015 to 2018 initiatives are considered. The marine litter identification used by *Ocean Initiatives* is also based on international reference lists, but the distinction between foamed polystyrene and other plastic materials is only made for non-identifiable fragments. It should also be noted that cleaning are not performed on standardized beach length preventing the expression of results in number of litter per 100 m of beach as generally done in official monitoring programmes.

The third and final citizen science dataset considered in the present study comes from the operation "*Plastique à la loupe*" created and coordinated by the "Tara Océan" foundation (Tara Océan, 2021). This programme is conducted in collaboration with Cedre, the French National Centre for Scientific Research (CNRS) and Sorbonne University. The programme, launched in 2020, offers secondary school students the opportunity to contribute to the assessment of plastic pollution on beaches and riverbanks of metropolitan France. The data are collected according to a scientific protocol adapted from the OSPAR protocol and consisting in the collection and identification of stranded litter on beaches and riverbanks. The dataset provided by the Tara Océan foundation covers only 2020 and includes 25 beach surveys and 25 riverbank surveys. Following the example of the OSPAR survey list modified in 2018, data from the "*Plastique à la loupe*" programme discriminate several types of foamed polystyrene litter types, including fish boxes, food containers, cups and non-identifiable fragments, providing complementary quantitative data on EPS/XPS pollution for mainland France.

3.1.2. Data analysis

As data from the different datasets were obtained on different spatial scales, with different protocols and within either official monitoring or citizen-science programmes, it was not possible to consider them together for analysis. Therefore, each datasets were analysed separately. Nevertheless, in order to compare obtained results, similar calculations were performed on each datasets. All calculations were made on Excel and maps were prepared using the QGIS software.

Abundance and distribution

Abundances were expressed, when possible, as number of foamed polystyrene litter items per 100 m of beach. When the length of the beach surveyed was unknown, the abundance was expressed in number of foamed polystyrene litter items. When several surveys were carried out on a same site, the abundance at the survey site level was obtained by calculating the median of all surveys performed over the period considered. Abundances at higher scales were obtained by calculating the medians of medians obtained at survey site level.

Beach litter data are known to be heterogeneous and the use of medians is appropriate (i) for the skewed beach litter data distributions (Schulz et al., 2019) and (ii) to support decision-making as they provide a snapshot of the typical situation without influence of extreme events.

Percentages of EPS/XPS pollution were obtained by dividing the number of EPS/XPS items collected by the total number of plastic items or total litter collected on all survey sites at the scale and over the period considered.

Distribution was assessed by comparing abundances of the different survey sites and by mapping the data at the scale considered.

Composition

Composition was assessed by comparing the abundance of the different EPS/XPS litter types surveyed. In addition, the Top 5 of most abundant litter types was calculated using the total number of each EPS/XPS items collected at the scale and over the period considered.

3.2. Case study on EPS/XPS accumulations on the French coastline

This work was conducted in collaboration with the Interreg Atlantic project CleanAtlantic ("Tackling marine litter in the Atlantic Area", EAPA_46/2016). As part of the CleanAtlantic project, Cedre (France) with the support of Data Terra (France) launched in 2020 an online survey on macro-litter on the coastline of France, with a three-fold objective: to (i) diagnose beach litter pollution and identify main accumulation sites; (ii) identify measures in place to reduce stranded litter and (iii) review clean-up operations. As part of the diagnosis of beach litter pollution, specific questions on foamed polystyrenes pollution were included in the questionnaire in order to provide inputs to the present study.

NB: the same online survey will be launched in 2022 in other Atlantic area countries and additional information will be obtained for Ireland, Portugal, Spain and United Kingdom, as part of the extension of the CleanAtlantic project.

The survey lasted one month and was circulated to over 400 French stakeholders. It targeted the stakeholders involved in implementing and financing clean-up, namely: local authorities, primarily municipalities; marine protected areas; certain public institutions; and associations and cooperatives specialised in marine litter. The questionnaire was geared towards local granularity, and therefore targeted local stakeholders liable to have very good field knowledge.

With only 105 usable responses out of the 303 received, the survey obtained a limited number of responses. However, the responses showed a relatively even spatial coverage of mainland France coastline and provide a good understanding of the local beach litter situation (Figure 3). Respondents were mainly coastal municipalities and non-governmental associations. However, in relation to the total number of coastal municipalities, participation rates appeared to be extremely low. The main roles played in the field of beach clean-up by the respondent organisations were, in more or less equal proportions, awareness-raising (influence of associations) and conducting clean-ups. More details are available in the final report of the CleanAtlantic study (Kerambrun et al., 2021).

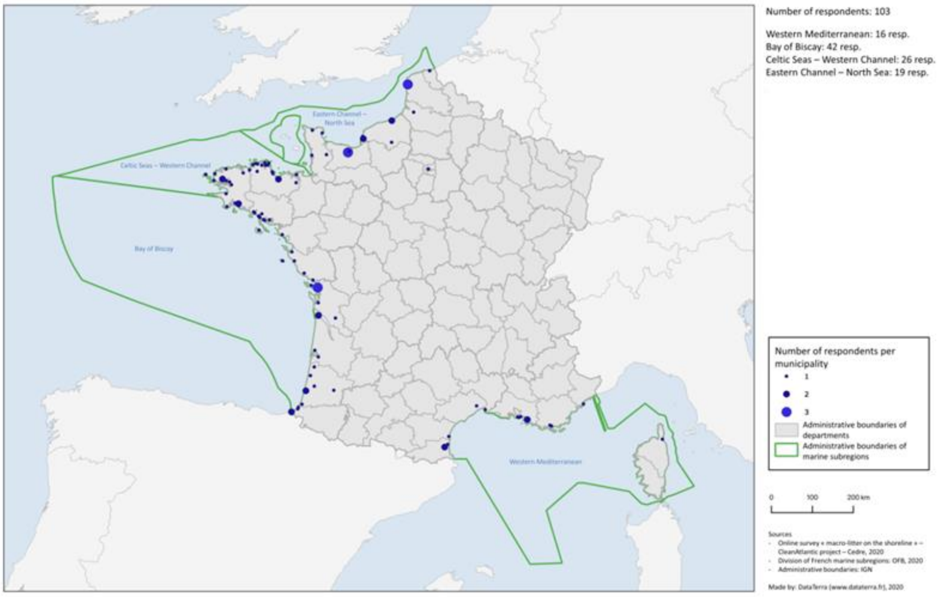

Figure 3: Location of the respondents

3.3. Qualitative analysis of EPS/XPS pollution in the marine environment

The qualitative analysis of EPS/XPS pollution was performed by reviewing existing pictures of EPS/XPS litter found in the marine environment. Pictures were obtained from the literature, newspaper articles and from Cedre photo library.

3.4. Information gathering on pathways and sources

Information on existing sources and pathways were obtained by considering projects and/or programmes studying litter composition in rivers and urban water systems and by analysing pictures of EPS/XPS litter types that could be attributed to known sources. Pictures were obtained from the literature, newspaper articles and from Cedre photo library.

4. Results and discussion

4.1. Quantitative assessment of EPS/XPS pollution on the North-East Atlantic coastline

As presented in the previous section, 2018 is a turning point for the quantitative assessment of foamed polystyrenes as these litter types were included as "test items" in the survey list used for the OSPAR Beach litter monitoring. So the assessment presented below distinguishes periods before and after 2018.

4.1.1. EPS/XPS pollution before 2018

Assessment in United Kingdom over 2010-2016 (Beachwatch programme data, MCS).

The dataset provided by the Beachwatch programme identifies 8 types of foamed polystyrene litter, as presented Table 1.

Table 1: Foamed polystyrene items identified in the Beachwatch survey list.

Polystyrene: Buoys
Polystyrene: Fast food containers/cups
Polystyrene: Fish boxes
Polystyrene: Fibreglass
Polystyrene: Foam/sponge/insulation
Polystyrene: Packaging
Polystyrene: Polystyrene pieces < 50 cm
Polystyrene: Other

Over 7 years, 2014 different survey sites were monitored along the UK coastline by the Beachwatch programme, some of them over several years. The location of these sites is shown in Figure 4(a). Of these, 709 sites were 100 m in length, the length defined by the OSPAR or MSFD beach litter monitoring protocols, which are harmonised between the different Member States.

When comparing the results obtained, differences are observed between medians obtained for all the sites and medians only taking into account 100 m sites. Indeed, medians obtained on 100 m sites are generally higher, which can be explained by a scale phenomenon during collections. A rule of thumb says that the longer the site, the less thorough the collection. Therefore, when standardising the data to a length of 100 m, the longer sites will tend to have a lower concentration in litter items than the shorter sites. Of the 1 305 survey sites with a length different than 100 m, 241 are shorter while 1 064 are longer than 100 m, which can explain the significant differences observed between the median total count of all sites and the median total count of 100-m sites. In order to obtain results that are consistent with current harmonised monitoring programmes (OSPAR, MSFD), only sites with a length of 100 m are considered in the present study.

Detailed results, i.e. median abundances in total litter items, in litter items made of plastics (including foamed polystyrenes) and in foamed polystyrene items are presented in Appendix 1. Median abundances of foamed polystyrenes on the 100 m sites are shown in Figure 4(b). EPS/XPS pollution appears to be widespread over the UK coastline though heterogeneously distributed between survey sites.

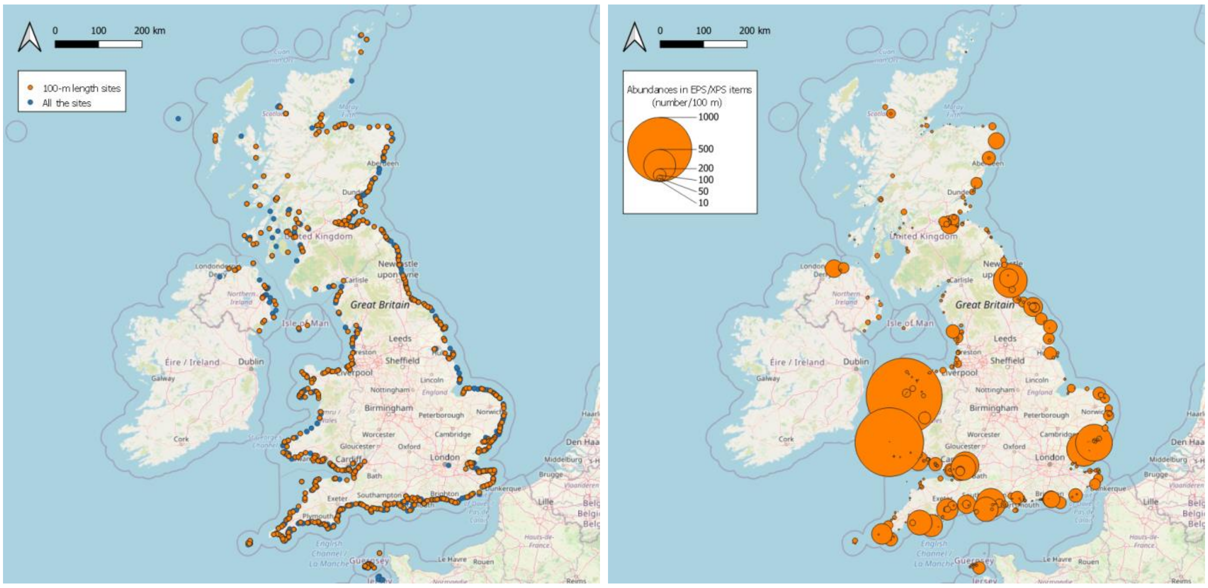

Figure 4: survey sites of the Beachwatch programme (2010-2016, MCS UK) (source: Cedre)

(a) Location of all the 2014 survey sites. *(b) Relative abundance of the 100 m length survey sites.*

When considering 100 m sites, median abundances of foamed polystyrenes per year vary between 18 and 26 items/100 m, which represented about 5% of the total litter abundance each year and 10% of the total plastic abundance (Figure 5).

