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"Assessment of Marine Debris on the Belgian Continental Shelf: occurrence and effects"

«AS-MADE»

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North Sea

FINAL REPORT

ASSESSMENT OF MARINE DEBRIS ON THE BELGIAN CONTINENTAL SHELF: OCCURRENCE AND EFFECTS
"AS-MADE"

SD/NS/12

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SUMMARY

Marine debris is an increasing worldwide problem, due to an ever increasing global plastic production and continuing indecent disposal. This debris is not only aesthetically displeasing, it can adversely affect marine live and even pose a (hygienical) threat to humans. Although this debris is quite variable in type, plastics account for the majority of marine litter: 60-80% of all marine debris is estimated to be plastic. Recently it has been discovered that these large pieces of plastic debris can degrade into smaller pieces: microplastics with dimensions as small as 20μm (and possibly even smaller) have been detected in the water column and sediment worldwide.

The objectives of this project were to study the presence of marine debris (including the degradation products, e.g. microplastics) in the Belgian marine environment, based on dedicated quantitative monitoring surveys of the seabed, the sea-surface and the beach, and to assess the effects of this debris on selected marine species (invertebrates and seabirds). Additionally, an evaluation of the financial impacts of this form of pollution (removal vs. prevention) were made.

A large number of items (64,290 items.km^{-1}), representing a weight of 92.7 kg of litter per km of beach, were reported along the Belgian coast. These figures are some of the highest recorded globally. Plastic items were most abundant on all four beaches, in both sampling periods. Among these plastics, industrial pellets, the precursor for the production of plastic consumer products, were most abundantly recorded. Beach characteristics such as touristic pressure and sedimentation regime do not seem to explain differences between sampled beaches in terms of amount and composition of recorded debris. Other factors, such as wind direction and sea currents, however, could play an important role.

Microplastics were present in all samples, from all beaches sampled. On average 8.4 $\pm$ 1.1 particles per kg of dry sediment were detected. Higher concentrations of microplastics were detected at the high water mark. Heavy PVC particles on the other hand, were more abundant in the highly dynamic zone of the low water mark. These concentrations of microplastics are much lower than those reported in other studies. Even an earlier assessment of microplastics along the Belgian coast found values almost 20 times higher. It is still unclear what caused this discrepancy.

Sampling of the Belgian Continental Shelf yielded an average concentration of 3125 $\pm$ 2829.5 items per km². These values appear to be quite high compared to the values reported for other regions. However, comparison between studies is difficult since the mesh sizes used vary from 15mm up to 55mm. No large items were retrieved from the BCS, resulting in a low average weight: 0.43 $\pm$ 0.70 kg per km². However, since

trawling is only possible is certain areas (uniform of substrate, uniform of depth), the results obtained might not be representative for the entire Belgian Continental Shelf.

Floating marine debris was assessed using two different techniques. In the visual study, the density of floating debris was 0.66 items.km^{-2} (0.53 items.km^{-2} were plastic items). Sampling the sea surface using a neuston net, an average density of 3875 $\pm$ 2723.7 items per km^2 were recorded. This large difference between the two survey methods is attributed to the fact that the majority of items floating in the Belgian part of the North Sea are smaller than 1cm and hence almost impossible to spot from a distance. The density marine debris floating on the Belgian part of the North Sea is quite high, compared to internationally reported values of floating marine debris.

Analysis of stomach content data and entanglement data of seabirds were investigated from 1992 to 2010, in order to assess the impacts of macrodebris on marine species. 95% of Northern Fulmars had ingested some kind of plastic. On average, Fulmars had 48.2 pieces in their stomach. 51% of birds had more than 0.1 gram of plastic in their stomach, well above the level of 10% fixed to qualify the North Sea as being clean (EcoQO = Ospar Ecological Quality Objective).
0.6% of beached birds were found entangled, with Northern Gannets appearing to be most sensitive to entanglement. The birds were essentially entangled in fishery gear, but also six-pack rings, plastic bags, sheets and plastic cups.
The effects of ingestion of microplastics by invertebrates were tested experimentally. Two model species, *Mytilus edulis* (filter feeder) and *Arenicola marina* (deposit feeder), were exposed to different sizes of microplastics at a total concentration of 110 particles per mL. Uptake and translocation were studied and the possible adverse effects were evaluated by assessing physiological and behavioural responses. After exposure, lugworms had on average 19.9 $\pm$ 4.1 particles in their tissue and coelom fluid, while mussels had on average 4.5 $\pm$ 0.9 particles in their tissue and 5.1 $\pm$ 1.1 per 100μL of extracted hemolymph. No significant adverse effects of the ingestion and translocation of microplastics were detected during this short-term exposure, both in mussels and lugworms.

The economic impact of marine litter along the Belgian coast was assessed by sending out specially developed questionnaires to four key sectors of human activity that could be affected by marine litter, i.e. touristic organisations, municipalities, harbours and marinas, and sea fisheries.
All municipalities remove marine litter from their coastline, especially from high usage beaches, ensuring that their beaches are attractive and safe for tourists. This entails an average cost of €32,375 per municipality per year.

All harbours and marinas surveyed take action to remove marine litter, spending between 1 and 5 hours per month manually removing litter. 80% of harbours and marinas reported their users had experienced incidents (fouled propellers, fouled anchors and blocked intake pipes and valves) related to marine debris, with fouled propellers being the most commonly reported type of incident. The costs for removing marine litter varies between €250 and €10,000 per harbour per year, with an average cost of €4262.6.

Marine litter affects the fishing industry in a variety of ways, which can result in both additional costs and reduced revenue for fishing vessels. The economic impact of marine litter on fishing vessels include the overall cost of fouling incidents and the loss of earnings resulting from reduced fishing time due to clearing litter from nets. Loss of fishing time accounts for the majority of costs: on average €22,779 per vessel per year. The average cost per fouling incident is €471. Based on these average figures, marine litter costs the fishing industry around €2.16 million each year.

Keywords: Marine debris; Beached debris; Floating debris; Seafloor debris; Plastic; Ingestion; Entanglement

1. INTRODUCTION

1.1 Context

1.1.1 General

Our seas and oceans are subjected to many different kinds of threats. One of these threats is marine debris. The accumulation of anthropogenic debris in the marine environment is an increasing problem worldwide. This debris is not only aesthetically displeasing, but can also be a nuisance to boaters and the shipping industry, and can adversely affect marine biota (Derraik, 2002). Reported effects on marine organisms include entanglement in nets, fishing line, ropes and other debris, which can inflict cuts and wounds or cause suffocation or drowning; and ingestion, causing obstructions in throats or digestive tracts. Some animals even starve to death as debris that does not pass out of the stomach can give a false sense of cessation, causing them to stop eating. Marine litter can also be dangerous for human health and safety as beach visitors can be harmed by broken glass, medical waste, discarded fishing lines and syringes (Sheavley & Register, 2007).

Although the debris is quite variable in type, plastics account for the major part of marine litter due to their extensive use. It is estimated that plastics contribute from 60% to 80% of the total marine debris (Gregory & Ryan, 1997). Glass, metal objects and fishing nets are also found in considerable quantities (Galgani et al., 2000). The dominant types and sources of debris come from what we consume (including food wrappers, beverage containers, cigarettes and related smoking materials), what we use in transport, and what we harvest from the sea (fishing gear). In 1991 it was estimated that land-based sources account for up to 80% of the world's marine debris pollution (GESAMP, 1991).

Decades ago, most of our waste was produced out of organic, degradable materials. Now, our solid wastes often contain synthetic elements – plastics – which degrade very slowly and are buoyant. The continuous input of large amounts of these materials has lead to their gradual accumulation in the marine and coastal environment. This debris comes in many types, shapes and sizes. Plastic beverage bottles, packing straps, synthetic fishing line, food wrappers as well as pre-production resin pellets are but a few examples of the litter present in our oceans (Sheavley & Register, 2007). Approximately 57 million tons of plastic are produced annually in Europe alone. Globally this figure increases to 265 million tons per year (PlasticsEurope, 2011). Despite the magnitude of this potential problem little quantitative information is available on the amount of plastics that eventually ends up in our marine environment, but it is estimated that up to 10% of all newly produced plastics end up in our seas and oceans (Griffin, 1988). This would mean that presently up to 26.5 million tons of plastics per year find their way to the marine environment.

Recently, it has been discovered that the large, visible pieces of plastic debris, can degrade into smaller fragments with dimensions as little as 20μm and possibly even smaller. These so-called microplastics (defined as items < 1mm) are present in the water column and sediments and have been reported to be ingested by polychaete worms, barnacles and amphipods in laboratory trials (Thompson et al., 2004). Additionally, there is the potential for plastics to adsorb, release and transport chemicals, but it remains to be shown whether toxic substances can pass from plastics to the food chain (Mato et al., 2001).

Despite many research and monitoring actions, the (quantitative) distribution of marine litter remains unclear. Some of the main reasons for this are:

i. there is a lack of standard methods and units used to quantify the debris;
ii. studies almost always focus on litter in only one marine compartment (e.g. beach litter);
iii. to date, only a few studies have examined the occurrence and effects of microplastics.

Moreover, while the most obvious effects on marine organisms (e.g. entanglement or ingestion) are documented, many environmental impacts are less well understood (Sheavley & Register, 2007). These include:

i. source and fate of microscopic fragments/plastic fibers;
ii. accumulation and dispersion of toxic substances associated with (micro-) plastics;
iii. impact of marine debris on the species at the base of the food chain;
iv. bio-transfer of pollutants associated with (micro-) plastics (Sheavley & Register, 2007).

1.1.2. Marine debris worldwide – Prevalence and effects

Most of the research on marine debris has focused on coastal and benthic debris. Plastics are generally the predominant type of litter, and their proportion consistently varies between 60% and 80% of the total marine debris (Gregory & Ryan, 1997). As a consequence, many studies focus on plastics alone.

1.1.2.1 Debris on the seafloor

In the past 15 years, several studies have examined the prevalence of debris in/on marine sediments worldwide. Between 1992 and 1998 the seafloor along the European coastlines was sampled with bottom trawl nets with a 20 mm mesh size (Galgani et al.,

2000). Results varied greatly with concentrations ranging from 0 to 101,000 items per km². This latter value was found in the Ligurian Sea (France). The Celtic Sea had an average of 528 items per km² and the highest average number of *plastic* items was found in the Adriatic Sea (263 plastic items per km²). A Greek survey in the Mediterranean also using bottom trawls (Stefatos et al., 1999) observed between 89 and 240 items per km². Korean researchers found up to 130 kg of litter per km² on the sea bed of the East China Sea and the South Sea of Korea (Lee et al., 2006). Hess et al. (1999) reported up to 158 items per km² in Alaska.
However, even though all of the above studies were performed with bottom trawl nets, the mesh sizes used in these studies varied between 37μm in the Alaskan study, up to 6.5 cm in the Korean study. This makes comparison of the results difficult. Moreover, in the Korean study, results where expressed in weight per km², while in the other studies, the number of items per km² was reported. There is a clear need for a standardisation of the sampling methodology. Nonetheless, these results show that pollution of the marine environment by debris is a global problem.

1.1.2.2 Coastal area

Floating marine debris can wash ashore where it accumulates on beaches next to the litter discarded by tourists. This visible garbage fraction has sparked major concerns among beach visitors and policy makers. In this context the OSPAR commission stated that "marine litter is a serious local, national and international issue as recently recognised by the United Nations". Hence, during the last years a lot of monitoring campaigns have tried to tackle the problem. A first example of such a project is 'Beachwatch' in the United Kingdom (UK). Each year, a cleaning action is organised, during which all encountered debris types are recorded. Even though annual variation occurs, results from the litter surveys indicate that since 1994, beach litter has increased by 88.5% (Beachwatch, 2010).

At the 2001 meeting of the Biodiversity Committee, the OSPAR commission agreed on the execution of the Pilot Project on Monitoring Marine Beach Litter. In 2003 it was agreed to prolong the project for another three years. This project gathered data from beach litter surveys in nine participating countries (including Belgium), using an agreed methodology to monitor the litter over 100m and 1km stretches of strategic beaches, at least three times per year. It was the first Europe-wide project using a standard method which was aimed at monitoring marine litter on beaches and identifying the sources and quantitative trends in marine litter on the beaches.
During the 2001-2006 surveys, a time trend could not be established, but regional differences were clear. Most items were encountered along the coasts South-West of the UK (Celtic Sea) and in the Northern part of the North Sea (on average up to

approximately 900 items per 100m). On the coasts more to the South, less items were counted. This difference is in accordance with the results from seafloor surveys.

A considerable number of surveys were conducted on various beaches throughout the world. Barnes & Milner (2005) counted up to 80 items per 100m of coastline at Tristan da Cunha, in the Southern Atlantic Ocean. Claereboudt (2004) encountered up to 179 items per 100m at the coasts of the Oman Gulf. In the United States, Jones (1995) surveyed the beaches of Hawaii, California, Texas and Mexico. Results ranged from 262 items per km of beach in Hawaii, up to 8,000 items per km in Mexico. The same author found up to 11,200 items per km on Australian beaches. In Indonesia, up to 29,100 items were found in a survey on 23 islands (Willoughby et al., 1997).
Unfortunately, it is impossible to compare the results of these studies, since the types and sizes/volumes/quantities of the litter encountered were insufficiently characterized.

1.1.2.3 Floating debris

A number of studies addressed the prevalence of debris floating on seas and oceans. In a few studies, scientists scanned the sea surface visually, noting floating debris. In this way, 0 to 20 items (mostly plastics) per km² were found in the Northern part of the Atlantic Ocean (Barnes & Milner, 2005). Around the UK and North Western Europe, these values were highest: 10 to 100 items per km². More to the north around the Svalbard archipelago, only 0 to 3 items were counted per km². Uneputty & Evans (1997) studied Ambon Bay in Indonesia in the same way and found up to 4 items per m². Other high values were found in the Mediterranean sea (1.5 to 25 items per km²) and the coastal waters of Chili (1 to 36 items per km²).
However, it is recognized that the results of these types of studies do not allow a quantitative evaluation of the problem as visual detection only informs us on large items. This is why surveys examining floating debris have recently been conducted with nets (mesh size smaller than 5-10mm). In this way, the Northern part of the Pacific Ocean was sampled (Moore et al., 2001). This is an area of high pressure with a clockwise ocean current in which floating debris is forced into a central area with little wind and current influence: an area also known as the "Great Pacific Garbage Patch". Up to 334,270 plastic items, or 5114g of were found per km². At a depth of 10m, only half of this concentration was found. The concentrations of plastic particles were compared to the plankton concentration in this area and it was reported that the plastics were about 7.5 times more abundant (on a mass basis) than plankton. The largest particles were polypropylene/monofilament particles – originating from fishing lines – which were found in a concentration of 36,857 particles per km². Other types of debris were plastic films (95,642 per km²), fragments (195,484 per km²) and preproduction pellets (531 per km²). Small amounts of Styrofoam and tar were also detected. Important

in this study by Moore et al. (2001) is that particles smaller than 1mm were also found in very high concentrations (e.g. 127,864 fragments per km^2).
Research on the occurrence of these so-called microplastics in intertidal and subtidal sediments and the water column, was done by Thompson et al. (2004). These authors focused primarily on fibers, of which they found up to roughly 6 fibers in 50mL of sediment. This peak concentration was found in subtidal sediments. In the water column they encountered up to 0.04 fibers per m^3. A lot of different polymers were encountered (e.g. acryl, polyethylene, polypropylene, polyester, polymethylacrylate...).

1.1.2.4 Effects

Marine debris is clearly a global issue, affecting all major water bodies above and below the surface. This debris can adversely impact humans, wildlife and the economic health of coastal communities (Sheavley & Register, 2007).

Humans:

Sewage related debris, medical waste and other potential biohazards are considered as a potential danger to human health, either when stranded on beaches or when circulating in coastal waters (Rees & Pond, 1994). Beach visitors can be harmed by broken glass, medical waste, discarded syringes and fishing line. Also, the presence of medical and personal hygiene debris indicates that bacterial contamination, including *E. coli*, other harmful bacteria, and viruses may be present in these waters. This could be dangerous to the health of people coming into contact with these waters or can even lead to the closure of tourism beaches. Marine debris can lead to problematic entanglement, and particularly the entanglement of divers in monofilament gill nets which are floating around in the water column or attached to wrecks.

Coastal Communities:

Damage to coastal communities caused by marine litter can be grouped into a number of general categories. These include damage to fisheries, fishing boats and gear, damage to cooling water intakes in power stations, contamination of beaches (requiring cleaning operations), contamination of commercial harbours and marinas (demanding cleaning operations), and contamination of coastal grazing land, causing injury to livestock (UNEP, 2005). Fishermen reported problems with propeller fouling, blocked intake pipes and damaged drive shafts. Marine litter-related damage includes also safety risks at sea (demanding rescue services) due to fouling of propellers (Hall, 2000).
Marine debris also makes shorelines unattractive and potentially hazardous, which forces communities and governments to spend considerable funds for beach

maintenance. Marine debris discourages people from fishing, boating, swimming, and visiting coastal areas (Sheavley & Register, 2007).

Wildlife:

Marine wildlife is possibly the group of organisms mostly affected by the debris. The threats to marine life are primarily mechanical due to ingestion of plastic debris and entanglement in packaging bands, synthetic ropes and lines, or drift nets (Laist, 1997; Quayle, 1992).

Many birds have been found to contain small items of debris in their stomachs. This is the result of their mistaking the litter for food (e.g. Day et al., 1985; Laist, 1997). There is evidence that some seabirds specifically select certain plastic shapes and colours, mistaking them for potential prey items (Derraik, 2002). The same could be true for fish, as various species were found to have plastic debris in their guts which were all of the same type of white plastic spherules, indicating selective feeding (Carpenter et al., 1972). The consequences of this ingestion of debris include reduction of food uptake due to the plastics reducing the storage volume of the stomach and the feeding stimulus. This in turn can lead to decreased overall fitness; blockage of gastric enzyme secretion, lowered steroid hormone levels, delayed ovulation and reproductive failure (Derraik, 2002). It is also suggested that plastic pellets could be a route for PCBs (or other contaminants) into marine food chains (e.g. Carpenter et al., 1972). There is limited evidence for this bio-transfer: Ryan et al. (1988) related PCBs in bird tissues to that associated with ingested plastic particles. Besides fish and birds, sea turtles, whales and dolphins have also been found to ingest plastic, sometimes with death as a result (Derraik, 2002).

Entanglement in marine debris, especially in discarded fishing gear, is another serious threat to marine wildlife. Once an animal is entangled, it may drown, have its ability to catch food or to avoid predators impaired, or incur wounds from abrasive or cutting action of attached debris. Sea mammals in particular, are vulnerable to entanglement (Derraik, 2002).

1.1.3. Prevalence of marine debris in Belgium

From the limited studies available it may be suggested that in the Belgian coastal waters, the amount of floating debris is rather low compared to other locations. Less than 1 (visible) item per ha was encountered in the study conducted by Galgani et al. (2000). This is probably due to the hydrodynamics in this area. Indeed there is a current going from south to north on the east side of the North Sea. This current ends in an "eddy" on the west side of Denmark, where higher concentrations of debris are found.

Two Belgian beaches (one in Oostende and one in Koksijde) were studied in the framework of the Pilot Project on Monitoring Marine Beach Litter initiated by OSPAR. Results of the surveys between 2002 and 2006 in the MIRA (2007) report. On average, approximately 1,000 items were collected per km, with a maximum of 4,340 objects during the winter of 2003/2004, The latter was probably due to weather conditions and ocean currents.
With this amount of debris, Belgium scores a little below the average of the rest of the world and of Europe. Roughly 80% of the collected debris consisted of plastic items. Besides plastics, regularly encountered items were paper, cardboard, rubber, wood, metal and glass. Real trends in composition and amount of debris could not be established due to the limited time line.
Next to the surveys performed in the context of the OSPAR project, other initiatives have provided insights into the prevalence of marine debris along the Belgian coast. In 2007 for example, the annual "Lenteprikkel op het strand" was organized for the fourth time by the Coordination Centre for Integrated Coastal Zone Management. It should be noted that this institute is a partner in the project proposal. In total, 2,379kg of litter were gathered by 711 volunteers over a distance of 9.9km of beach. The most important components of the litter were rope and textile (Maelfait, 2007). Although the above unprocessed data is available the mentioned project partner, no detailed data analyses, data management and reporting and/or publishing effort have been performed.

To date there is no published information available on the occurrence of microplastics in Belgian marine waters. However, the Laboratory for Environmental Toxicology and Aquatic Ecology - the promoter of the current project proposal – has, in the past year, conducted research on the presence and distribution of microplastics along the Belgian coast. These data have been published in 2011 (Claessens et al, 2011). In summary, we observed up to 156 particles (sum of fibers and granular particles) per kg of sediment collected on beaches, up to 269 particles per kg in the subtidal areas of the Belgian Continental Shelf (off shore station), and up to 390 particles per kg of sediment taken from Belgian coastal harbours. In this study we not only quantified the micro-plastics but also identified, using infra-red spectrophotometry, the different types of plastics. The developed collection, separation and identification techniques are now available to be used in further monitoring studies.

The impact of marine debris on wildlife is often assessed through stomach analyses of marine (feeding) birds. For the Belgian marine area, Northern fulmars have since 2002 been used as an indicator for the impact of anthropogenic litter in the sea (MIRA, 2007). To this end, the stomach contents of these birds were analysed for the occurrence of plastics particles. This indicator is being tested by a working group as OSPAR-Ecological

Quality Objective (EcoQO: van Franeker et al., 2005; van Franeker & the SNS working Group, 2008).The Research Institute for Nature and Forest (INBO) – a partner in the project proposal - is the Belgian representative in this working group. The study revealed elevated plastic ingestion by seabirds in the southern North Sea and especially in birds that washed up on Belgian beaches: they all contained very high numbers of plastic particles. During the period 2002-2006, in total 188 birds were found, of which 98% had plastics present in their stomachs. Number of items varied between a few to more than 100 items per bird. However, this dataset has not yet been analysed in detail, so trends or information on ratios of the different types of plastic are not yet available. Seabirds may get entangled in plastic material (fishing lines, packing of six-packs etc.). In Belgium such data is systematically collected during the monthly Beached Bird Surveys (BBS) that are conducted by INBO. However, the data is still enclosed in 'notes' and no results on occurrence and trends have been published yet.

From the above, it is clear that marine litter threatens Belgian marine ecosystems as well, and that further monitoring and analyses of available unprocessed data (which has been or is being collected by the three project partners) is necessary. Additionally, there is a lack of information on the distribution of floating marine litter, and litter on the seafloor. Moreover, no literature has yet been published on the presence and/or distribution of microplastics in the Belgian environment.

1.2 Objectives

The overall aims of the present project were:

i. to study the presence of marine debris (including the break-down/degradation products, e.g. microplastics) in the Belgian marine environment, based on the available literature data and on dedicated quantitative monitoring surveys of the seabed, the sea-surface and the beach;
ii. to assess the effects of this debris (including possible associated micro-contaminants) on selected marine species (invertebrates and birds);
iii. to evaluate the financial impact of this form of pollution (removal vs. prevention);
iv. to develop and evaluate science-based policy evaluation tools.

2. METHODOLOGY & RESULTS

2.1 Integrated database development

2.1.1 Database development

In a first phase, an inventarisation was made of all existing data on marine debris. These included volunteer sampling data ("Fishing for Litter" and "Lenteprikkel") and data collected within a scientific framework (entanglement of birds, observations at sea, beach monitoring). The differences in sampling, quality and restriction of access were documented on the level of sampling type.

Because of the different types of data collection and projects, no standardized procedure or parameter could be identified. The beach sampling was executed following OSPAR guidelines, others UNEP or specific project related. To make integration possible, a standardised list of parameters was created (Parameters_ASMADE) and linked to the original parameters. At the same time the OSPAR and UNEP categories were integrated to enable reporting to OSPAR or UNEP if needed. At the level of sampling station the same integrated procedure was followed.