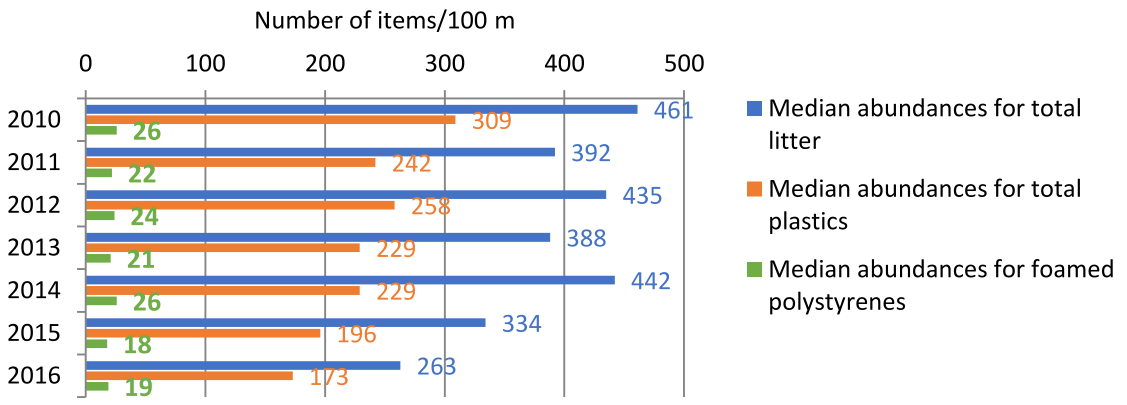

Figure 5: Median abundances for total litter, total plastics and foamed polystyrenes, on the UK coastline based on Beachwatch data collected on 100 m survey sites over 2010-2016 (MCS UK).

Looking in more details at the different litter types made of foamed polystyrene, non-identifiable pieces smaller than 50 cm represent the largest part with 9 items/100 m per year, followed by insulation foam (around 3 items/100 per year) and cups and food containers (around 1 item/100 m per year).

Foamed polystyrene pieces represent a large majority of the foamed polystyrene litter items collected on survey sites. Considering all the litter items collected over the 7 years from 2010 to 2016, foamed polystyrene pieces are the fifth most collected litter types. The Top 5 of the most collected litter types in the Beachwatch programme from 2010 to 2016 is shown in Figure 6.

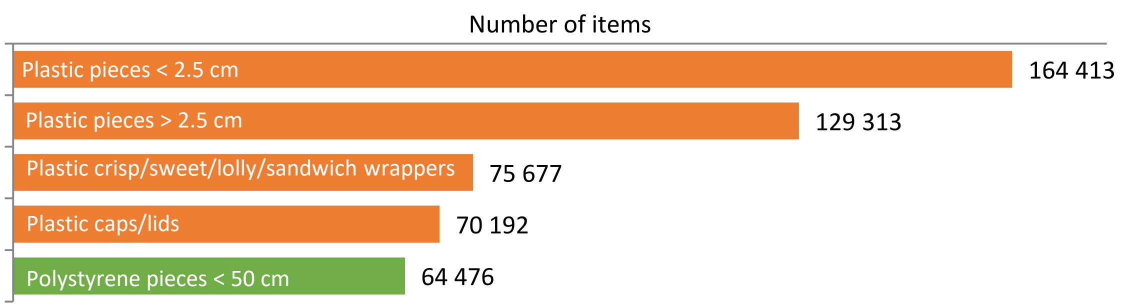

Figure 6: Top 5 of most collected litter types on the UK coastline based on Beachwatch data collected on 100 m survey sites over 2010-2016 (MCS UK).

Assessment in the Baltic Sea over 2013-2018 (HELCOM data)

The assessment of foamed polystyrene pollution in the Baltic Sea region involves 92 survey sites in 7 different countries of the HELCOM Convention: Germany, Denmark, Estonia, Finland, Lithuania, Poland and Sweden. The survey sites are shown in Figure 7.

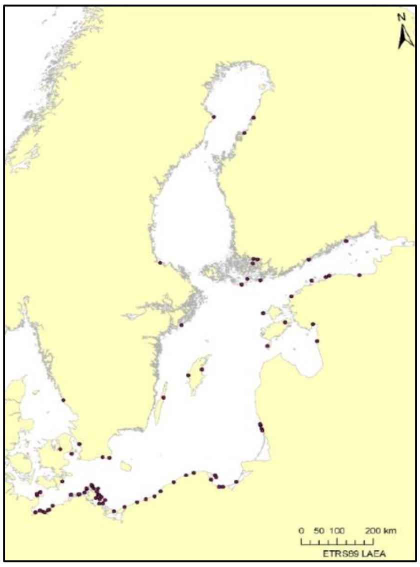

Figure 7 : Map of the Baltic Sea with location of the 92 sites used for the assessment of EPS/XPS occurrence on beaches in Lassen et al. (2019).

Since the monitoring protocols prior to 2018 do not distinguish between foamed polystyrenes and other types of plastics, the assessment of the presence of foamed polystyrenes on the coastline of the Baltic Sea region is based on quantities of plastic litter types that may be foamed polystyrenes. These litter types were identified by experts from different countries and divided into two categories: “Mainly EPS items” and “Occasionally EPS items”. Litter types which are likely to be made of foamed polystyrene according to the final report of the HELCOM EPS/XPS study, are presented in Table 2 (Lassen et al., 2019). Based on this classification percentage of “Mainly EPS items” and “Occasionally EPS items” were calculated for each country.

Results show that the proportions vary from one country to another. In Denmark and Poland, the percentages of litter which are classified as “mainly EPS items” reached 12% and 4% respectively of the total plastic abundance. In contrast, for the other 5 countries, this percentage does not exceed 1%. On the other hand, “Occasionally EPS items” are comprised between 1 (Sweden) and 63% (Germany). However, these results should be considered with caution as they are only indicative of EPS/XPS pollution. Furthermore, the report points out that the large differences observed between countries may be due to the significant heterogeneity between the selected beaches.

From 2018, Denmark apply the modifications of the reference monitoring lists as recommended by OSPAR into its surveys by distinguishing between foamed polystyrenes and other types of plastics. Thus, on the basis of 19 surveys, distributed over 6 survey sites (3 in OSPAR, 3 in HELCOM), the proportions of foamed polystyrenes are assessed and represent 11% of artificial polymers (1-14% in OSPAR, 7-20% in HELCOM).

Table 2: Beach litter monitoring programs protocols used by HELCOM countries for classification of beach litter and associated categories constituted mainly or occasionally of EPS according to Lassen et al. (2019).

Country	Monitoring protocol	Mainly EPS items	Occasionally EPS items
Denmark	modified OSPAR/TG ML	G82: polystyrene pieces 2.5-50 cm, G83: polystyrene pieces > 50 cm, G58: polystyrene fish boxes	G10: food containers, G33: cups, G62: floats, G63: buoys
Poland	modified OSPAR/TG ML	G76: Plastic/polystyrene pieces 2.5-50 cm, G77: Plastic/polystyrene pieces > 50 cm, G124: Other plastic/polystyrene items	G10: food containers, G33: cups, G62: floats, G63: buoys G57/G58: fish boxes
Germany Lithuania	OSPAR		6: food containers, 21: cups, 34: fish boxes, 37: floats/buoys, 46: plastic/polystyrene pieces 2.5-50 cm, 47: plastic/polystyrene pieces > 50 cm, 48: other plastic/polystyrene items
Sweden Estonia Finland	UNEP/MARLIN	FP02: Food containers and cups	FP01: Foam sponges, FP03: Foam buoys, FP04: Foam insulation and packaging, FP05: Other foam items

Assessment across several countries over the period 2014-2017 (Ocean Initiatives data, Surfrider Foundation Europe)

Annual data from Ocean Initiatives (Surfrider Foundation Europe) cover the time period from 2014 to 2017 and come from surveys performed across 30 different countries, detailed in Appendix 2. The available data only provide results on abundance of polystyrene fragments (2.5-50 cm). It must be noted that lengths of sites monitored are presented qualitatively, which does not allow a normalization of results according to the beach length and a strictly-speaking quantitative assessment of the pollution.

Of all the different countries covered by the programme, France and Spain present more data than other countries, where surveys are carried out more punctually.

Considering results obtained in France, the country with the most surveys available, the median number of foamed polystyrene fragments collected per year on survey sites with lengths between 100 and 200 m, ranged from 11 to 44 items. In Spain, results ranged from 15 to 88 items, indicating EPS fragments are litter types commonly found during these surveys.

4.1.2. EPS/XPS pollution from 2018

Assessment in the OSPAR maritime area over 2018-2020 (OSPAR Beach litter monitoring data)

From 2018, the OSPAR Protocol allowed to distinguish foamed polystyrenes from other plastics for several litter types that may be encountered in either foamed polystyrene or other plastic materials. However, the survey of these new litter types (also called “test items”, listed in Table 3) was only optional.

Thus, from 2018, seven countries (France, Ireland, Portugal, Norway, Denmark, the Netherlands and Germany) started to collect data on EPS/XPS items. Survey sites for which test items have been reported and the median abundances obtained over 2018-2020 are shown in Figure 8. This figure shows that EPS/XPS pollution is widespread. However, the distribution is heterogeneous between survey sites.

Table 3: List of EPS/XPS “test items” introduced in the OSPAR survey list in 2018 (EPS/XPS litter types are highlighted in yellow).

Category	***OSPAR id***	***Litter type***
Plastic/polystyrene	*610*	*Food containers incl. fast food containers - plastic*
Plastic/polystyrene	*620*	*Food containers incl. fast food containers - expanded polystyrene*
Plastic/polystyrene	*211*	*Cups - plastic*
Plastic/polystyrene	*212*	*Cups - expanded polystyrene*
Plastic/polystyrene	*341*	*Fish boxes - plastic*
Plastic/polystyrene	*342*	*Fish boxes - expanded polystyrene*
Plastic/polystyrene	*1171*	*Plastic pieces 0-2.5 cm*
Plastic/polystyrene	*1172*	*Expanded polystyrene pieces 0-2.5 cm*
Plastic/polystyrene	*461*	*Plastic pieces 2.5-50 cm*
Plastic/polystyrene	*462*	*Expanded polystyrene pieces 2.5-50 cm*
Plastic/polystyrene	*471*	*Plastic pieces > 50 cm*
Plastic/polystyrene	*472*	*Expanded polystyrene pieces > 50 cm*

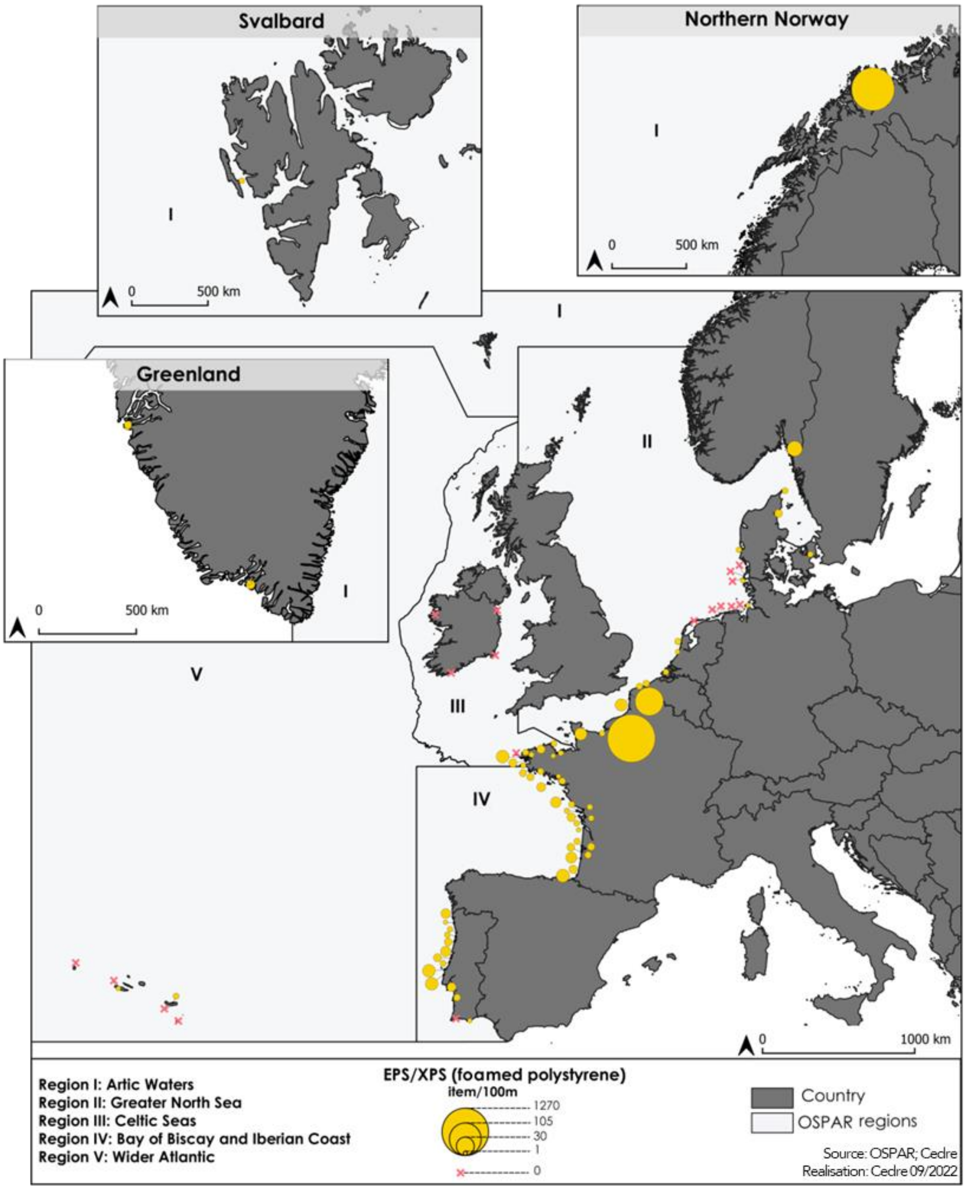

Figure 8: Foamed polystyrene median abundances for OSPAR survey sites in Norway, Denmark, the Netherlands, Germany, France, Ireland and Portugal, from 2018 to 2020. I: Arctic Region, II: Greater North Sea Region, III: Celtic Seas Region, IV: Bay of Biscay and Iberian Coast Region; V: Wider Atlantic Region.

In Norway, only three monitoring sites are surveyed and there are only a limited number of surveys between 2018 and 2020, i.e. 6 surveys in total for the three sites located either in the OSPAR Arctic and Greater North Sea regions. Nevertheless, these surveys show that foamed polystyrenes can be found during monitoring campaigns in the Arctic region. In May 2019, 1,027 fragments of foamed polystyrenes, excluding the ones smaller than 2.5 cm, were collected in one survey. In the Greater North Sea Region, three annual surveys were conducted at one monitoring site. Median abundances of foamed polystyrenes vary between 53 litter items/100 m and 137 litter items/100 m (more than 90% of the abundances are made up of fragments greater than 2.5 cm). It should be noted that fragments of foamed polystyrene smaller than 2.5 cm, which are not taken into account in the abundance calculations, have non-negligible abundances ranging from 87 small fragments/100 m to 216 small fragments/100 m for the three monitoring sites.

In Denmark, two distinct regions are identified: metropolitan Denmark and Greenland (This distinction is made because these two regions do not belong to the same OSPAR regions). Metropolitan Denmark has 4 monitoring sites with a median abundance of foamed polystyrene of 4 items/100 m. The median EPS/XPS abundance per survey site is shown in **Erro! A origem da referência não foi encontrada.** and it can be seen that all sites have a median of at least 3 foamed polystyrene items/100 m. However, the percentage of foamed polystyrenes remains low compared to the total plastic items collected (3% of total litter collected). Taking each site in Denmark independently, the share of foamed polystyrenes compared to other plastics varies between 1% and 16%, which is consistent with the results obtained in the Baltic report (Lassen et al., 2019). Considering the beach litter types identified as foamed polystyrene, only fragments (> 2.5 cm) show non-zero abundances. It means that, in at least half of the surveys conducted, polystyrene fragments were found, indicating this litter type is frequently found.

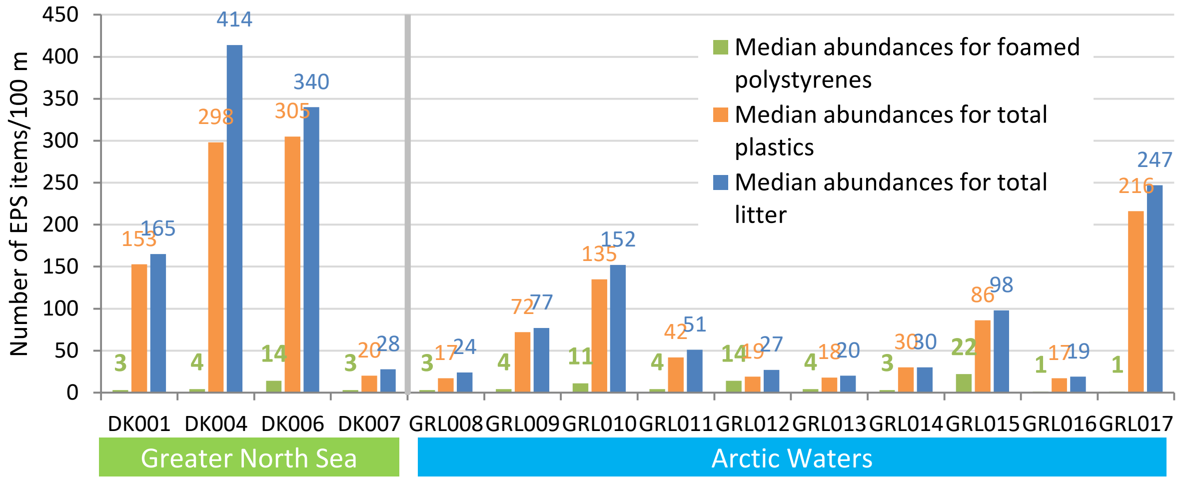

Figure 9 : Median abundances for total litter, total plastics and foamed polystyrenes found on OSPAR survey sites in Denmark and Greenland (DK=Denmark sites, GRL=Greenland sites) over 2018-2020.

For Greenland, the median abundance is also estimated at 4 foamed polystyrene items/100 m, for 10 survey sites. However, the total and plastic abundances are lower than in metropolitan Denmark. The share of foamed polystyrene is therefore higher, at around 16% for Greenland as a whole. With regard to the types of polystyrene foam litter in the list of test items, again the fragments (> 2.5 cm) show a persistent pollution.

In the Netherlands, foamed polystyrenes are less abundant than in Denmark with a median value of 2 litter items/100 m.

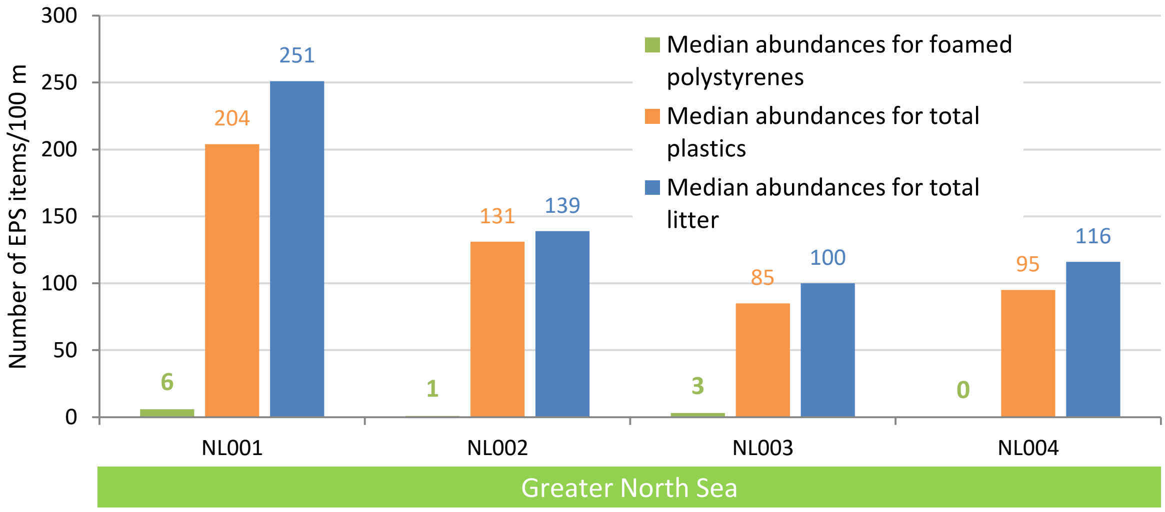

Figure *10* shows that none of the four Dutch monitoring sites have important foamed polystyrene pollution. The EPS/XPS litter types represent between 1% and 5% of the total plastic litter collected between 2018 and 2020 (between 1% and 4% of total litter collected).

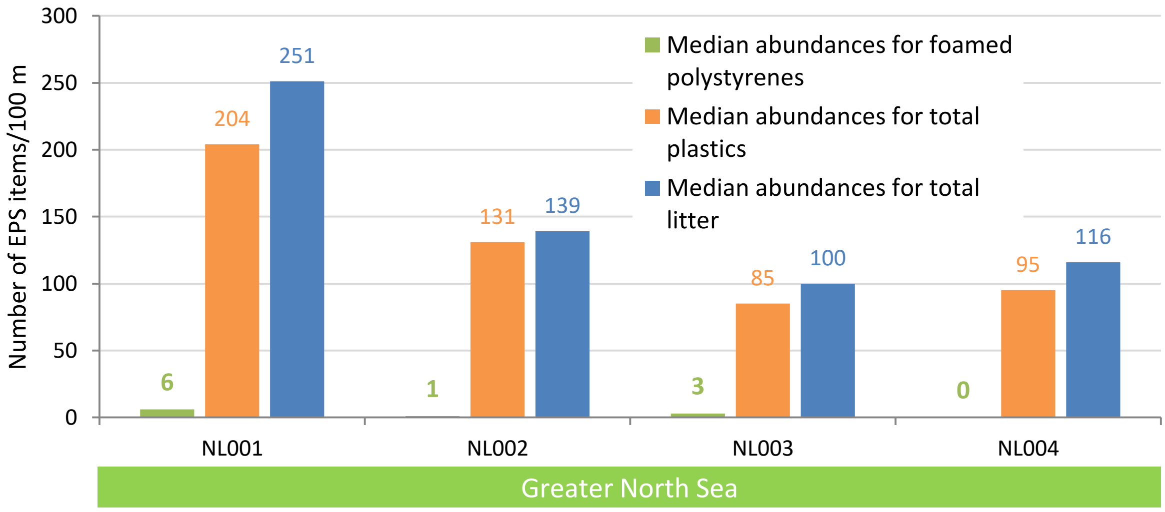

Figure 10: Median abundances for total litter, total plastics and foamed polystyrenes found on OSPAR survey sites in the Netherlands over 2018-2020.

In Germany, foamed polystyrenes are rarely found, with zero median abundance for almost all monitoring sites (7 sites). Only two sites had median abundances of 1 foamed polystyrene item/100 m of beach. The median abundance of EPS/XPS is therefore equal to zero for the country, despite a median abundance of 64 plastic items/100 m.

In France, foamed polystyrenes are also present on the coastline with a median abundance of 6 litter items/100 m in a set of 38 monitoring sites. Overall, EPS/XPS represent 20% of plastics collected between 2018 and 2020 (18% of total litter collected). These litter items are found in very high quantities in sites in the Greater North Sea region in the north of the country. Indeed, it can be seen in

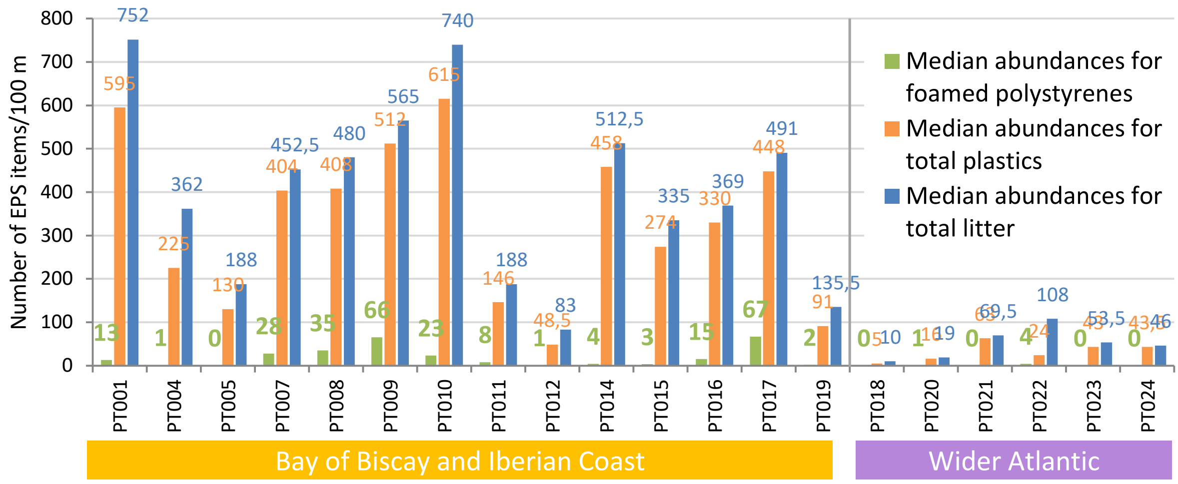

Figure *12* that four monitoring sites in this region (i.e. FR016, FR015, FR004 and FR025) have median abundances of foamed polystyrenes greater than 50 litter items/100 m, two of which have extreme abundances of 439 litter items/100 m (63% of the plastics collected) and 1,270 litter items/100 m (84% of the plastics collected). At the French part of Greater North Sea Region, foamed polystyrenes represent 52% of the plastics collected (47% of total litter collected; notably because of the heavily polluted sites) over 2018-2020.