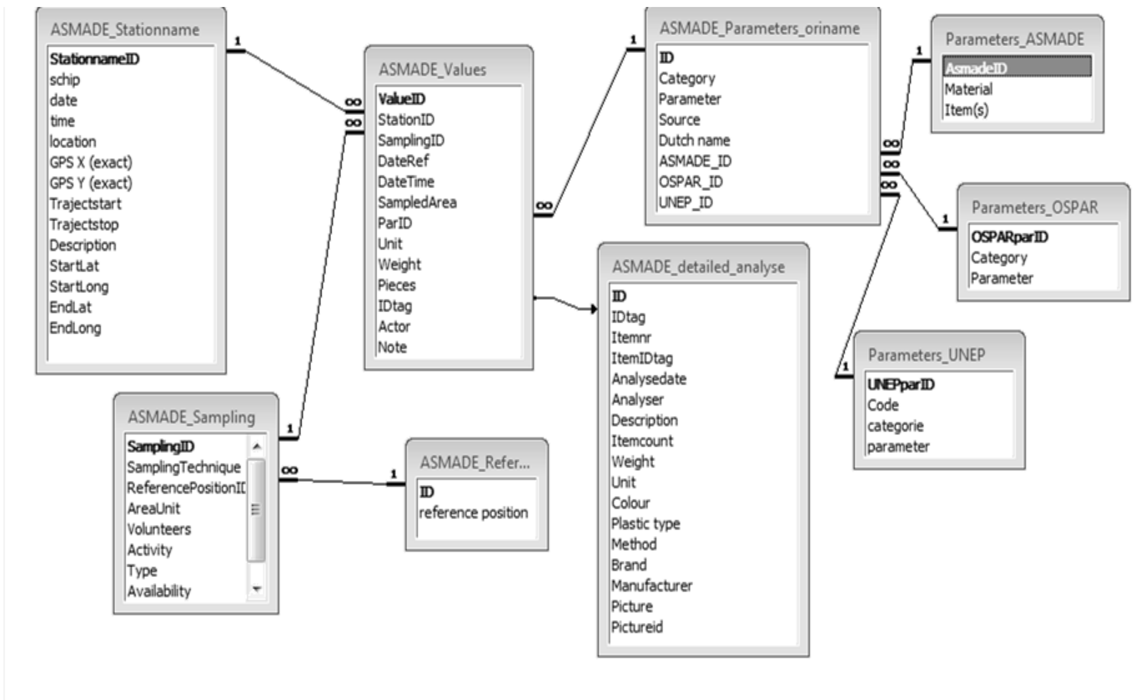

Figure 1: AS-MADE database structure

According to the above mentioned structure all data was standardised and integrated in a first simple database (with only a sampling table, value table and parameter table). Because the database will be integrated in the AS-MADE website, some preliminary questions were formed so people would be able to easily extract information from the database. Due to these questions, and as the database will possibly be used to disseminate on Marine Litter, some adjustments were made such as translations, the separate stations & samplings, a different column for the type of units: weight or pieces,...

An integrated database has been developed as mentioned (Figure 1). The database will be made available at the website (www.vliz.be/projects/as-made) when all types of data have been collected (May 2012).

2.2 Monitoring

2.2.1 Beach monitoring

A first beach monitoring campaign was conducted in August 2010. To this end, four locations were selected ensuring a maximum diversity in sedimentation regime (erosion or accretion) and touristic pressure. The selected locations are presented in Table I.

The same locations were visited again during a second monitoring campaign in March - April 2011.

Table I: Locations selected for the beach monitoring campaigns

Location	Sedimentation regime*	Touristic pressure
De Panne – Westhoek	Accretion	Low
Oostduinkerke	Accretion	High
De Haan	Erosion	High
Zwin	Erosion	Low

* Deronde (2007)

2.2.1.1 Analysis of macrolitter

At each location, a beach section of 100m parallel to the water line was established.

In each of these sections, all visible macrolitter (> 1mm) was carefully collected between the low and the high water mark. The entire trajectory was recorded with a GPS to obtain detailed geometric information of the sampling area. At the laboratory, the collected litter was sorted and classified according to a classification list developed to subsequently allow the automatic classification according to both the existing OSPAR (OSPAR, 2010) as UNEP (UNEP, 2009a) lists. The litter abundances were expressed both as number of items and weight of the litter per beach section.

A total of 51,428 items, weighing a total of 74.19kg, were collected along the 4 beaches during the two sampling periods, in total 800m of sampled beaches. Plastic items were the most abundant, representing about 95.5% (range 49.7% - 98.9%) of all debris collected. Industrial pellets constitute an important part of the recorded plastic debris, ranging from 5 to almost 92% of all beached litter. If these pellets are removed from the dataset, plastics make up 76.5% of all recorded debris. The ten most common plastic items are represented in Table II.

Overall, pollution levels ranged from 339 – 21,744 items per 100m beach front, with a mean of 6,429 items.100m^{-1} ($\pm$ 6.767.1 items.100m^{-1}). In terms of weight, recorded beached debris ranged from 1.52 – 32.90kg.100m^{-1} (mean: 9.27 $\pm$ 10.45kg.100m^{-1}).

Abundances of beached debris during summer 2010 were high, with on average 58.5 $\pm$ 21.4 items.m^{-1} recorded, this corresponds to a weight of 38.7 $\pm$ 3.3 g.m^{-1}. Plastic debris made up 96.6% of all items collected in August 2010 (Table III). Industrial resin pellets made up a large part of this plastic debris: for De Panne - Westhoek and Zwin, almost 92% of all plastics were pellets.

Table II: Top 10 plastic litter items recorded during beach monitoring in 2010 and 2011.

	2010	2011	Percentage of Total Plastics
Resin pellets	19,493	22,119	84.72%
Fragments	1,295	1,599	5.89%
Monofilament line & nets	775	1588	4.81%
Bottles & lids	167	266	0.88%
Cigarette butts	197	170	0.75%
Sweet packages	109	236	0.70%
Plastic bags	98	30	0.45%
Cutlery, straws & cups	118	94	0.43%
Foamed plastic	41	62	0.36%
Other plastic items	71	22	0.19%

Table III: Beached macrodebris recorded during summer 2010 (August)

	De Panne - Westhoek	**Oostduinkerke**	**De Haan**	**Zwin**
Abundance (n° of items.100m^{-1})				
Plastic	4,991	7,719	2,960	6,930
Pellets	*4,714*	*6,077*	*2,271*	*6,431*
Cloth	20	27	12	0
Glass	46	35	7	2
Ceramics	18	22	10	4
Metal	3	75	24	2
Paper	17	27	60	3
Rubber	7	34	39	15
Wood	15	20	29	14
Other	8	97	63	40
Total	**5,125**	**8,056**	**3,204**	**7,010**
% Plastic	97.40	95.82	92.38	98.86
% Pellets	91.98	75.43	70.88	91.74
Weight (g.100m^{-1})				
Plastic	820.6	1,886.9	2,305	2,651
Cloth	71	44	39	0
Glass	364	136	93	20
Ceramics	1,233	748	712	132
Metal	88.3	225	115	14
Paper	72	77	221	172
Rubber	11	80	50	69
Wood	869	187	741	418
Other	292.5	452.2	46	41
Total	***3,821.4***	***3,836.1***	***4,322***	***3,517***
% Plastic	21.47	49.18	53.33	75.38

Pollution levels varied between locations, when considering the total amount of numbers of beached debris recorded (Figure 2). Oostduinkerke, characterised by high touristic pressure and sedimentation, has the highest number of items recorded, i.e. 80.6 items.m^{-1}. Zwin (low touristic pressure and erosion) is the second most polluted beach with 70.1 items.m^{-1}. These high pollution levels are attributed to the high numbers of industrial pellets found on these beaches (Table III).

In terms of weight, however, there are no notable differences between the different locations, touristic pressure or sedimentation regime (Figure 3).

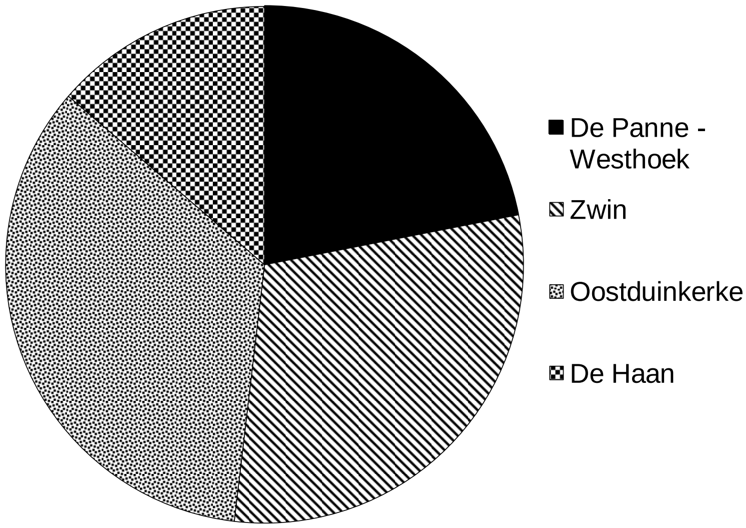

Figure 2: Share of each sampled beach section in the total numbers of beached marine debris recorded in 2010 (De Panne – Westhoek: 21.91%; Zwin: 29.96%; Oostduinkerke: 34.43%; De Haan: 13.70%).

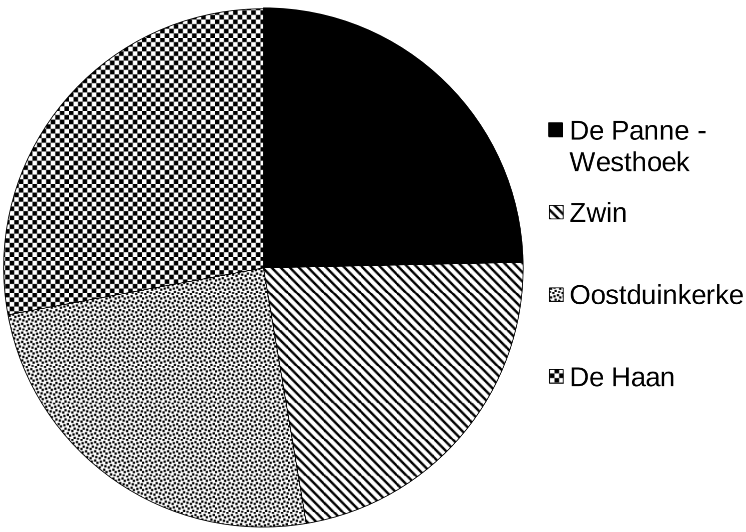

Figure 3: Share of each sampled beach section in the total mass of beached marine debris recorded in 2010 (De Panne – Westhoek: 24.66%; Zwin: 22.70%; Oostduinkerke: 24.75%; De Haan: 27.89%)

In spring 2011, similar abundances were observed: on average 70.7 $\pm$ 10.1 items.m^{-1}. In terms of weight, however, average contamination levels were elevated to 145.9 $\pm$ 131 g.m^{-1} (Table IV). Plastic debris constituted 94.6% of all recorded debris. Industrial pellets were present in smaller quantities when compared with 2010 (Table III & Table IV), with one exception: the Zwin beach shows extremely high pellet counts for this period. Almost 20,000 pellets were recorded, corresponding to 91.6% of all debris collected on the Zwin beach, compared to 5 to 43% for the three other sampling locations. The lowest percentage of plastic (49.73%) was recorded in De Panne – Westhoek in 2011, due to very high abundances of ropes and string (category 'Cloth')

(Table IV). On the other beaches, the category Cloth makes up less than 3% of the total beached debris, on De Panne – Westhoek 20,22% was made up of cloth items.