In the remaining OSPAR sites on the French coast, the abundance is heterogeneous but foamed polystyrenes remain omnipresent, with medians varying between 1 item/100 m and 73 items/100 m (excluding one site where no foamed polystyrene was recorded). Thus, the proportion of foamed polystyrenes varies between 1% and 20% of plastics collected for these sites. Overall for survey sites in the OSPAR Celtic Seas and Bay of Biscay and Iberian Coast regions, foamed polystyrene represents 5% of the plastics collected (4% of total litter collected). Finally, as observed in the other countries, the main types of foamed polystyrene reported in France are essentially non-identifiable fragments.

In Ireland, where the median total abundances of the four monitoring sites are low compared to other countries (between 9 items/100 m and 98 items/100 m), the median abundances of foamed polystyrenes are zero over the whole period 2018-2020. Of all the surveys entered into the OSPAR database, 15 non-identifiable fragments larger than 2.5 cm, 5 non-identifiable fragments smaller than 2.5 cm and 1 foamed polystyrene cup were found in Ireland between 2018 and 2020.

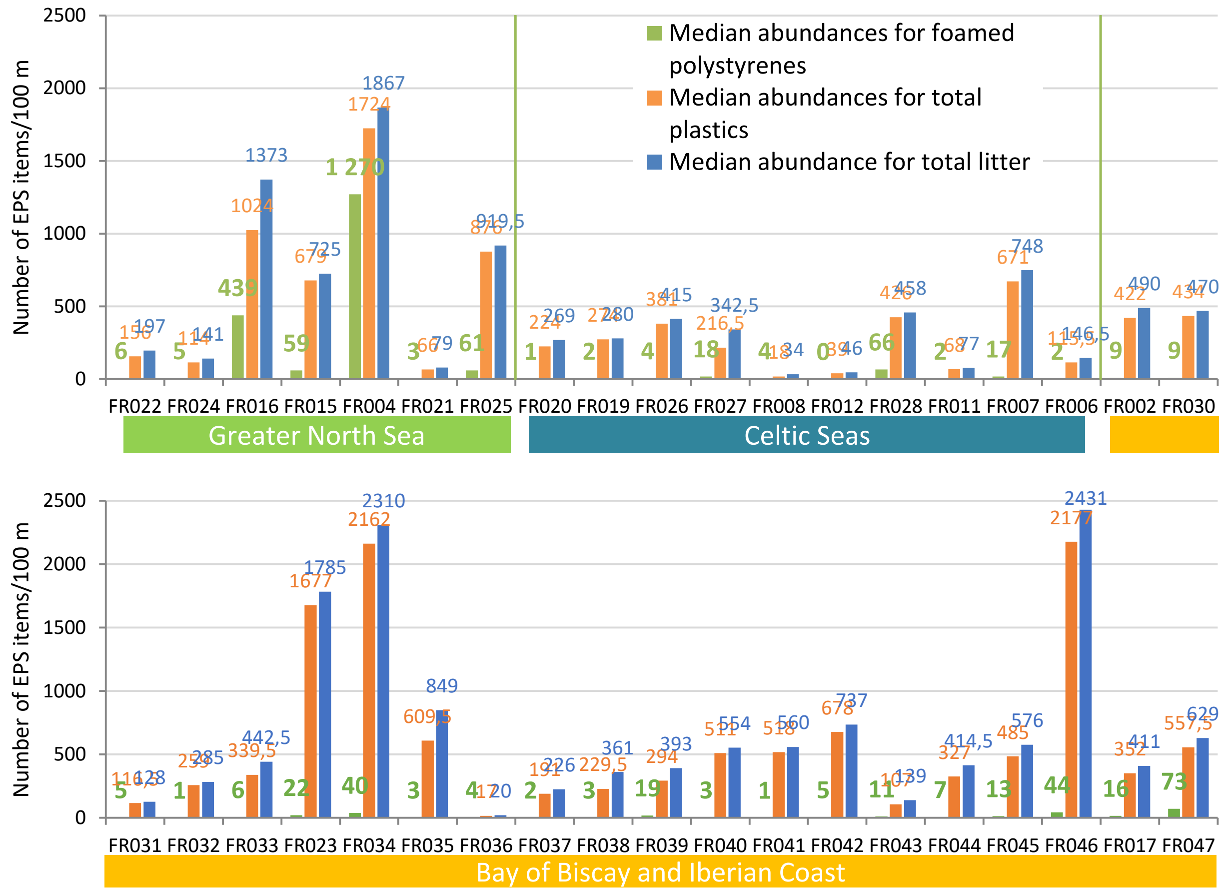

Figure 11: Median abundances for total litter, total plastics and foamed polystyrenes found on OSPAR survey sites in France over 2018-2020.

In Portugal, as in Denmark, sites are located along the coastline of two distinct regions, on the Iberian Peninsula (OSPAR region Bay of Biscay and Iberian Coast) and in the Azores (OSPAR region Wider Atlantic). Along the Iberian coast, the median abundance of foamed polystyrene is around 10 items/100 m. The distribution of median abundances between the 14 sites considered is shown in

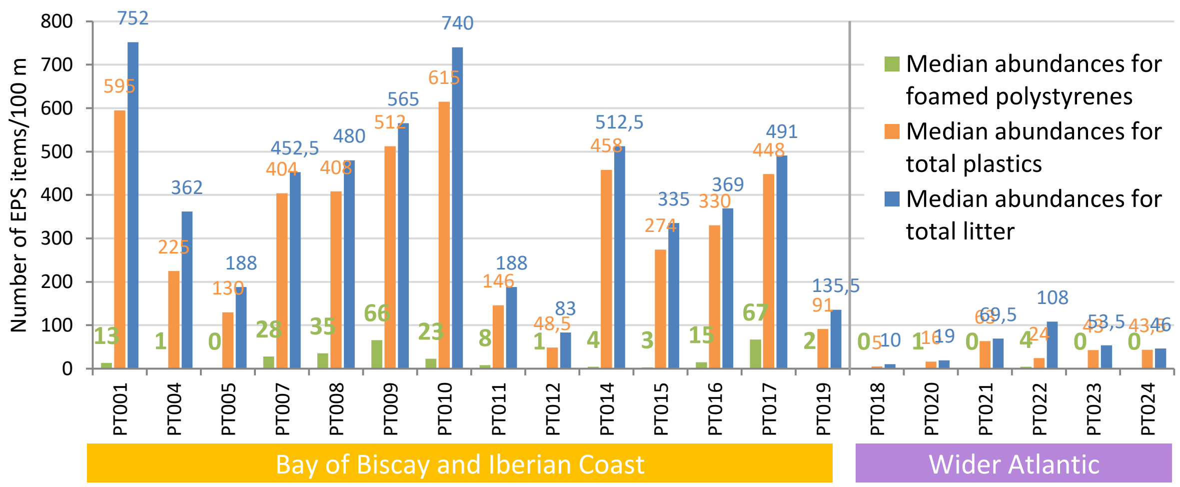

Figure *12* and again it shows that levels are heterogeneous, ranging from 1 item/100 m to

67 items/100 m (excluding one site where no foamed polystyrene was found). In terms of percentages, this represents between 1% and 31% of the total plastics collected over the two years. Again, the only EPS/XPS litter type with non-zero median abundance at the monitoring sites in Iberian Portugal was non-identifiable fragments.

In the Azores, the median abundances of foamed polystyrenes are much lower than on the Iberian coast, with a median abundance of zero for the whole region. Only two of the six sites concerned have non-zero medians at 1 item/100 m and 4 items/100 m. However, as the levels of pollution by litter are much lower at the sites in the archipelago than on Portuguese sites on the continent, foamed polystyrenes represent for these two sites 5% and 16% of total plastics, respectively.

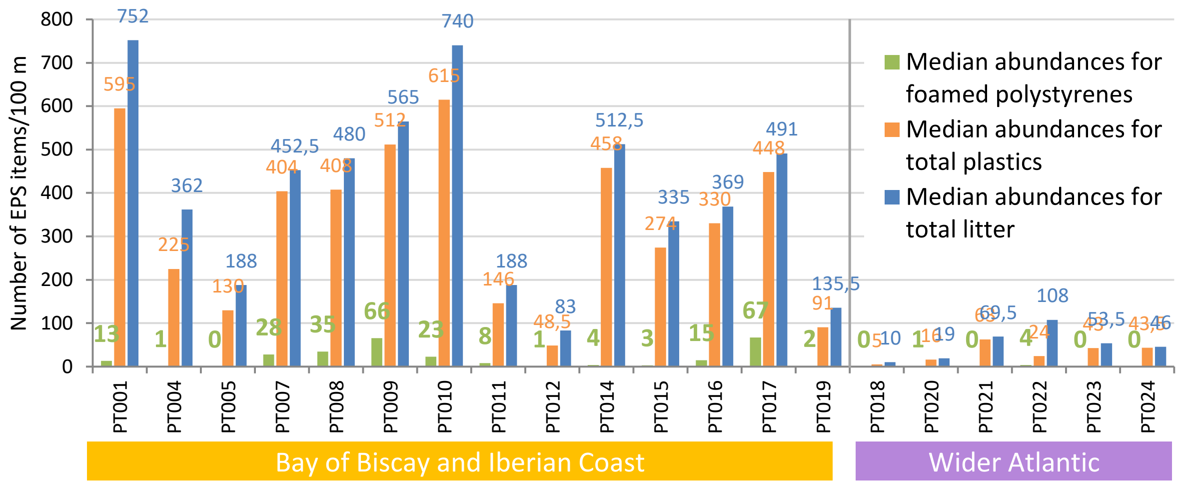

Figure 12: Median abundances for total litter, total plastics and foamed polystyrenes found on OSPAR survey sites in Portugal, over 2018-2020.

Overall, over 2018-2020 in the OSPAR countries where EPS/XPS are surveyed, the median abundance of foamed polystyrenes is 4 litter items/100 m, representing 15% of the total plastics collected (13% of the total litter collected). These results indicate EPS/XPS pollution is frequent and widespread in the OSPAR area. However, abundances appear to be heterogeneous, as shown in Figure 8. Looking at the foamed polystyrene litter types in detail, only non-identifiable foamed polystyrene fragments have non-zero medians across the Atlantic Area with 3 litter items/100 m for fragments > 2.5 cm.

Assessment in France in 2020 ("Plastique à la loupe", Tara Océan Foundation)

The citizen-science programme "Plastique à la loupe" provides additional data for France on EPS/XPS pollution as the programme surveys the foamed polystyrene litter types included in 2018 in the OSPAR survey list (Table 3).

The advantage of the programme is that it covers not only several coastal sites, but also river sites, making it possible to go upstream of estuaries to assess the contribution of rivers to marine pollution by foamed polystyrenes. The location of the 50 sites surveyed in 2020 (25 on beaches, 25 on riverbanks) is shown on Figure 13. It is important to note that site lengths vary between 10 m and 100 m. In order to be comparable, data were normalized to 100 m of beach/riverbanks. In addition, since the monitoring programme is recent only one survey was carried out for each site.

In the present section dedicated to beach litter pollution, only data obtained on beaches are considered. Data obtained on riverbanks are considered in the last part of the report.

Based on results obtained, foamed polystyrene pollution appears to be present in several sites with a heterogeneous distribution. Median abundance of foamed polystyrenes obtained on the 25 available coastal sites is 18 items/100 m and foamed polystyrenes represent 38% of the plastics collected (34% of the total litter collected). Finally, whatever the site, the majority of foamed polystyrene litter is made up of non-identifiable fragments, up to 98% considering all the EPS/XPS litter collected on all 25 coastal sites of the programme.

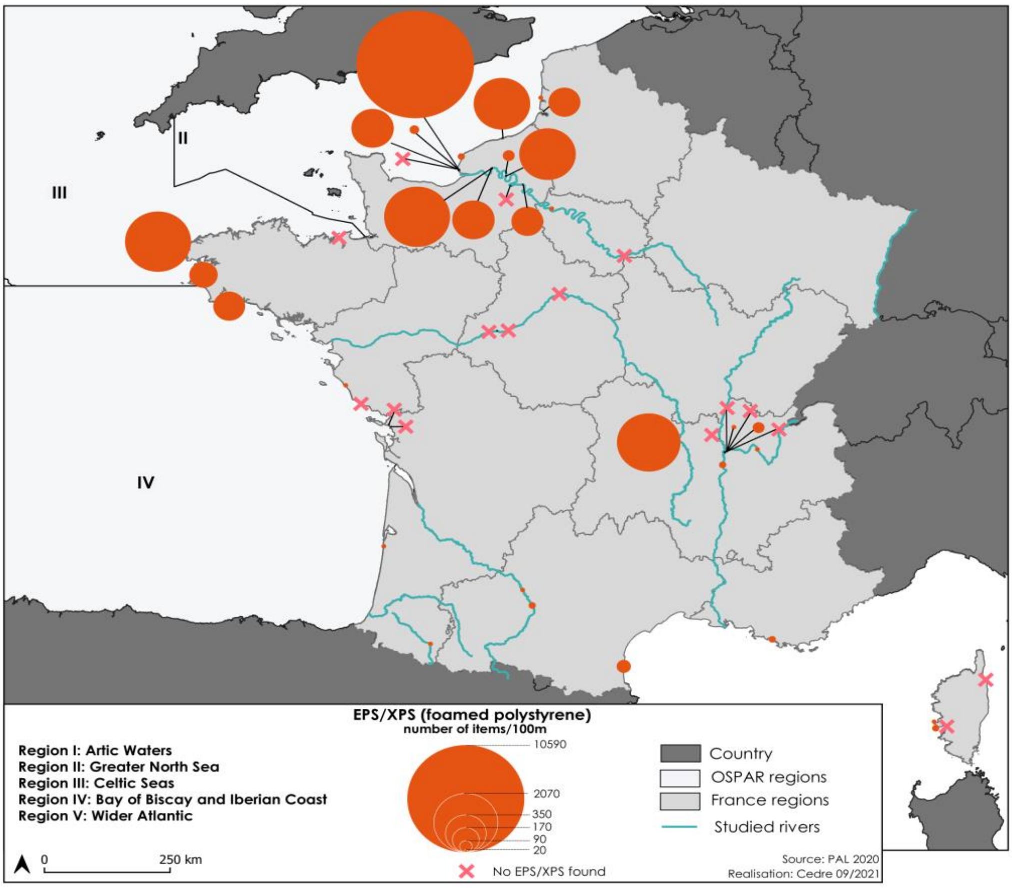

Figure 13: Foamed polystyrene abundances recorded in 2020 in France, on the 50 sites surveyed by the citizen science programme “Plastique à la loupe” (Tara Océan Foundation).

Key messages regarding the quantitative assessment of EPS/XPS pollution on the North-East Atlantic coastline

- Quantitative data on EPS/XPS pollution are scarce, especially before 2018.
- OSPAR beach litter data represent the most extensive set of fit-for-purpose data.
- Overall, EPS/XPS pollution appears to be frequent and widespread on the North-East Atlantic coastline.
- Over 2018-2020, in OSPAR countries monitoring foamed polystyrene (DK, NL, DE, FR, IR, PT), EPS/XPS pollution is abundant representing 15% of total plastics and 13% of total litter found on beaches, with a median of 4 items/100m.
- However, the EPS/XPS distribution is highly heterogeneous with median abundances per survey site, ranging from 0 to 1270 items/100m.
- Among litter types observed, the most frequent are non-identifiable fragments.

4.2. Identification of EPS/XPS accumulation sites on the French coastline

The online survey on macro-litter on the coastline of France, launched during the CleanAtlantic project, confirmed results of the quantitative assessment. Among the 105 respondents, 63 (60%) confirmed the frequent presence of EPS/XPS in their area, mostly in the form of fragments or objects, particularly in the Bay of Biscay (Figure 14).

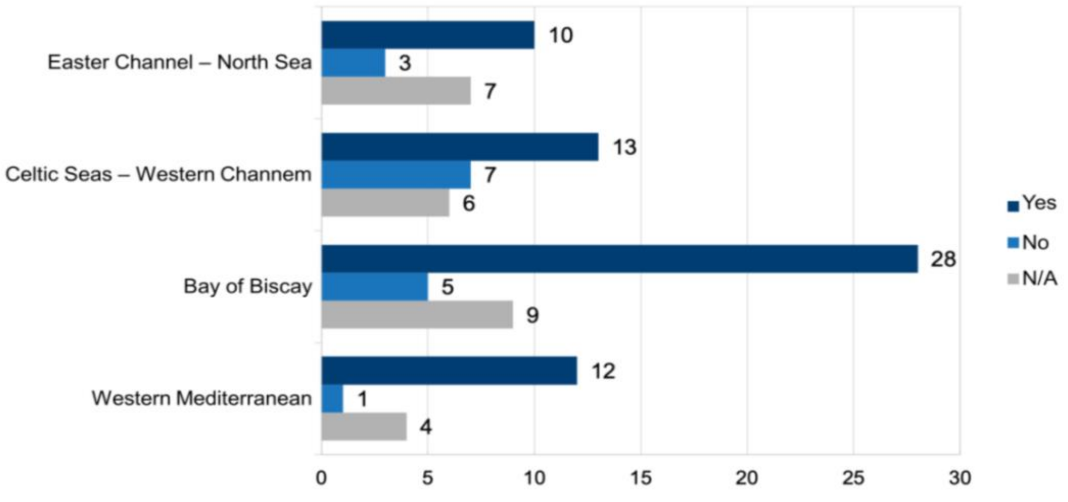

Figure 14: Foamed Stranding frequency of foamed polystyrene (French marine sub-regions).X-axis indicates the number of responses. (Kerambrun et al., 2021)

Survey results also show that accumulation sites are widespread on the French coast with 36 coastal accumulation sites with high proportions of EPS/XPS also identified across the different French marine sub-regions (Figure 15). One accumulation site in the Seine river was also mentioned.

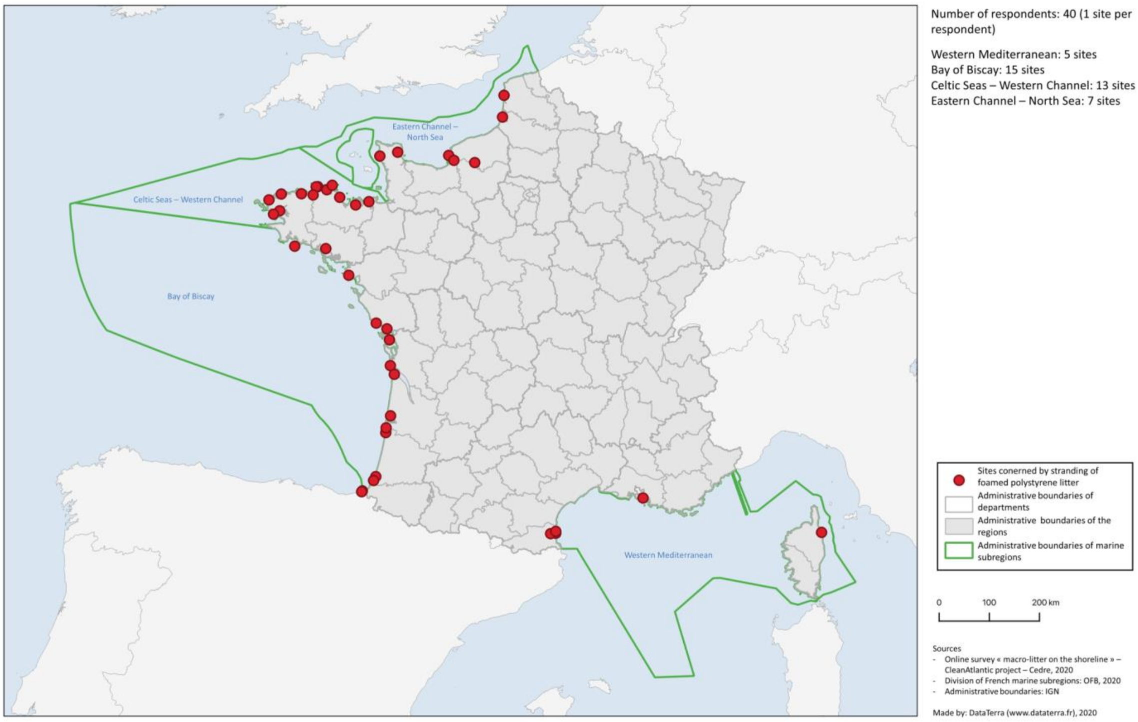

Figure 15: Location of the accumulation sites for stranded foamed polystyrene

Key messages regarding the identification of EPS/XPS accumulation sites on the French coastline

- The online survey provided the location of 36 EPS/XPS accumulation sites on the French coastline.
- Results confirmed foamed polystyrene pollution is abundant, frequent and widespread on the French coastline.

4.3. Qualitative assessment of EPS/XPS pollution in the marine environment

The qualitative assessment conducted by analysing different sources of data and pictures, provided complementary facts regarding the composition of EPS/XPS pollution the marine environment. These facts are detailed below.

4.3.1. EPS/XPS pollution is multisize

EPS/XPS litter observed in the marine environment appears to be multisize as either very large items down to very small ones can be found as illustrated in Figure 16.

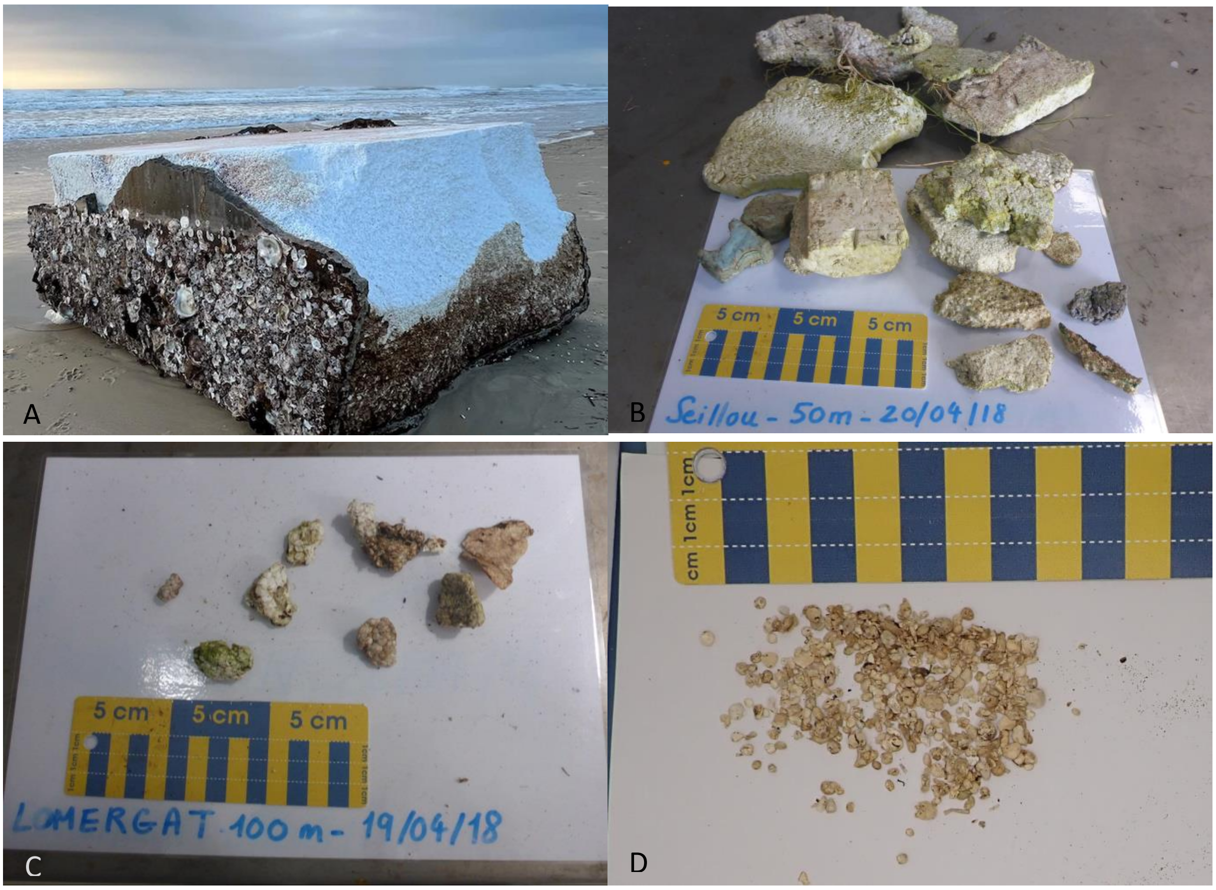

Figure 16: Examples of the large size range of EPS/XPS items collected on coastlines. A: very large EPS item coming from a broken pontoon on the Australian coastline (source: ABC News/Sharyn Kerrigan); B: macrosize (>2.5 cm) EPS/XPS items collected on the French Atlantic coastline (source: Cedre); C: mesosize (0.5-2.5 cm) EPS/XPS items collected on the French Atlantic coastline (source: Cedre); D: microsize (<0.5 cm) EPS/XPS items collected on the French Atlantic coastline (source: Cedre).