Table IV: Beached macrodebris recorded during spring 2011 (March – April)

	De Panne - Westhoek	Oostduinkerke	De Haan	Zwin
Abundance (n° of items.100m^{-1})				
Plastic	369	4,538	230	21,384
Pellets	*35*	*2,171*	*15*	*19,898*
Cloth	150	154	10	6
Glass	99	50	14	29
Ceramics	71	71	10	109
Metal	9	62	5	2
Paper	3	30	39	14
Rubber	5	53	5	22
Wood	23	60	18	64
Other	13	190	8	114
Total	**742**	**5,208**	**339**	**21,744**
% Plastic	49.73	87.14	67.85	98.34
% Pellets	4.72	41.69	4.42	91.51
Weight (g.100m^{-1})				
Plastic	446	5,262	50.5	1,858.8
Cloth	131	642	<1	3
Glass	514	446	108	133
Ceramics	6,794	5,851	69	20,515
Metal	63	314	6	14
Paper	8	91	22	5
Rubber	1	220	118.9	56
Wood	1,612	1,610	1,128	10,296
Other	1	261	21	22
Total	**9,570**	**14,697**	**1,523**	**32,902.8**
% Plastic	4.66	35.16	3.32	5.65

Because of the high pellet count in Zwin, the debris collected on this beach section constitutes almost 80% of all recorded debris during 2011, with approximately 217.4 items.m^{-1}. If these industrial pellets are not taken into account, the Zwin-collected debris only makes up around 30% of the total amount of debris recorded (Figure 4), corresponding to only 18.5 items.m^{-1}. In terms of weight, again the Zwin beach stands out: here, 32.90kg of debris was collected. This is 56% of the total mass of debris recorded (Figure 5). This is mainly attributable to two categories, namely 'Ceramics' and 'Wood' (Table IV). A large amount of ceramics (i.e. bricks and tiles) boosts up the total mass collected, as well as heavy timber. Oostduinkerke for instance, had similar numbers of wood items (60 compared to 64 in Zwin), but the weight of these items was about 6 times higher in Zwin than Oostduinkerke.

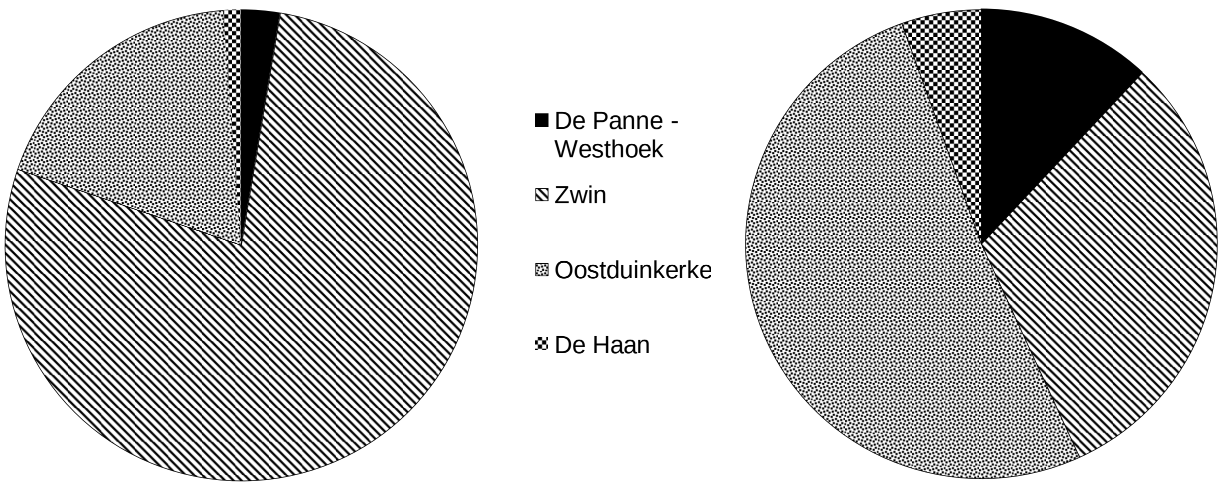

Figure 4: Share of each sampled beach section in the total numbers of beached marine debris recorded in 2011. Left: With pellets (De Panne – Westhoek: 2.65%; Zwin: 77.57%; Oostduinkerke: 18.58%; De Haan: 1.21%). Right: Without pellets (De Panne – Westhoek: 11.95%; Zwin: 31.21%; Oostduinkerke: 51.35%; De Haan: 5.48%).

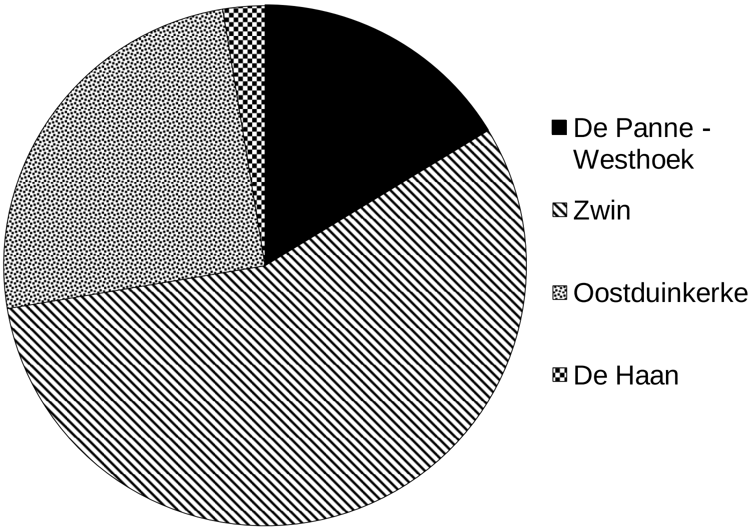

Figure 5: Share of each sampled beach section in the total mass of beached marine debris recorded in 2011 (De Panne – Westhoek: 16.31%; Zwin: 56.06%; Oostduinkerke: 25.04%; De Haan: 2.60%).

2.2.1.2 Analysis of microplastics

For the analysis of microplastics, sand was collected in each beach section, at 6 locations: 3 at the high water mark (0m, 50m and 100m) and 3 at the low water mark (0m, 50m and 100m).

This was done by sampling the top 5cm of sand with a small core. At each of the 6 locations, this was repeated until approximately 2L of sand was collected. For the extraction of the microplastics from these samples, a new extraction method was developed.

The extraction method for microplastics currently most widely used, was developed by Thompson et al. (2004). This technique relies on the density of a saturated salt solution for the extraction of microplastics from sediment samples. When this salt solution (~1.2kg $NaCl.L^{-1}$) is added to the sample, microparticles of low enough density will float to the surface. This method, however, will only be efficient for polymers with a density lower than that of the saturated saline concentration, i.e. $1.2g.cm^{-3}$. Therefore, this technique is not suitable for the extraction of polymers with a high density, such as PVC (density ~$1.36g.cm^{-3}$) or PET (density ~$1.4g.cm^{-3}$), which will not float in this solution. Hence, results based on this extraction method will be an underestimation. In order to overcome this, a new device fro the extraction of microplastics was developed.

This new device, based on the principle of elutriation, and its operational procedure is schematically represented in Figure 6. After the extraction, the material collected on the 38μm sieve is subjected to an extraction in a sodium iodide (NaI) solution with a density of approximately 1.6kg L^{-1}. This is done to separate the microplastics from heavier particles (including sand) that are potentially present after the elutriation. To this end, the material on the sieve is transferred to a 50mL centrifuge tube after which 40mL of the NaI solution is added. After vigorous shaking, the mixture is centrifuged for 3 minutes at 3500g. The top layer is then vacuum filtered over a membrane filter.

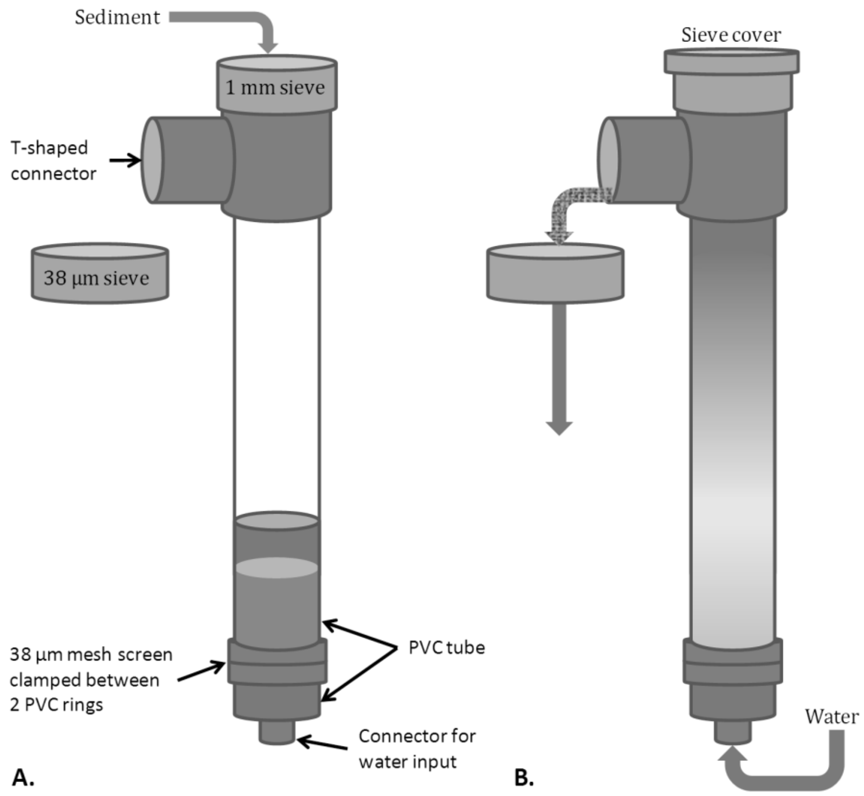

Figure 6: Schematic representation of the elutriation device used to extract microplastics from sediments

On average, a concentration of 16.7 $\pm$ 2.2 particles.L^{-1} sediment were found for the 4 sampled locations. Using an average sediment density of 1600kg.m^{-3} (Fettweis et al., 2007), and 1.25 as wet sediment/dry sediment ratio (Claessens et al., 2011), an average microplastic concentration of 13.1 $\pm$ 1.7 particles.kg^{-1} dry sediment is found, ranging from 7.4 to 9.7 particles. kg^{-1} dry sediment. As can be seen from Table V concentration of microplastics differ between the low water mark and high water mark: less particles are present at the low water mark (9.2 $\pm$ 2.4 particles.kg^{-1}) compared to the high water mark (16.9 $\pm$ 3.2 particles.kg^{-1}).

Table V: Microplastic counts for beach samples at the low water mark and high water mark. Numbers are given for a volume of 6L sediment.

	De Panne - Westhoek	**Oostduinkerke**	**De Haan**	**Zwin**
Low Water Mark				
Pellet	0	0	1	0
PVC pieces	14	51	18	29
Fibre blue	11	8	10	13
Fibre black	11	8	5	9
Fibre white	4	3	4	20
Fibre red	1	4	0	2
Fibre tangled	0	0	1	0
Plastic pieces yellow	2	7	4	8
Plastic pieces green/blue	0	0	2	6
Plastic pieces pink	12	0	10	5
Plastic pieces red	0	0	0	0
Plastic pieces black	0	0	0	0
Concentration (particles.L^{-1})	**9.2**	**13.5**	**9.2**	**15.3**
High Water Mark				
Pellet	0	1	0	0
PVC pieces	0	0	2	0
Fibre blue	67	21	57	61
Fibre black	76	55	51	47
Fibre white	0	13	2	5
Fibre red	7	4	9	7
Fibre tangled	0	0	0	0
Plastic pieces yellow	4	3	0	5
Plastic pieces green/blue	2	2	0	9
Plastic pieces pink	0	0	0	6
Plastic pieces red	1	0	1	0
Plastic pieces black	0	0	1	0
Concentration (particles.L^{-1})	**26.2**	**16.5**	**20.5**	**23.3**
Total Concentration (particles.L^{-1})	**17.7**	**14.8**	**15.0**	**19.3**

At the low water mark, PVC pieces and fibres make up the same share of the total amount of particles recorded (both around 40%), at the high water mark fibres are dominant with 92.9% of all microplastics recovered.

2.2.1.3 Discussion

92.7 kg of litter per km (92.7 $g.m^{-1}$) of beach is a lot. Although this is not nearly the highest value ever reported, it does, however, exceed a lot of internationally reported levels of beached marine debris. In the USA, Gilligan et al (1992) reported 45.0 $kg.km^{-1}$ on the beaches of Georgia. On the Falkland Islands 18.3 $kg.km^{-1}$ was reported by Otley & Ingham (2003), and Claereboudt (2004) found on average 29.7 kg per km of sampled beach in Oman. More closer to home, Martinez-Ribes et al (2007) reported 32.9 kg of beached marine debris per km of beach on the Spanish Balearic Islands. However, recording marine debris along the beaches of Indonesia, Willoughby et al (1997) estimated the weight of the litter to be in the range of 1000 $kg.km^{-1}$, while in Curaçao contamination levels reached on average 5,769.7 $kg.km^{-1}$ on windward beaches (Debrot et al, 1999).