4.3.2. EPS/XPS pollution is mostly fragmented

As shown by quantitative results, EPS/XPS items observed in the marine environment appear to be mostly fragmented. This can be explained by the fact that foamed polystyrenes, especially EPS which are an agglomerate of small beads, are very fragile and break easily into smaller fragments or release individual beads. Mechanical fragmentation occurs when particles are subjected to mechanical stresses from waves, rocks, sand and other forces or substances with which the polymer may interact in the ocean (Barnes et al., 2009; Song et al. 2017). Illustrations of non-identifiable EPS/XPS fragments and EPS beads found in the marine environment are shown in Figure 17 and Figure 18, respectively. This ability to break down makes the pollution difficult to tackle as the number of particles become higher and higher.

In addition, due to their lightweight, EPS/XPS items float and are easily transported by wind and currents over long distances and have a high dispersion capacity in the environment (Figure 17). Monitoring conducted in France confirms that foamed polystyrenes represent a non-negligible part of the pollution of floating litter (Gerigny et al., 2018).

In addition, this fragmentation make difficult to identify the sources of pollution as litter items are too fragmented to allow the identification of the original product. This lack of information regarding the sources makes difficult to take appropriate reduction measures.

Figure 17: EPS/XPS non identifiable fragments found on the French coastline (source: Cedre). A and B: fragments collected in the Bay of Brest, C: fragment observed on the Oléron island coastline (indicated by the red arrow), D: Marine EPS fragments blown inland, behind the beach by the wind in Marsilly (indicated by red arrows)

Figure 18: EPS beads observed on the Mediterranean coastline (Cavalaire, France) (source: Cedre)

4.3.3. EPS/XPS pollution can undertake aging

Once in the marine environment, EPS/XPS litter also appear to age by photo-oxidation and/or erosion. Photo-oxidation of foamed polystyrene by sunlight leads to a yellowing and production of a yellow powder (Figure 19). The yellowing phenomena of foamed polystyrene under outdoor conditions, is a well-known phenomenon described by Andrady and Pegram (1991). In this study, authors exposed foamed polystyrene outdoors in air and floating in seawater. They observed a higher deterioration rate in seawater than in air, possibly due to the removal by the seawater of the outer protective yellow-colored layer formed during early exposure to sunlight.

Figure 19 : Photo-oxidised EPS fragment with a yellowed surface and forming a yellow powder (Source: Cedre)

EPS/XPS fragments observed in the marine environment are also generally eroded due to either photo-oxidation or mechanical erosion. These phenomena lead to the formation of rounded fragments or fragments with eroded beads on their surface (see Figure *20*20).

These aging phenomena contribute to the fragmentation of foamed polystyrenes. Studies have shown that the combination of UV radiation with mechanical abrasion leads to fragmentation (Song et al., 2017). This fragmentation can occur rapidly. Indeed, the effects of thermooxidative ageing and hydrodynamic conditions on expanded polystyrene (EPS) have been tested in the laboratory and it showed that fragmentation of mesoplastic objects is observed after 2 days of exposure, though more distinct after 4 days, with higher abundances for smaller fractions, implying a higher release of smaller sizes or a multistage fragmentation (Mattsson et al., 2021).

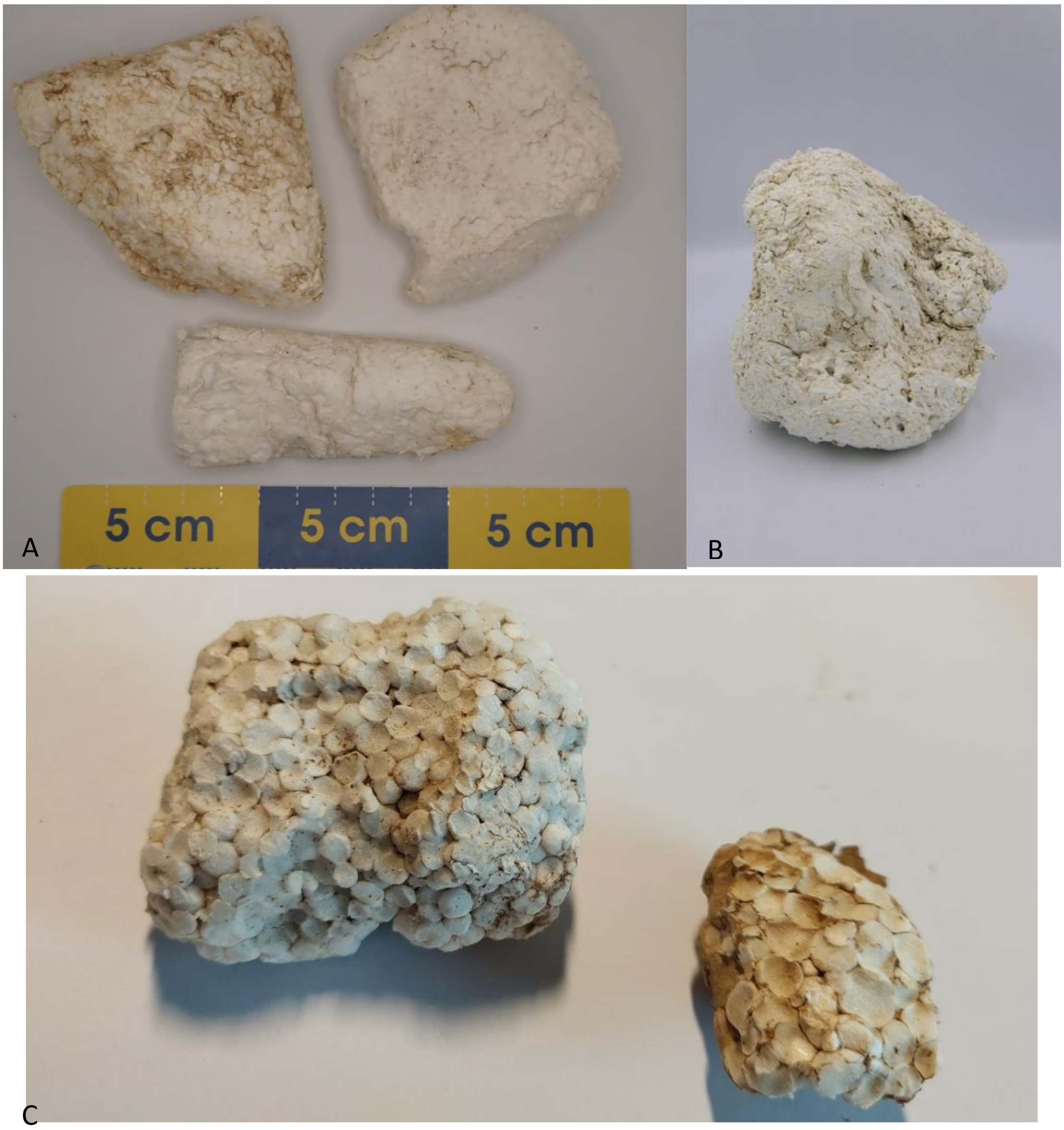

Figure 20 : Eroded EPS fragments collected on the French coastline (source: Cedre). A and B: Rounded fragments, C: EPS fragments with eroded beads on their surface

4.3.4. EPS/XPS pollution interacts with biota

EPS/XPS litter are also known to interact with biota. Different interactions listed below can be observed in the marine environment.

- **Ingestion by wildlife**

Studies show that EPS/XPS litter can be ingested by wildlife (Jang et al., 2018; Tang, 2020). Cadée (2002) observed that 80% of foamed plastic debris on the Dutch coast showed peckmarks of birds and suggested that the birds mistake polystyrene foam for cuttle bones or other food (Figure 21).

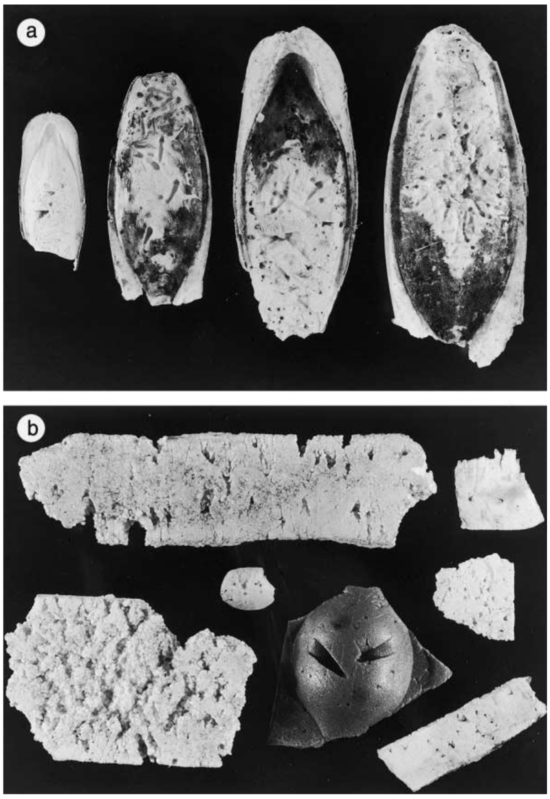

Figure 21 : (a) Peckmarks in cuttlebones from the Dutch coast. Marks as present in the smallest cuttlebone (9 cm length) are very probably from Northern Fulmars (made at sea). Such peckmarks are mainly observed in cuttlebones recently washed ashore. The other specimens also show other types of peckmarks; they have been on the beach for some time, and other birds such as gulls might have pecked them. (b) Peckmarks in foamed polystyrene and other spongious plastic washed ashore on the Dutch coast, even chips of only 3 cm length (center) contain peckmarks. Smaller particles are ingested entire. (Cadée, 2002)

- **Colonization and transport of species**

EPS/XPS litter are also known to be colonized by biota and transport species over long distance by prevailing winds and currents (Barnes and al., 2009; Jang et al., 2016). They can thus be a potential vector for the introduction of invasive species (Gregory, 2009; Miralles, 2018).

Some pictures of EPS collected on beaches and colonized by fauna (especially barnacles) are shown in Figure 22 and 23.

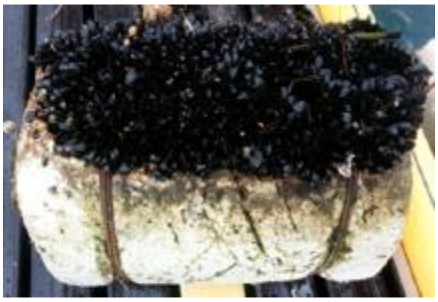

Figure 22 : Mussel sampling on a foamed polystyrene buoy (Jang M. and al., 2016)

Figure 23 : EPS fragments colonized by fauna (barnacles) (source: Cedre). A: sample collected on a beach in Gironde (France), B: sample collected on a beach in San Vicente (Cabo Verde), C: sample collected in Eparses islands (Indian Ocean), D: sample collected in the Bay of Brest (France).

- **Habitat for borer organisms**

Observations made in the field indicate that EPS/XPS products or litter present in the marine environment can serve as a habitat for borer organisms. On the French coastline, EPS/XPS litter with excavated galleries can be observed (Figure 24).

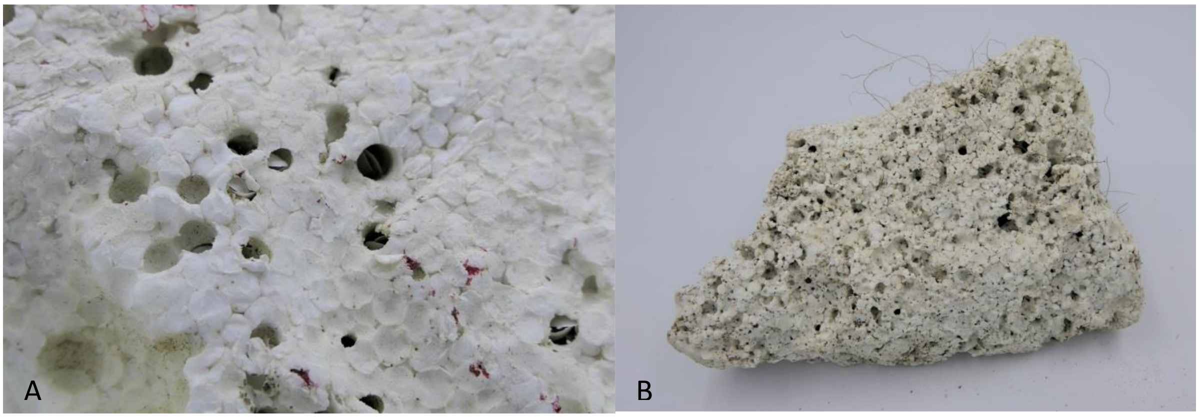

Figure 24 : EPS litter with excavated galleries made by burrowing organisms (source: Cedre). A: sample collected in Eparses islands (France, Indian Ocean), B: sample collected on the Atlantic coast of France.

This phenomenon has been described in 2012 by Davidson who showed that boring organisms (especiually isopods) were able to damage EPS floats under docks, expelling copious number of microplastic particles (see Figure 25).

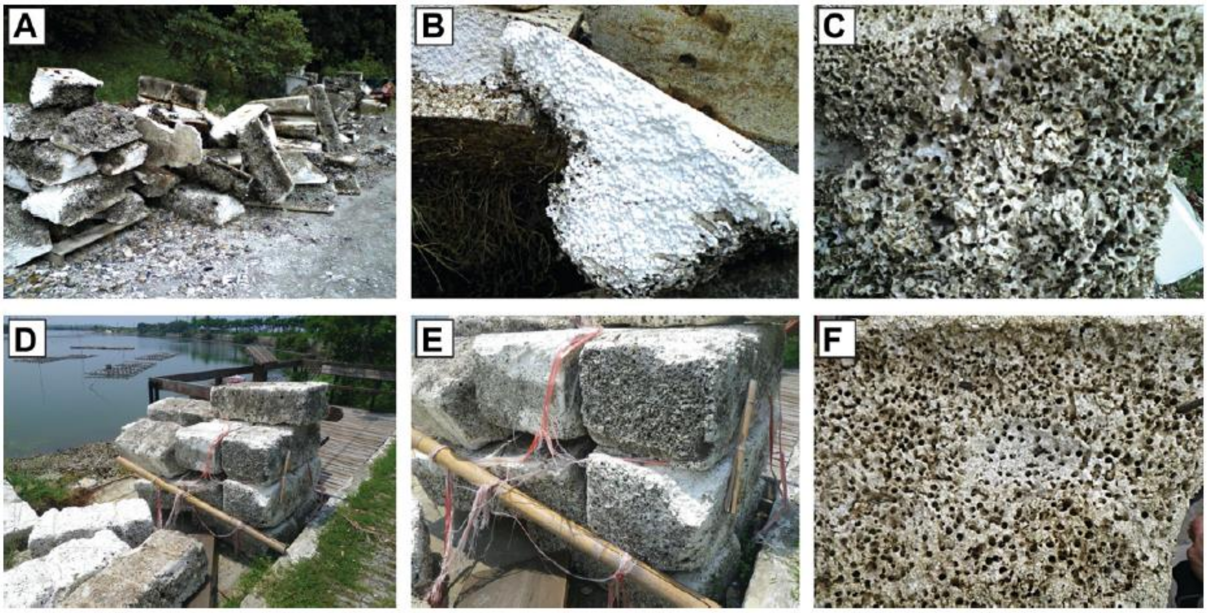

Figure 25 : Extensive burrowing by populations of boring isopods damaged the polystyrene floats in the docks used by aquaculture facilities in (A–C) Yaquina Bay, Oregon, USA (Sphaeroma quoianum; 7/15/2007) and (D–F) Tainan, Taiwan (presumably Sphaeroma terebrans; 8/5/2010). The floats in A and D were approximately 1 m and 2 m in length, respectively. Images in C and F are at differing scales, but the burrows pictured in these images are similar in size (8–10 mm). (Davidson, 2012)

An experimental study conducted in 2018 showed that polychaetes were also able to burrow into EPS blocks and create numerous microplastic EPS particles. Results showed that a single polychaete can produce hundreds of thousands of microplastic particles per year. These results reveal the potential role of marine organisms as producers of EPS microplastics in the marine environment. (Jang and al., 2018).

- **Interaction with dunal plants**

EPS litter can also interact with plants such as dunal plants. Figure 26 shows EPS fragments collected on the French coastline and with root system going inside the material.

This phenomenon was also observed in Italy by Poeta et al. (2017). The authors observed that EPS were interacting with living dunal plants as 5% of items were perforated or had roots of plants in them (Figure 27 and Figure 27). Authors indicated that EPS mechanical, thermal and water retention properties could be a key factor to facilitate plant growth in dunal habitats. However, EPS could also represent an indirect threat as clean-up activities might increase trempling pressure on dunes.

Figure 26: Interaction of EPS fragments with plants (source: Cedre)

Figure 27: Example of dunal plants perforating expanded polystyrene debris deposited on a beach litter (Tyrrhenian central Italy). Photo: C. Battisti (Poeta and all, 2017)

Key messages regarding the qualitative assessment of EPS/XPS pollution in the marine environment

- EPS/XPS products are lightweight and easily broken down leading to the production of large amounts of fragments that float and can be transported and disseminated over long distances.
- EPS/XPS pollution is multisize going from very large items (several meters large) down to a few millimetres. It is mainly made of fragments that can be eroded due to mechanical processes or photo-oxidation.
- EPS/XPS litter are known to interact with biota by being ingested by species like birds, by being colonised by species and transported them potentially over long distances, by constituting a new habitat for borer species leading to the release of large amounts of microplastics in the marine environment and by interacting with living plants.

4.4. Qualitative information on identified pathways and sources

As stated above, EPS/XPS litter are generally too fragmented and degraded to identify original products and associated pathways and sources. However, several pathways and sources have been identified as contributors to the pollution of the marine environment by EPS/XPS litter.

4.4.1. Identified pathways

- **Rivers**

Rivers are well-known pathways for EPS/XPS litter entry in the marine environment. Indeed, sampling and monitoring conducted on riverbanks indicated that EPS/XPS pollution is frequently observed. Several pictures of EPS/XPS litter found on riverbanks in France are shown in Figure 288.

When considering existing projects or citizen science programmes, some quantitative information can be obtained on EPS/XPS abundance in river systems.

As stated above, the citizen science programme "Plastique à la loupe" conducts monitoring on French riverbanks. Results obtained in 2020 indicated that on the 25 sites surveyed, the median abundance of foamed polystyrene was highest at the sites located on the Seine, the river that flows into the Channel, with 125 litter items/100 m, representing 10% of the total plastics collected at these sites. The median abundances of the other rivers ranged from 0 item/100 m (Loire) to 15 items/100 m (Garonne), much lower than those observed on the Seine. For the Loire, only one of the 5 monitoring sites has a non-zero abundance of foamed polystyrenes, with 1,480 non-identifiable foamed polystyrene fragments collected, representing 11% of the total plastics collected on the site.

Figure 28: EPS/XPS litter found on French riverbanks (indicated with red arrows, source: Cedre). A: sample collected along the Liane river, B: sample collected along the Seine river, C: sample collected along the Dordogne river, D: sample collected along the Bidassoa river.

Other studies on riverine litter confirm foamed polystyrenes are found in rivers. The exploratory research project RIMMEL (Riverine and Marine floating macro litter Monitoring and Modelling of Environmental Loading) (González-Fernández et al., 2018) observed that polystyrene fragments (between 2.5 cm and 50 cm) are ranked at the fifth place of the general top items list, representing a proportion of 6.35% of total items collected over 53 rivers and streams that ended in European Seas. Another study on aquatic litter focused on macro-litter pollution in the Huveaune basin, in France (Tramoy et al., 2019), a short urban river of about 50 km. Main objectives were to identify the main categories of macro-litter generated by the basin, to give orders of magnitude of the flows of macro-plastics transiting in the river and to compare these flows with those of the Seine estuary. Without considering the work on macro-plastic flows, the study highlighted the non-negligible presence of foamed polystyrenes in the water course. These items represent 5% to 7% of the litter in some collection systems. The study also highlights the prevalence of small litter, including polystyrene fragments smaller than 2.5 cm. These small polystyrene fragments represented up to 4% of litter collected.

In addition to river, brackish lagoon can also be a pathway of foamed polystyrenes to the sea. On French social media, an important EPS/XPS pollution has also been reported in the pond of Berre (a brackish lagoon flowing into the Mediterranean Sea) in 2021 as illustrated in Figure 29.

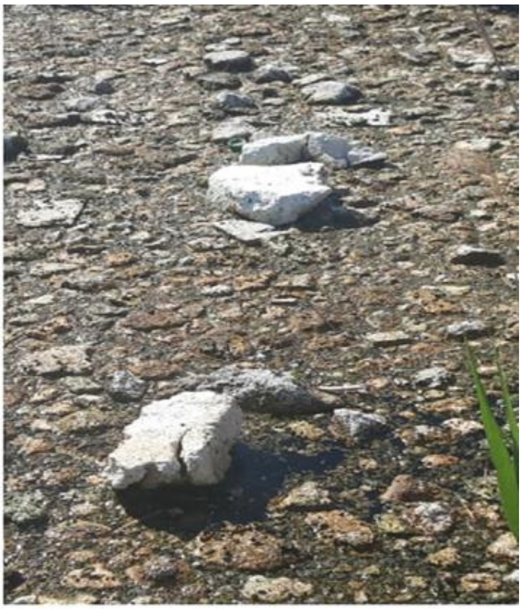

Figure 29: EPS/XPS pollution in the brackish Berre lagoon (France) (source: Opération Mer Propre).

- **Urban water systems**

Urban water systems are also a pathway of EPS/XPS pollution discharge in aquatic environment. Analyses of litter collected in street drains and in a floating siphon in Brest city rainwater system (France) showed the presence of multisize fragments of EPS/XPS among other plastic litter (Figure 30 and Figure 31). It must be noted that Brest is a coastal city and rainwater collected in the city are directly released in the sea along with litter transported.

Figure 30: Multisize EPS collected in a floating siphon in Brest rainwater system (surrounded in red) (source: Cedre)

Figure 31 : EPS/XPS litter found in street drains in Brest (France, source: Cedre)

- **Extreme events**

Extreme events like floods or storms are also a pathways leading to release of foamed polystyrene pollution in the marine environment. Following floods in Queensland (Australia) in 2022, several pontoons partly made of EPS, were destroyed and washed ashore releasing large pieces of pontoon along with smaller fragments and beads detached from broken pontoons (Figure 32).

Figure 32 : Pontoons washed ashore in Queensland (Australia, source: ABC News, Alison Foley).

Another example of extreme event leading to a release of EPS/XPS pollution in the marine environment is the tsunami that severely affected Japan in 2011. Following the event, huge amount of litter crossed the Pacific Ocean and landed on the west coast of United States and Canada. In Alaska, large quantities of foamed polystyrene litter were reported as shown in Figure 33.

Figure 33 : EPS/XPS fragments found among other litter on Montague Island (Alaska) following the 2011 tsunami in Japan (source Liberation, Chris Pallister, Gulf of Alaska Keeper)

4.4.2. Identified sources

As foamed polystyrenes have multiple uses, there is a large diversity of potential sources of pollution. The study conducted in the Baltic Sea in 2019 reviewed the different sources of EPS/XPS pollution (Lassen et al, 2019). Authors identified fishing, aquaculture, fish transport and processing as important contributors of EPS/XPS pollution in the Baltic Sea.

According to the study, fish transport and processing are potentially important sources of EPS for the sea. EPS is used for fish boxes, buoys used to mark fishing nets, floats for fishing nets, mooring buoys or even spring buoys used in fish farming can be made of EPS. EPS can end up in the environment due to wear and tear of equipment, loss at sea or in ports, or breakage during handling.

Take-away packaging such as XPS cups or food containers are also a source of EPS/XPS release. They end up in the sea when they are dumped on beaches or when wind and rainwater wash them into stormwater drainage systems or rivers.

EPS/XPS is also used as a building material. When insulating floors or walls of hollow buildings, EPS beads can be used to fill the cavities. Blocks can also be installed during the construction of a building to serve as insulation. Finally, EPS/XPS can be incorporated into other materials such as concrete to lighten the load.