With an average of 64,290 items per km (64.3 items $.m^{-1}$), the Belgian beaches are also in the top part of the range of number of items beached marine debris reported. On the Southern beaches of Australia, Edyvane et al (2004) reported only 31.6 items per km, while beaches in Northern Australia had around 91.5 $items.km^{-1}$ (Whiting , 1998). More recently, 9100 $items.km^{-1}$ were reported by Santos et al. (2009) In the Northeast of Brazil. High numbers of debris were reported in Indonesia by Willoughby et al (1997), on average 17,365.2 $items.km^{-1}$, and on the Balearic Islands (Martinez-Ribes et al, 2007), on average 35 670 $items.km^{-1}$ But the highest numbers of debris recorded was by Debrot et al (1999): windward beaches on Curaçao had on average 75,560 items per km of beach. While this very high concentrations of marine debris in Curaçao is attributed to large amounts of plastic fragments (67% of all plastic), along the Belgian coastline marine litter is dominated by resin pellets (84.72% of all plastic) (Table II).

The most abundant items were plastic items, both in 2010 as in 2011 (Table III and Table IV). This dominance of plastic is very common (Gregory and Ryan, 1997; Willoughby et al, 1997; Otley & Ingham, 2003; Santos et al, 2009; Widmer & Hennemann, 2010). The percentage of plastic items found on the four sampled beaches falls within the 60 – 80% proportion reported by Gregory & Ryan (1997). This is mainly due to their high persistence, durability and low density, making the plastics float which in turn will lead to accumulation on the beach (Derraik, 2002).

The most abundant type of plastics retrieved from the four sampling stations, both in 2010 and 2011, were industrial plastic pellets (Table II), which are precursors for the production of plastic consumer products. Since they are only used in plastic industry, the presence of these pellets on Belgian beaches can only be attributed to accidental spillage during transport or storage in nearby ports. The top three of the plastics most commonly recorded is further completed by plastic fragments and monofilament line, ropes and nets, representing respectively 5.89% and 4.81% of all plastic items recovered from all four sampling station in both sampling years. As can be expected, the origin of plastic fragments could not be traced. Ropes, nets and monofilament fishing line, however, are fishing related items, originating from either recreational or commercial fishing activities. In 2011 almost double the amount of fishing related items were detected compared to 2010 (Table II). Because of the high persistence of plastics in the environment, this increase in items related to fishing might not only be due to an increase in the activity, but could merely be attributed to the prevailing winds (e.g. more inland winds in March-April 2011).

In 2010, there was almost no difference in the weight of beached marine debris between sampling stations (Figure 3). There are no effects of the sedimentation regime nor touristic pressure. In terms of number of items, however, there are some noticeable differences. Between the highest and lowest concentration (i.e. Oostduinkerke and De Haan), there is a difference in the total number of items of 4,852, of which 3,806 are pellets (Table III). Since the average weight of plastic pellets collected during the sampling period was around 0.03 grams, this difference of almost 3,800 items constitutes a weight difference of only 114 grams. Since resin pellets are associated with industrial activities (transport and storage), different touristic pressure between beaches (Table I) is not an explanatory variable for differences in the presence of pellets among beaches. Neither is sedimentation regime. It is true that Oostduinkerke and De Haan differ in sedimentation regime, respectively characterised by sedimentation and erosion (Table I). But the beach at Zwin is also characterised by erosion, and this sampling location has the second highest concentration of items recorded (i.e. 6,930 items.100m^{-1}). It even has the highest number of pellets recorded in 2010: 6,431 (Table III). It seems that typical beach characteristics (sedimentation regime and touristic pressure) do not explain the variation in number and weight of marine litter observed on Belgian beaches in 2010. More likely, sea currents and prevailing wind directions play an important role in the distribution of marine debris (Debrot et al, 1999).

In 2011, differences among the four sampled beaches are more pronounced than in 2010, and this both in terms of number of items as well as in terms of weight (Table IV, Figure 4 & Figure 5). During this second sampling campaign, Zwin dominated with a total of 21,384 items, which is almost 5 times the amount of items detected in Oostduinkerke the sampling location with the second highest concentration (i.e. 4,538 items.100m^{-1}). Again, this difference is attributable to the presence of large amounts of industrial pellets: in Zwin, a record amount of 19,898 resin pellets was recorded. However, what differs between this sampling campaign and the one in August 2010 is the distribution of these pellets among the beaches. Whereas in 2010 percentages of pellets were between 71 and 92% of all beached debris, in 2011 these percentages

were down to 4 – 5 % for beaches at De Panne and De Haan, where only 35 and 15 pellets were recovered, respectively. But even when removing resin pellets from the dataset, differences between sampling locations remain large (Figure 4).After removal of the resin pellets, the share of Zwin falls down from 77.57% to 31.21%, while the share of Oostduinkerke increases, from 18.58% to 51.35%. Not only were more cloth and metal items recorded in Oostduinkerke but more plastic items (other than pellets) were present at Oostduinkerke than Zwin.
In terms of weight, however, it is a different story. At the Zwin beach two times the weight of Oostduinkerke was collected. The influence of pellets is negligible. The average weight of one pellet is approximately 0.03 grams, hence for Zwin the total weight of all 19,898 pellets is only 596.94g, which is only 0.02% of the total weight recorded. At Zwin beach large ceramics and wooden items were collected, weighing respectively 20.52kg and 10.30kg (Table IV). At the other locations also, many ceramics and wooden items were collected, but at Zwin the dimensions of these items was larger. As was noticed in 2010, the beach characteristics do not seem to explain differences between sampled beaches. Other factors, wind directions and sea currents, however could play an important role (Debrot et al, 1999).

Although differences between beaches do not seem to related to characteristics such as sedimentation regime and touristic pressure, sampling period, however, does seem to be an important factor. Comparing the data of 2010 and 2011, there seems to be a large difference for beaches between these two periods. Abundances of beached litter were clearly higher in 2010, when pellets are not taken into account. Since the sampling campaign in 2010 was in August, the presence of tourism does seem to have an influence on the amount of debris present on beaches. The fact that there was no difference between beaches could be due to the fact that most tourism-related debris will end up in the water and will be transported between beaches. The 2011 sampling campaign, however, was characterised by the high total weight collected: in 2011 a total weight of 58.69kg was collected, compared to 15.47kg in 2010. The type of debris collected on the beaches differed between remarkably between the two periods. In spring 2011 33.23kg of ceramics and 14.65kg wood was collected, compared to 2.83kg ceramics and 2.22kg wood in 2010 (Table III & Table IV). These types of debris aren't associated with tourism but with construction, since mainly tiles, bricks and processed timber were collected. These items could for instance end up in the North Sea through loss during transport.

Microplastics were present in all samples of every sampled beach. The observed concentrations of microplastics, on average 13.1 $\pm$ 1.7 particles.kg^{-1} dry sediment, are lower than any of the concentrations reported earlier (Table VI). All these references used the saturated salt solution of Thompson et al (2004), and hence should be an underestimation of the real concentration of microplastics present, since this method is unsuitable for the extraction of high-density plastics. It is therefore surprising that for the sampling campaign of 2011 lower concentrations were observed. These microplastics were extracted from the sediment using elutriation and NaI, a technique developed for this project and the especially for the extraction of high-density plastics. Therefore, it was expected that the concentrations of microplastics determined with this method would be higher than those with the saturated salt method.

Samples from the high and low water mark were separately analysed, and the results show that higher concentrations of microplastics are found at the high water mark (Table V). The zone near the low water mark is a highly dynamic zone: most of the time it is submerged, and therefore is subjected to a constant deposition/re-suspension cycle. The top layer of the sediment in this zone will be highly disturbed during flooding, and settled particles will hence be re-suspended. Particle transport into permeable sediments has been shown to reach down at least 1.5cm into the sediment (Rusch and Huettel, 2000). The high-water mark on the other hand, is a much calmer zone: it will only be submerged during high tide, and this for short periods only. Particles, such as microplastics, that settle in this zone will thus be less prone to re-suspension than particles at the low water mark.. This is reflected in the difference between the concentrations of microplastics at these two zones, with lower concentrations at the low water mark and higher concentrations at the high water mark (Table V). At the low water mark, higher concentrations of PVC particles are detected than at the high water mark. This can also be explained by the difference in dynamics between these two zones. PVC is a high-density polymer (density ~1.36g cm^{-3}), and hence is able to settle at higher water speeds than plastics with a lower density. In contrast with this, light fibres were detected in higher concentrations at the high water mark, where the speed of the water and waves are slower than at the dynamic low water mark, enabling them to settle.

Table VI: Maximum concentrations of microplastics found in sediments worldwide. All concentrations are expressed as either number of particles or mg kg^{-1} dry sediment

Country	**Location**	**Maximum Concentration**	**Unit**	**Reference**
India	Ship-breaking yard	89	mg kg^{-1}	Reddy et al, 2006
UK	Beach[a]	9	# kg^{-1b}	Thompson et al, 2004
UK	Estuarine[a]	35	# kg^{-1b}	Thompson et al, 2004
UK	Subtidal[a]	86	# kg^{-1b}	Thompson et al, 2004
Singapore	Beach	16	# kg^{-1}	Ng & Obbard, 2006
UK	Sewage disposal site	15	# kg^{-1b}	Browne et al, 2011
Belgium	Harbour	391	# kg^{-1}	Claessens et al, 2011
Belgium	Continental Shelf	116	# kg^{-1}	Claessens et al, 2011
Belgium	Beach	156	# kg^{-1}	Claessens et al, 2011

[a] Only fibre concentrations were reported

[b] Original unit (# fibres $50mL^{-1}$ sediment) converted using an average sediment density of 1600kg m^{-3} (Fettweis et al., 2007) and 1.25 as average wet sediment/dry sediment ratio.

2.2.2 Belgian Continental Shelf (BCS) monitoring

A single campaign sampling the Belgian Continental Shelf (BCS) was conducted in September 2010, on board the research vessel 'Zeeleeuw'.

2.2.2.1 Macrolitter on the seafloor

Five sampling grids of 5x5km (Figure 7) were established according to UNEP guidelines (UNEP, 2009a) in which a 800m bottom trawl was conducted in three randomly selected sub-blocks of $1km^2$. For the sampling grids 1 and 2 (AM1 and AM2) only two sub-blocks were sampled, instead of three as described by UNEP guidelines (UNEP, 2009a).

Each trawl was manually searched for litter of any type, which was then classified according to the UNEP classification list (UNEP, 2009a).

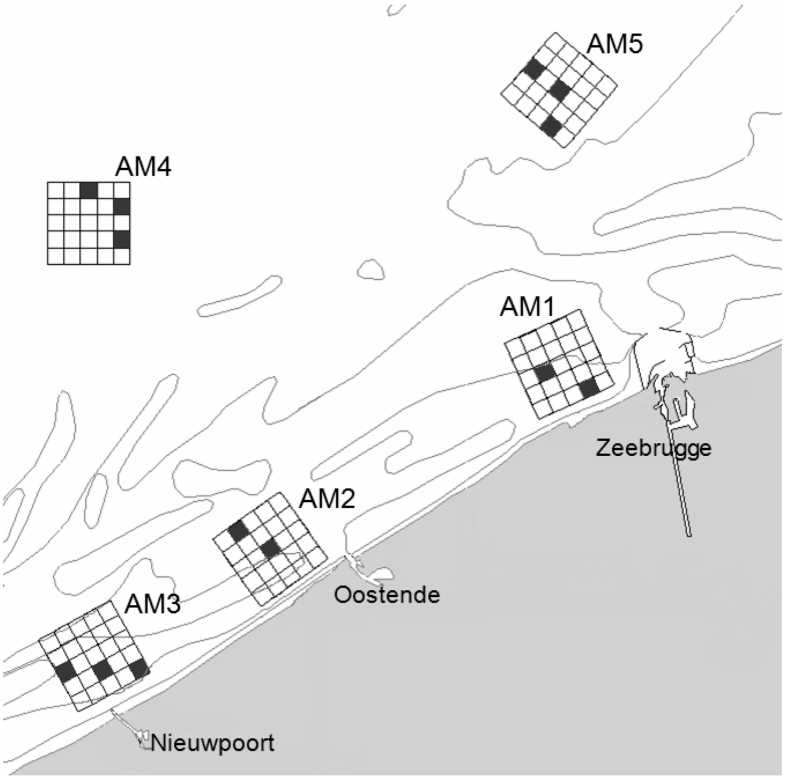

Figure 7 : Sampling grids on the Belgian Continental Shelf (BCS), sampled sub-blocks are indicated in black.

A total of 117 items, weighing a total of 16.87g, were recovered from the 10.4km of BCS sampled. This corresponds to an average value of 3125 $\pm$ 2829.5 items.km^{-2}, ranging from 1250 – 11,526.5 items.km^{-2}. The mean values of items recorded per sampling grid are represented in Figure 8. Sampling grids AM2 – AM5 appear to have similar abundances of benthic debris (average: 2092 $\pm$ 349.9 items.km^{-2}), whereas the sampling grid close to the harbour of Zeebrugge (AM1) exhibits an approximately four times higher abundance, i.e. 8593.8 $\pm$ 4198.4 items.km^{-2}.
In terms of weight an average value of 428.8 $\pm$ 703.4 g.km^{-2}, ranging from 75 – 2653.1 g.km^{-2}, was recorded. As can be seen from Figure 9, sampling grid AM1not only displays the highest amount of benthic macrolitter of all sampled grids, but here also the highest value in terms of weight of benthic debris was recorded.

Only three categories of items were recorded during this sampling campaign: 'Plastic', 'Cloth' and 'Paper'. Plastics make up the largest part of items recorded (95.7%). Second most abundant items were categorised as 'Cloth' (3.4%), and only one piece of cardboard box was recovered, making the share of the 'Paper' category only 0.9% of the total amount of items recorded. In terms of weight, plastic items still represent the highest share with 68.8%. 'Cloth' now makes up 31.1% of the total weight of benthic macrodebris, the weight of 'Paper' is restricted to only 0.2%.

Taking a more detailed look at the items retrieved in the trawls, fishing gear and related items make up the majority of the recovered items (Figure 10). Monofilament line, mostly used for angling or long-line fishing, represents 63.3% of all items retrieved. Combined with other fishing gear (such as nets, lure and traps), the total of fishing related items makes up 71.8%. Plastic fragments represent 19.7% of the retrieved items. Cloth items recovered from the trawls were mostly pieces of rope (3.4% of all items).

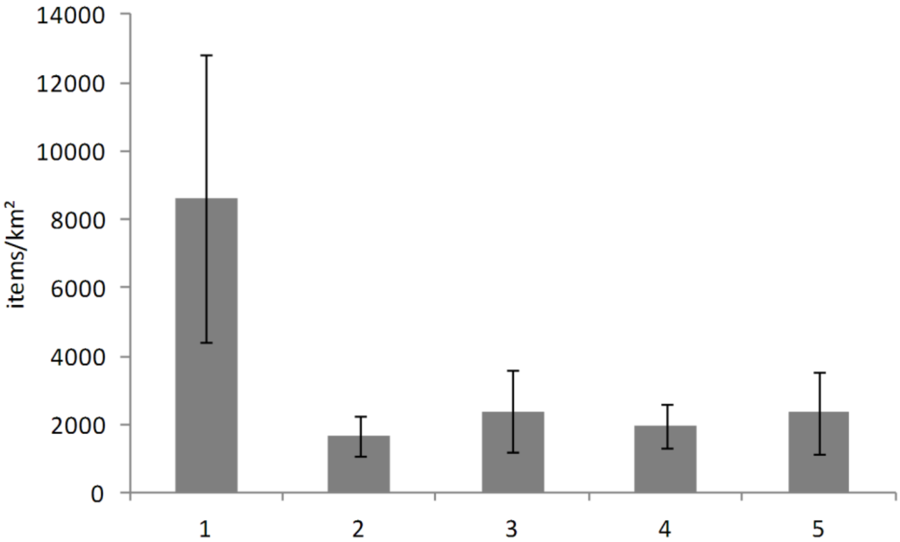

Figure 8: Number of items per km² of benthic debris recovered from the 5 sampled grids on the BCS.

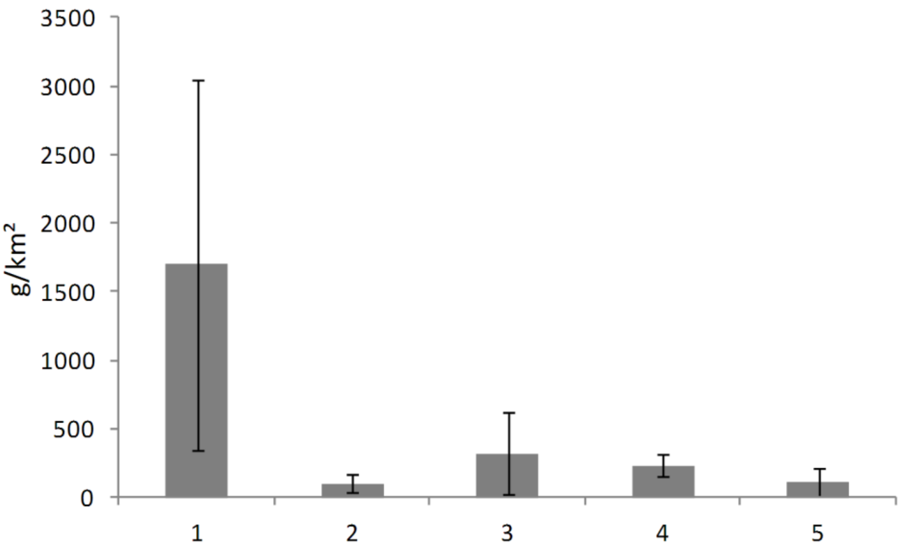

Figure 9: Weight (in gram.km^{-2}) of benthic debris recovered from the 5 sampled grids on the BCS.

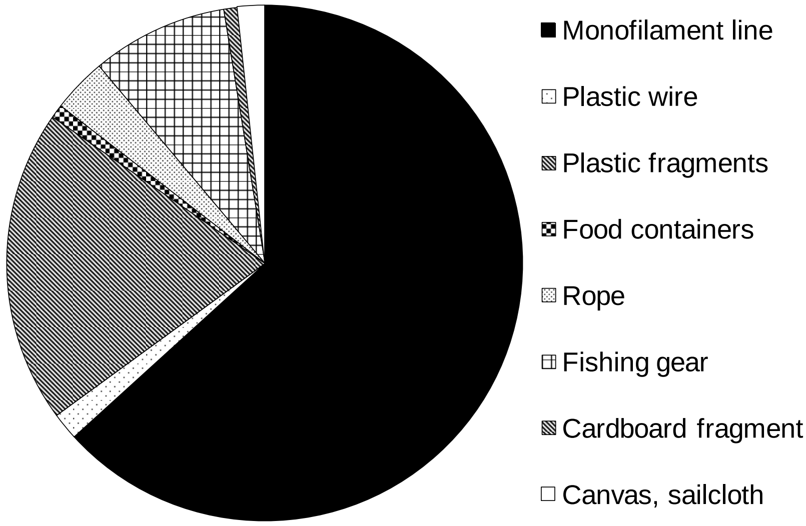

Figure 10: Composition of the benthic macrolitter on the Belgian Continental Shelf. 63.3% is monofilament line, 19.7% are plastic fragments, 8.6% is fishing gear, and 3.4% is rope.

2.2.2.2 Discussion

Benthic macrodebris on the BCS has only been assessed once. The UNEP guidelines for benthic litter assessment (UNEP, 2009a) postulate that per sampling grid of 25km², three randomly chosen sub-blocks should be sampled by performing 800m trawls per sub-block. For this sampling campaign this resulted in a total trawling distance of 10.4km. Since the speed of the research vessel is highly restricted during these trawls (2.9 – 4.1 knots), this sampling strategy is very time consuming and energy intensive. Because of the use of bottom trawl nets the sampling of benthic marine litter resulted in a lot of bycatch, especially bottom dwelling marine organisms ended up in the trawls. Additionally, because these trawling activities involve the towing of heavy gear over the seabed it can cause large scale damage to the sea bottom, destructing habitats.

Because of the abovementioned reasons, it was decided that no second sampling campaign of the BCS would be performed, since the negative impacts of this sampling strategy were too high compared to the limited amount of debris sampled with this method.

During the single sampling campaign of the BCS (September 2010), an average of 3125 $\pm$ 2829.5 items.km^{-2} were recorded. Other studies, assessing the benthic marine debris by using trawl nets, found quite diverse densities.

Sampling of the Mediterranean seafloor near Greece yielded between 89 to 240 items per km² in 1999 (Stefatos et al., 1999). Galgani et al. (2000) sampled the seafloor along the European coastline and results varied greatly, with concentrations ranging from 0 to 101,000 items.km^{-2}, with the latter being recorded in the Ligurian Sea (France). Highest number of plastic items was recorded in the Celtic Sea: 156 ± 54 plastic items.km^{-2}, or 29.5% of the total amount of items retrieved. In the Bay of Biscay far less items were recorded per km^2 (i.e. 142 ± 25 items.km^{-2}) but here 79.4% were plastics. For the (Western part of the) North Sea, an average density of 156 ± 36.8 items.km^{-2} were found, with 48.3% of all items being plastic.

The values for benthic litter found on the Belgian Continental Shelf in September 2010 are up to 20 times higher than those observed by Galgani et al. (2000) for the North Sea. Also, plastic concentrations (95.7%) on the BCS are also higher than any other region in studied in Europe. Highest percentages of plastics were found in the Bay of Biscay (92.5%) (Galgani et al., 1995), lowest in the Celtic Sea (29.5%) (Galgani et al., 2000). Since this latter study is also the only other study assessing benthic litter in the North Sea, it is not possible to compare the BCS with other regions in the North Sea.

Values that actually approximate the densities for the BCS, are found in the Mediterranean. Galgani et al. (2000) recorded values of 1935 ± 633 items.km^{-2} for the North western Mediterranean, a highly touristic region. Here, no assessment of the plastic benthic litter was performed.

However, even though all of the above studies were performed with bottom trawl nets, the mesh sizes used in varied from 15mm in Stefatos et al. (1999), up to 55mm in Galgani et al. (1995). This makes comparison of the results difficult, especially since the mesh size of the trawls used during this project was only 10mm.

In terms of weight recorded values for the BCS are very low compared to the weight of benthic debris on the seabed of the East China Sea and South Sea of Korea, where Lee et al. (2006) recorded up to 130kg.km^{-2}. The recorded 0.43 ± 0.70 kg.km^{-2} for the BCS is two orders of magnitude smaller. Even the highest recorded value of 2.65 kg.km^{-2} is far beneath the Korean value.

An explanation for the low recorded weight and the very high recorded densities can be found in the composition of the benthic litter. 63.3% of all items recorded is monofilament line (Figure 10), and the average weight of the monofilament line on the BCS is 62.8 ± 72.8 g.km^{-2}. Lee et al. (2006) on the other hand, found much larger items (e.g. fish pots, entire nets and ropes) weighing several kg per km^2.

There are, however, some remarks concerning the interpretation of the results of the benthic litter assessment. During this sampling campaign, two different trawl nets were used. In two of the five sampling grids (AM1 and AM3) an otter trawl was used, while in the other sampling grids (AM2, AM4 and AM5) a beam trawl was used to sample the litter on the BCS. Even though both nets had mesh sizes of 10mm, they differ in the amount of disturbance they invoke on the seabed. While a beam trawl slides over the bottom, an otter trawl acts like a plough, digging up to 15 cm into the seabed. An otter

trawl could thus retrieve items from the seabed that had already been buried in the sediment. One could expect higher amounts of litter being recorded while using an otter trawl instead of a beam trawl. Indeed, looking at the densities of benthic litter (Figure 8), it seems that the effect of using two different types of trawl nets could explain the high number of items found in AM1. However, densities of debris at AM3 appear to be within the same range as the sampling grids sampled with a beam trawl. The large number of items recovered from the first sampling grid, could also be attributed to the proximity of the harbour of Zeebrugge. This debris could be originating from ships entering or leaving the harbour, and from spillage during activities in the harbour.
The results obtained for the assessment of benthic marine debris using trawling might not be representative for the entire BCS. Galgani et al. (1996) noted that trawling results are only partial since they concern those areas where trawling is possible. Those areas are uniform of substrate and uniform of depth (UNEP, 2009a). Visual surveys of benthic litter have shown that a large part of the litter is located in piles near special accumulation zones such as rocks and shipwrecks, or in channels and other depressions (Galgani et al., 1996). Trawlable areas, however, are low in such accumulations zones. The results represented here are thus not representable for the entire BCS, and could be underestimations.