The production of raw materials and the transport of EPS to processors is also a source of pollution. The handling of EPS/XPS in the form of unexpanded or pre-expanded polystyrene pellets can lead to releases to the environment.

The storage, transport and recycling of EPS/XPS as waste is also a source of environmental pollution.

One source of dust and small particles is during the demolition of buildings, when EPS is broken into small pieces to be put in a waste bin or to reduce the volume of storage.

The analysis of picture of EPS/XPS litter found in the marine environment confirmed sources identified in the Baltic Sea study as detailed below.

- **Fishing**

Below are examples of EPS/XPS fishing floats found on French beaches (Figure 34).

Figure 34 : Fishing floats found on French Beaches (source: Cedre)

- **Fish transport and processing**

Below is a picture of an EPS fish box found on French coastline (Figure 35).

Figure 35 : an EPS fish box observed on French coastline (source: Cedre).

- **Maritime infrastructure**

Below are pictures of a floating pontoon partly made of EPS, observed on the French coastline (Figure 36).

Figure 36 : Floating pontoon partly made of EPS (as indicated by the red arrow), observed on the French coastline (source: Cedre).

- **Food packaging**

Below is a picture of a XPS food box collected on the French coastline (Figure 37).

Figure 37 : XPS food box collected on the French coastline (source: Cedre).

- **Building**

Below is a picture of a XPS insulation board collected on the French coastline (Figure 38).

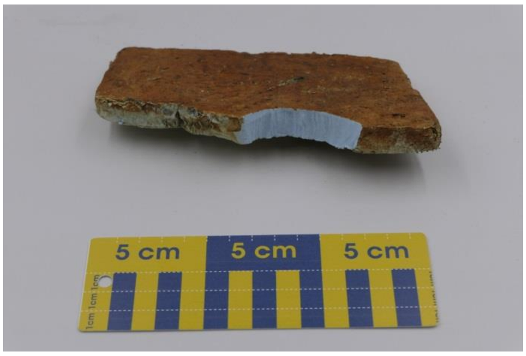

Figure 38 : XPS insulation board found on the French coastline (source: Cedre).

- **Other sources**

Below are pictures of other EPS products associated with agriculture (a seeding tray) and meteorological measurements (part of a radioprobe) (Figure 39).

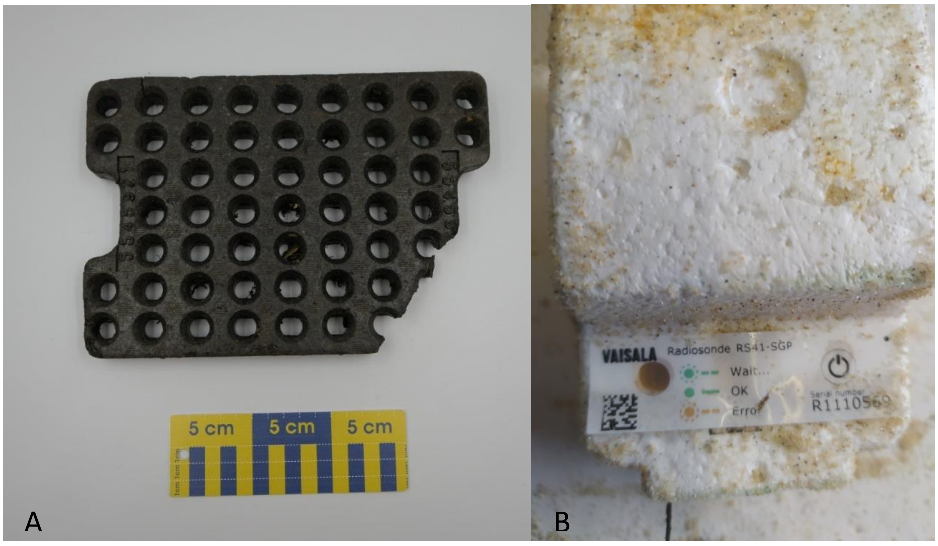

Figure 39 : A: EPS seeding tray, B: EPS from a radioprobe (source: Cedre).

Key messages regarding pathways and sources of EPS/XPS pollution

- River inputs, urban water inputs and extreme events are known pathways of discharge of EPS/XPS in the marine environment.
- Similarly to observations made on beaches, most of foamed polystyrenes collected in rivers and urban water systems are non-identifiable fragments, indicating fragmentation can occur before the entry in the marine environment.
- Sources of EPS/XPS pollution are multiple and their contribution is difficult to assess due to the important degradation of EPS/XPS products in the environment that makes difficult their identification.
- Identified sources are fishing, aquaculture, fish transport and processing, food packaging and construction. Other sources exist (*e.g.* agriculture or meteorological measurement gears) but they probably contribute less to the pollution.

5. Key messages

Quantitative data on EPS/XPS pollution are scarce for the North-East Atlantic coastline, especially before 2018.

OSPAR beach litter data represent the most extensive set of fit-for-purpose data.

Overall, EPS/XPS pollution appears to be frequent and widespread on the North-East Atlantic coastline.

Over 2018-2020, in OSPAR countries monitoring foamed polystyrenes (DK, NL, DE, FR, IR, PT), EPS/XPS pollution is abundant representing 15% of total plastics and 13% of total litter found on beaches, with a median of 4 items/100m.

However, the EPS/XPS distribution is highly heterogeneous with median abundances per survey site, ranging from 0 to 1270 items/100m.

Among litter types observed, the most frequent are non-identifiable fragments.

The online survey provided the location of 36 EPS/XPS accumulation sites on the French coastline.

The online survey confirmed foamed polystyrene pollution is abundant, frequent and widespread on the French coastline.

EPS/XPS products are lightweight and easily broken down leading to the production of large amounts of fragments that float and can be transported and disseminated over long distances

EPS/XPS pollution is multisize going from very large items (several meters large) down to a few millimetres. It is mainly made of fragments that can be eroded due to mechanical processes or photo-oxidation.

EPS/XPS litter are known to interact with biota by being ingested by species like birds, by being colonised by species and transported them potentially over long distance, by constituting a new habitat for borer species leading to the release of large amounts of microplastics in the marine environment and by interacting with living plants.

River inputs, urban water inputs and extreme events are known pathways of discharge of EPS/XPS in the marine environment.

Similarly to observations made on beaches, most of foamed polystyrenes collected in rivers and urban water systems are non-identifiable fragments, indicating fragmentation can occur before the entry in the marine environment.

Sources of EPS/XPS pollution are multiple and their contribution is difficult to assess due to the important degradation of EPS/XPS products in the environment that makes difficult their identification.

Identified sources are fishing, aquaculture, fishing transport and processing, food packaging and construction. Other sources exist such as agriculture or meteorological measurement but they probably contribute less to the pollution.

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APPENDIX

Appendix 1: Median abundances obtained per year by the *Beachwatch* programme on the UK coastline (MCS UK), considering all sites and only the 100 m sites.

Appendix 2: Annual median abundance in polystyrene fragments (2.5-50 cm) collected according to the length of the survey site and the different countries covered by Ocean Initiatives (Surfrider Europe Foundation, 2014-2017).

Table 1: median abundances obtained per year by the Beachwatch programme on UK coastline (MCS UK), considering all sites and the only 100 m sites.

			Median abundances (litter items/100 m)										
Year	Length	Number of sites	Total	Artificial polymers	Foamed polystyrenes	Polystyrene: Buoys	Polystyrene: Fast food containers/cups	Polystyrene: Fish boxes	Polystyrene: Fibreglass	Polystyrene: Foam/sponge/insulation	Polystyrene: Packaging	Polystyrene: Polystyrene pieces < 50 cm	Polystyrene: Other
2010	All	755	209	144	15	0	1	0	0	2	0	6	0
	100 m	236	461	309	26	0	2	0	0	4	1	12	0
2011	All	717	218	136	13	0	1	0	0	2	0	6	0
	100 m	249	392	242	22	0	1	0	0	3	0	10	0
2012	All	651	244	152	14	0	1	0	0	2	0	5	0
	100 m	300	435	257,5	24	0	2	0	0	3	1	11	0
2013	All	637	176	112	10	0	0	0	0	2	0	4	0
	100 m	252	388	229	21	0	1	0	0	3	1	8	0
2014	All	719	189	120	11	0	0	0	0	2	0	4	0
	100 m	319	442	229	26	0	1	0	0	4	0	11	0
2015	All	581	237	150	13	0	1	0	0	2	0	4	0
	100 m	352	334	196	18	0	1	0	0	3	0	6	0
2016	All	165	250	161	14	0	1	0	0	2	0	6	0
	100 m	123	263	173	19	0	1	0	0	3	0	8	0

Table 2: Annual median abundance in polystyrene fragments (2.5-50 cm) collected according to the length of the survey site and the different countries covered by Ocean Initiatives (Surfrider Europe Foundation, 2014-2017).

Country	Year	Number of surveys	Median abundance in polystyrene pieces according to the length of survey site (and number of surveys considered)				
			100-200 m	200-500 m	500-1000 m	> 1000 m	Not indicated
Algeria	2014	2		10 (1)		55 (1)	
Algeria	2015	1			50 (1)		
Algeria	2016	2		18 (2)			
Algeria	2017	1		40 (1)			
Argentina	2014	2	78 (2)				
Argentina	2015	1	6 (1)				
Argentina	2016	1	45 (1)				
Argentina	2017	3	8 (3)				
Belgium	2014	1				30 (1)	
Belgium	2015	1				10 (1)	
Benin	2016	1	100 (1)				
Brazil	2015	1			300 (1)		
Brazil	2017	1			15 (1)		
Bulgaria	2014	1			40 (1)		
Costa Rica	2015	1			67 (1)		
Denmark	2014	1	10 (1)				
France	2014	188	44 (50)	25 (68)	20 (43)	30 (25)	51 (2)
France	2015	143	27 (27)	20 (49)	20 (40)	30 (27)	
France	2016	81	11 (11)	60 (31)	24 (27)	22 (12)	
France	2017	66	12 (14)	25 (22)	50 (21)	30 (9)	
French Polynesia	2015	1		4 (1)			
French Polynesia	2016	1			40 (1)		
Germany	2014	2			50 (1)	5 (1)	
Germany	2015	4		20 (1)	50 (1)	6 (2)	
Germany	2016	1				3 (1)	
Germany	2017	4	47 (1)	43 (2)		7 (1)	
Greece	2014	1				10 (1)	
Greece	2017	1	203 (1)				
Guadeloupe	2014	1			30 (1)		
Guadeloupe	2017	2	7 (1)		4 (1)		
Ireland	2014	4	30 (1)	5 (1)	8 (2)		
Italy	2014	19	18 (4)	50 (6)	105 (4)	40 (5)	
Italy	2015	20	20 (5)	10 (6)	150 (4)	50 (5)	
Italy	2016	9	222 (2)	20 (3)	28 (3)	200 (1)	
Italy	2017	8		500 (5)	467 (2)	246 (1)	
Madagascar	2014	1		15 (1)			
Madagascar	2015	1	12 (1)				

Madagascar	2017	1		260 (1)			
Martinique	2014	2		50 (1)	10 (1)		
Mexico	2014	2			25 (1)	176 (1)	
Morocco	2014	4	21 (1)		10 (1)	132 (2)	
Morocco	2015	1			40 (1)		
Morocco	2016	1			10 (1)		
Morocco	2017	1			50 (1)		
Netherlands	2014	2			5 (2)		
Netherlands	2015	3	2 (3)				
New Caledonia	2015	1				10 (1)	
Norway	2014	1		2341 (1)			
Portugal	2014	3		50 (1)	125 (2)		
Portugal	2015	7	25 (3)	58 (4)			
Portugal	2017	3	100 (1)	20 (1)	50 (1)		
Reunion Island	2014	1			7 (1)		
Reunion Island	2016	1		1 (1)			
Reunion Island	2017	1		4 (1)			
Russia	2014	1			24 (1)		
Spain	2014	26	88 (10)	30 (11)	60 (5)		
Spain	2015	20	15 (7)	120 (3)	14 (5)	17 (5)	
Spain	2016	31	72 (17)	24 (5)	83 (7)	61 (2)	
Spain	2017	35	49 (16)	20 (9)	36 (8)	57 (2)	
Sweden	2015	2	50 (1)			2 (1)	
Switzerland	2014	3				30 (3)	
Switzerland	2015	2	60 (1)		50 (1)		
Switzerland	2016	2	466 (1)		50 (1)		
Tunisia	2014	2		94 (2)			
United Kingdom	2014	1	3 (1)				