During this project, there has been no assessment of the microplastics present in the sediment of the BCS. However, for the BCS concentrations of microplastics have been reported by Claessens et al. in 2011 (Table VII).
No significant differences were found for between coastal and off shore sampling stations. Observed concentrations, however, were higher than those reported in similar studies. A study in the UK (Thompson et al., 2004) recorded maximum concentrations of 2 – 10 times lower those observed by Claessens et al. (2011). It has to be mentioned that the technique used for the extraction of the microplastics in this study is still the technique pioneered by Thompson et al. (2004), and not the newly developed technique described in this report (§2.2.1.2). The concentrations mentioned here could thus be underestimations of the real concentrations, since the saturated salt solution used for the extraction is not suited for the extraction of high-density polymers , such as polyvinylchloride (PVC).

Table VII: Average concentrations of the different types of polymer particles (number of particles kg^{-1} dry sediment) on the Belgian Continental Shelf. The last column represents the total concentrations expressed as mg $microplastics.kg^{-1}$ dry sediment. Values in parentheses represent the standard deviation of the mean (according to Claessens et al., 2011).

	Station	Fibres	Granules	Plastic films	Total	Total ($mg.kg^{-1}$)
Coast	Zeebrugge	46.0 (4.7)	22.4 (0.9)	3.0 (0.9)	71.5 (6.4)	0.89 (0.07)
	Oostende	80.7 (4.7)	33.3 (7.7)	1.8 (0.9)	115.8 (13.3)	1.21 (0.29)
	Nieuwpoort	52.7 (10.4)	32.1 (4.3)	3.6 (1.7)	88.4 (12.9)	1.23 (0.07)
Off shore	S4	74.7 (1.9)	33.9 (3.4)	3.6 (0.0)	112.2 (5.3)	1.30 (0.11)
	S5	74.0 (6.6)	23.6 (2.6)	0.6 (0.9)	98.2 (8.3)	0.84 (0.05)
	S6	237.3 (22.6)	32.1 (2.6)	0.0 (0.0)	269.5 (20.1)	1.21 (0.07)

2.2.3 Sea surface monitoring

Floating litter and seabirds were monitored simultaneously during monthly ship-based bird surveys (2009-2010) on board of the research vessel 'Zeeleeuw'. Counts were conducted according to a standardized and internationally applied method (e.g. ESAS-database), as described by Tasker *et al*. (1984). While steaming, all visible litter in touch with the water located within a 300m wide transect along one side of the ship's track was counted ('transect count'). Taking the travelled distance into account, the count results can be transformed to litter densities.

The litter was classified in different categories depending:

i. on size: Small (<5x5cm), Medium (5x5 - 30x30cm) and Large (>30x30cm)
ii. on material: party balloons, sheets, hard plastics, threads, foamed and other/undetermined types)

As the smaller particles can less easily be detected at greater distances, a distance sampling correction factor is computed for each size class.

Additional to these visual surveys, floating litter was also collected using a neuston net. At three different sampling periods (September 2010, February 2011 and July 2011), 1km trawls were performed using a 2x1m neuston net with a 1mm mesh size. Any debris present in the net was labelled and, on arrival in the laboratory, classified according to a classification list developed to allow the automatic classification according to both the existing OSPAR (OSPAR, 2010) as UNEP (UNEP, 2009a) lists (see also §2.2.1.1).

At the first sampling period (September 2010) three gyres were visited and sampled. The presence and location of these gyres was derived from maps with the residual current vectors on the Belgian Continental Shelf. It was hypothesised that within these gyres, which are rotating ocean currents, floating debris would accumulate. After the first sampling campaign, however, it was decided that no second sampling of these gyres would be performed and new sampling stations were selected. These 12 sampling stations visited during 2011 were specifically chosen to be representative of the Belgian Continental Shelf. Sampling of the sampling stations AsM01 to AsM12 occurred in February and July 2011 (Figure 11).

Figure 11: Sampling locations visited during the three sampling periods in 2010 and 2011: Gyres 1 to Gyre 3 and sampling stations AsM01 to AsM12.

2.2.3.1 Analysis of floating litter – Visual survey

During the ship-based bird surveys 741 pieces of debris were detected, 80% of this litter was plastic (N=587). After removing the non-plastic items from the database and applying the correction factor, almost three times more small items (<5x5 cm), twice as many medium sized items (5x5-30x30 cm) but only 1.5 times the large objects (> 30x30 cm) should have been spotted. In total 1176 plastic items should have been spotted. A surface of 2202 km² was covered by the survey, which gives a plastic density of 0.53 items/km² and a debris density of 0.66 items/km² (correction factor was applied to the entire database, plastics and other debris to obtain the corrected number of debris, being 1449 floating objects)

After applying the size-specific distance correction factor to the different types of plastic it appears that more than half of the litter floating around is composed of sheet-like plastic (58%) (Figure 12). Hard plastic represent 20%, party balloons 10% and foamed plastic 4% of the spotted plastic items.

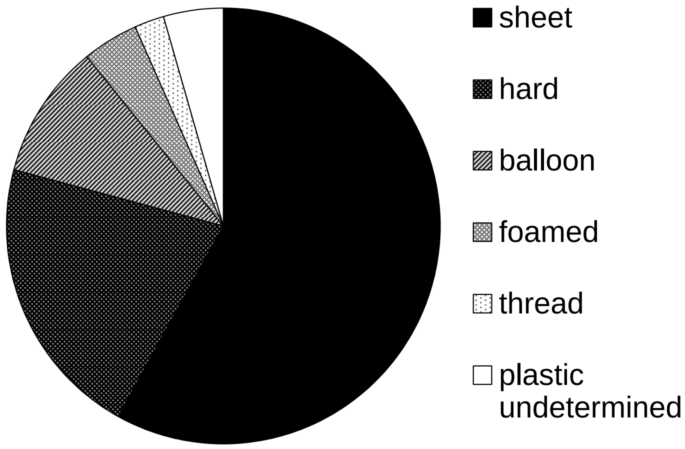

Figure 12 : Composition of the floating plastic litter on the Belgian Continental Shelf. 58% was sheets of plastic, 20% hard plastics and 10% party balloons.

2.2.3.2 Analysis of floating litter – Neuston net trawl

During the first sampling campaign (September 2010) a set of three gyres located in the Belgian part of the North Sea were visited. In total, 0.01km² were sampled resulting in 52 items recorded (5200 ± 4266.2 items.km^{-2}), weighing 13.74g (1.37 ± 1.89 kg.km^{-2}). Plastic items were the most abundant (98.1%). Only one non-plastic item was retrieved from the neuston net (i.e. a paper cigarette pack). The type of items most abundantly retrieved from the gyre samples were plastic fragments (88.5%). The plastic category is further complemented with a piece of monofilament, a sweet packet, a resin pellet and a bottle cap.

After this first campaign, 12 new sampling locations were visited. During the first sampling period (February 2011) a total of 102 items were recorded, weighing a total of only 1.51g. This corresponds to an average of 4250 ± 3333.7 items.km^{-2} (range 500 to 13,000 items.km^{-2}), or 62.8 ± 62.5 g.km^{-2} (range 1.32 ± 113.7 g.km^{-2}). In total four different categories of debris were recorded, with plastics being most abundant (97.1%). Of these plastic items, half was monofilament line (49.5%), fragments made up 36.4% of all plastic items. Cloth (piece of rope), rubber (rubber band) and a medical item (band aid) were the other categories items found in these samples.

In July 2011, 84 items weighing 10.74g were recorded in the neuston trawls at all 12 locations. On average, 3500 ± 2022.6 items.km^{-2} were recorded, ranging from 1000 to 9000 items per km². In terms of weight, this corresponds to an average weight of 447.5 ± 1163.1 g per km². Again, plastic items were most abundant, with 94.1% of all items. Most abundant item type was plastic fragments (50.6% of plastic items), sweet packets were second with 13.9% of all plastics items. Three other categories were recovered from the neuston samples: paper (2 fragments), metal (2 pieces of foil wrapper, and one sanitary item (cotton bud stick).

Collected floating debris was subsequently categorised according to size, more specifically this categorisation was based on the largest dimension. Five different size classes were created: <1cm; 1 – 2.5cm; >2.5 – 5cm; >5 – 10cm; >10cm.
Most abundant were items belonging to the smallest size class, this was consistent through all sampling campaigns (Figure 13). Samples taken from the three gyres (September 2010) consisted for 90.2% of items smaller than 1cm. The other size classes only represented 2 – 3.9% of all items. In February 2011 the distribution of items in the five size classes was more uniform: 37.4% <1cm, and 14.2% to 16.2% for the other size classes. Later that year, in July, items smaller than 1cm increased again in number: 59.5% of items belonged to this size class. 1 – 2.5cm represented 10.7% of items, while >2.5 – 5cm made up 14.3%. The two largest size classes comprise 6.0% and 9.5%.

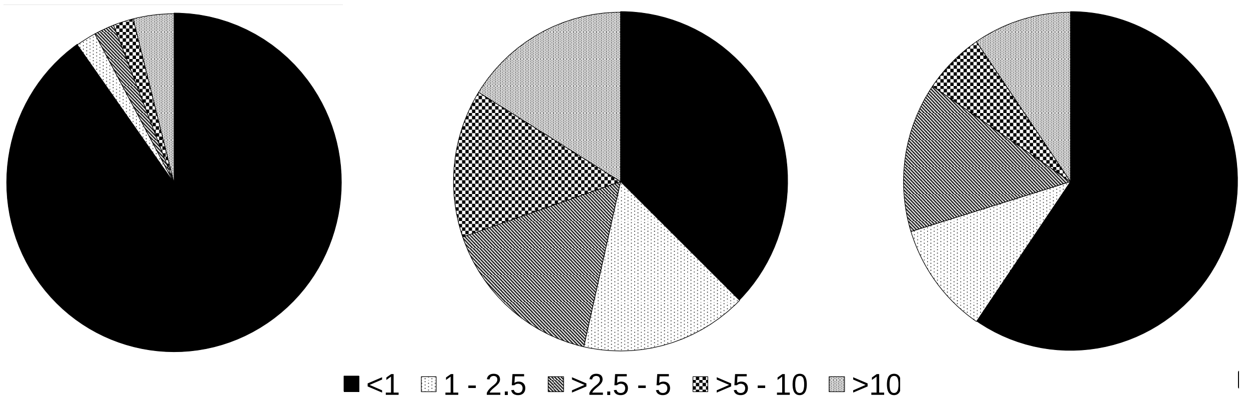

Figure 13: Size distribution of items retrieved from neuston samples. Left: Sampling campaign September 2010 (90.2% in the smallest size class). Middle: Sampling campaign February 2011 (37.4% in the smallest size class). Right: Sampling campaign July 2011 (59.5% in the smallest size class).

2.2.3.3 Discussion

In the visual study, the density of floating debris was 0.66 items per km² of which 0.53 items.km^{-2} were plastic litter. When comparing this to densities of seabirds, it shows that there was almost as many debris particles floating around at the Belgian marine waters as Razorbills and as many plastic items as Common Scoters (Razorbill and Common Scoter density respectively 0.67 ind.km^{-2} and 0.53 ind.km^{-2} at the BPNS during 1992-2008; Vanermen & Stienen 2009). Our study shows that floating litter can easily be counted with the ship-based surveys and can be combined with surveys of seabirds. The problem is that the link with plastic ingestion by seabirds is weak as even the smallest parts detected during visual surveys are too large to be ingested by the seabirds.

However these parts are keen to degrade and brake up into smaller pieces and can thereafter be ingested (Laist 1987), which is reflected by the large amount of users plastic in stomachs of Fulmars. But also larger parts are sometimes ingested by seabirds. In a stomach of a Northern Fulmar a piece of a party balloon was recovered and the ribbons from the balloons entangle the Fulmars (van Franeker, 2008). Party balloons were namely the third most observed litter item (10% of all plastic detected). Furthermore the monitoring of beached seabirds shows that litter at the sea surface can directly cause death/injury of marine wildlife.

During the first neuston campaign, sampling three gyres yielded a concentration of 5200 $\pm$ 4266.2 items.km^{-2}. This is quite high when compared to internationally reported values on floating marine debris (Table VIII). Since it seemed like these gyres did not accumulate floating marine debris, it was decided to discard them as sampling locations and 12 new sampling stations were created. Sampling more locations than only the three gyres, would also give a more complete representation of the Belgian part of the North Sea.
Sampling these new locations yielded a average debris concentration of 4250 $\pm$ 3333.7 items per km^2. This over 6000 times the density recorded during the visual study (§ 2.2.3.1)! This can be explained by the fact that visual surveys will only record items that are large enough to be visible for the surveyor on board the research vessel. Figure 13 shows that the majority of items retrieved from the neuston samples were items smaller than 1cm. Since these items are almost impossible to spot from a distance, the densities recorded during the visual survey and the neuston net trawl differ considerably.

Table VIII: The density and most abundant size class of floating debris in regions worldwide.

Region	**Density (items.km^{-2})**	**Most abundant size class**	**Reference**
Chile	17	/	Thiel et al, 2003
Southern Chile	19.3	/	Hinojosa & Thiel, 2009
North Atlantic Gyre	7758.7*	<1cm	Law et al, 2010
Northeast Pacific	9599.9*	<0.25mm	Doyle et al, 2011
Northern South China Sea	4.9	<10cm	Zhou et al, 2011

* Only density of plastic items recorded.

When comparing the size class distributions from the three different sampling campaigns (Figure 13), the smallest size class is always makes up the largest part of the distribution. However, there are some striking differences between campaigns. In September 2010 over 90% of all particles were smaller than 1cm, while in February 2011 only 37% were. A few months later, in July, 60% of items again belonged to the

smallest class. An explanation for this variation can be found in the types of items retrieved during each campaign. In September 2010 and July 2011, 88.5% and 50.6% of all items retrieved were plastic fragments and with the exception of 6 (on a total of 122) were larger than 1cm. In February 2010, items <1cm declined to only 37.4% of all items, due to the presence of a large number of pieces of monofilament line. In this period, 48% of all items were monofilament lines. Assigning items to the different size classes was based on the largest dimension of a item. Monofilament line is very thin (<1mm), but since most of the pieces were long (up to 1m), they were assigned to the larger sizes classes. This resulted in a shift towards the more larger size classes.
The type of items present in the neuston net trawl and their size also provide an explanation for the low average weight recorded for floating debris. An average, only 255.17 ± 829.11 g.km^{-2} was recorded. Since most of the items were fragments smaller than 1cm (often even smaller than 0.5cm), their weight was also very low, only a few milligrams or less. Pieces of monofilament line may give the impression that large items are present (because of their length), but since they are so thin, their weight is also very low. And finally, the material also plays an important role: the majority of the items retrieved were plastic, and one of the characteristics that make plastic so suitable for everyday use, is its light weight (Derraik, 2002).

2.3 Impact/effect assessment

2.3.1 Impact/effects of macrolitter

Stomach content data were collected from 2002 to 2006. 174 beached Northern Fulmars *Fulmaris glacialis* (Table IX) were collected during the winter beached bird surveys (BBS). The Fulmars were transported to the lab and frozen until the yearly dissection sessions at IMARES, Texel. Stomach analysis was performed by Dr. Jan-Andries van Franker of IMARES. When both the proventriculus and the ventriculus were present, the stomach was opened and the plastic items were removed and classified into two categories:

i. user plastics (sheets, threads, foamed, hard fragments or other types) and
ii. industrial pellets, which are small roundish plastic pellets of raw plastic

For each stomach, the incidence (presence or absence of plastic), the number of items and the weight per category were recorded.

Table IX: Number of beached Northern Fulmars sampled from 2002 to 2006 on the Belgian coast during the BBS.

Year	Sample size
2002	1
2003	21
2004	97
2005	44
2006	11
Total	**174**

In accordance with van Franeker et al. (2004) geometrical mean mass of plastics was used for statistical analysis because the mean mass often suffers from extreme values due to a few stomachs with a lot of plastic. The geometrical mean mass is calculated as the average of the logit-transformed data, which was back-transformed to a normal figure by taking its exponential value and subtracting 1 for numbers of items or 0.001 for mass of items.

The proportion of birds with more than 0.1 gram of plastic in their stomach was calculated as this figure reflects the degree of plastic pollution as set by OSPAR. The OSPAR's Ecological Quality Objective (EcoQO) is that less than 10% of the Fulmars exceeds this 0.1 gram to define the North Sea as clean.

Entanglement data were collected from 1992 to 2010. During winter months (October to March), regular beached birds surveys (BBS) were conducted along the entire Belgian coast. If possible all birds found during the monthly counts were identified to the species level and the degree of decay and obvious signs of death were noted (oil, entanglement, shot wounds etc.). If the beached bird was entangled, the type of entanglement was noticed with special attention to the fishing gear. The data is stored in a database that is hosted at the Research Institute for Nature and Forest and was analysed for the As-Made project.

2.3.1.1 Analysis of stomach content data

No less than 95% of the 174 dissected Northern Fulmars had some kind of plastic in their stomachs. When distinguishing between the two types of plastics, 56% of the birds contained industrial pellets and 94% had user plastics in their stomachs. On average Fulmars had 48.2 pieces in their stomachs (industrial pellets: 2.7 pieces per stomach and user plastics: 45.5 pieces per stomach).

On average the dissected Fulmars were loaded with 0.086 g of plastic (user + industrial, 2002-2006) with a maximum in 2003 of 0.130 grams. Expressed in grams, the Fulmars contained more user plastic (0.058 grams) than industrial pellets (0.009 grams), with maxima in 2003 for both plastic types (user: 0.077 grams; industrial: 0.013 grams) (Figure 14). Note that the sum of the geometrical mean mass (GMM) of user and industrial plastics is not the same as the GMM of all plastics because it integrates the single sample of 2002 and even more important because the GMM reduces the effect of extreme values.

On average 51% of the Fulmars had more than 0.1 gram of plastic in their stomachs (Figure 15). There seems to be a decrease in time of the Fulmars loaded with more than 0.1 gram of plastic, but no conclusions on trends can be taken yet because of the short duration of this research.

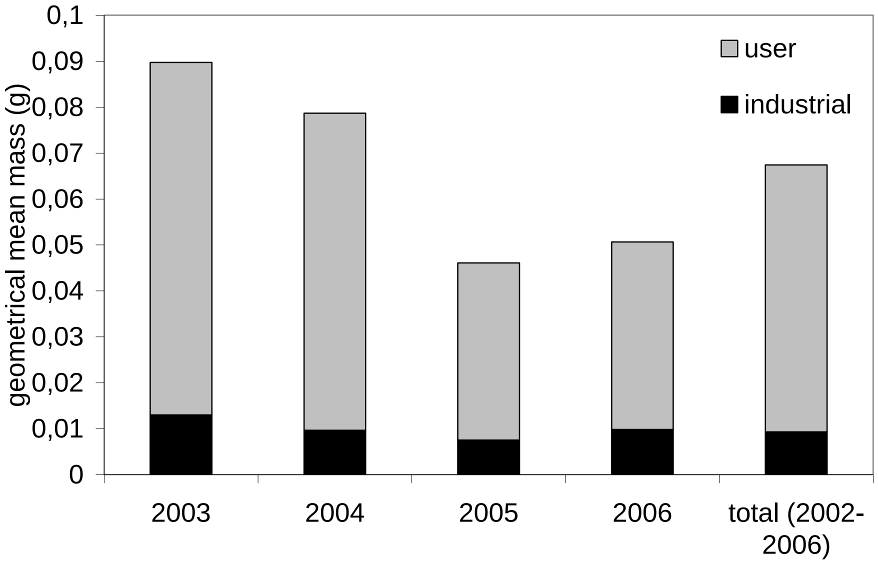

Figure 14: Geometrical mean mass of the user and industrial plastics from 2003 to 2006. On average (2002 – 2006) an individual Fulmar was loaded with 0.058 grams of user plastics and 0.009 grams of industrial pellets.

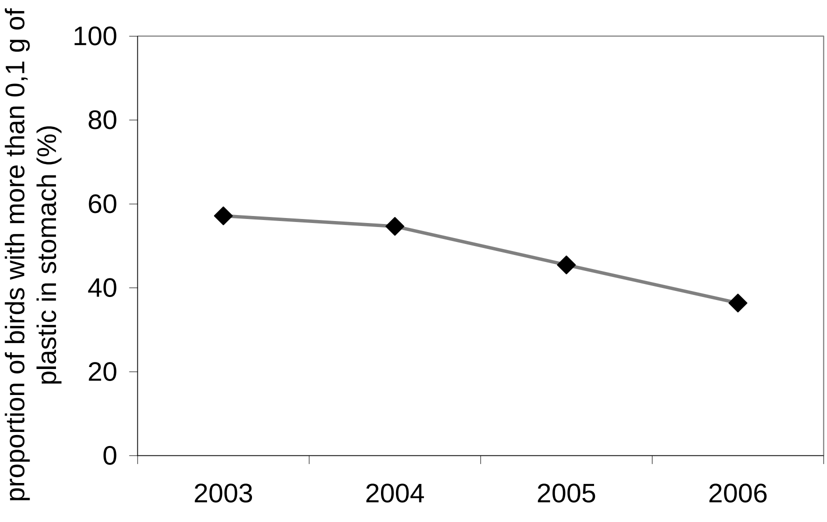

Figure 15: Proportion of Fulmars with more than 0.1 gram of plastics in their stomachs. On average 51% of the birds were above the level of 0.1 gram.

2.3.1.2 Analysis of entanglement data

10,260 beached birds divided over 103 species were counted during the BBS since 1992 on the Belgian coast (Figure 16). More than one third of the beached birds found were Alcidae (36.3%) (Common Guillemots *Uria aalge* 29.2%, Razorbill *Alca torda* 5.6% and other/undetermined alcids 1.5%). Gulls represent a little less than one third of the beached birds (28.5%) (Herring Gulls *Larus argentatus* 11.2%, Black-legged Kittiwake *Rissa tridactyla* 6.1%, Black-headed Gull *Chroicocephalus ridibundus* 4.5% and other gulls 6.7%). The Northern Fulmar (*Fulmarus glacialis*) represents 6.9% of the findings.

Only 0.6% of the beached birds were found entangled (N=56), belonging to 13 different species. Northern Gannets (*Morus bassanus*) compose more than one fourth of the entangled birds (Figure 17).

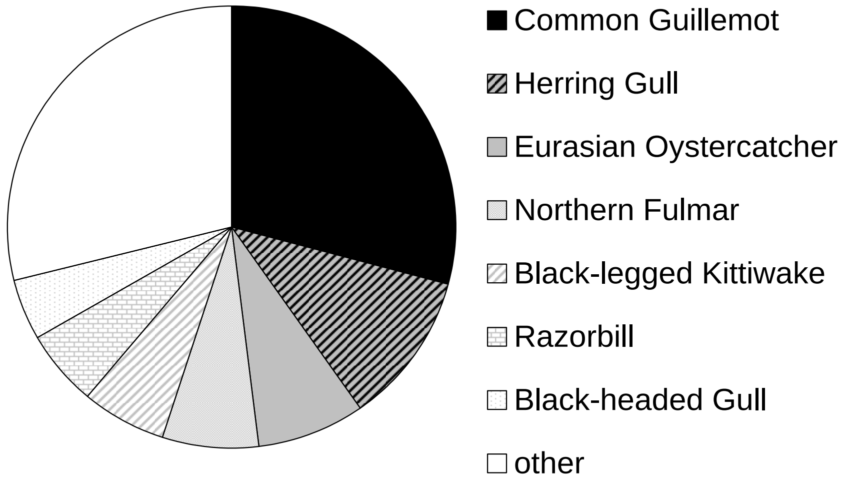

Figure 16: Species composition of the 10,260 birds beached on the Belgian coast from 1992 to 2010. Auks and Gulls were the main families found and represented each about one third of beached birds.

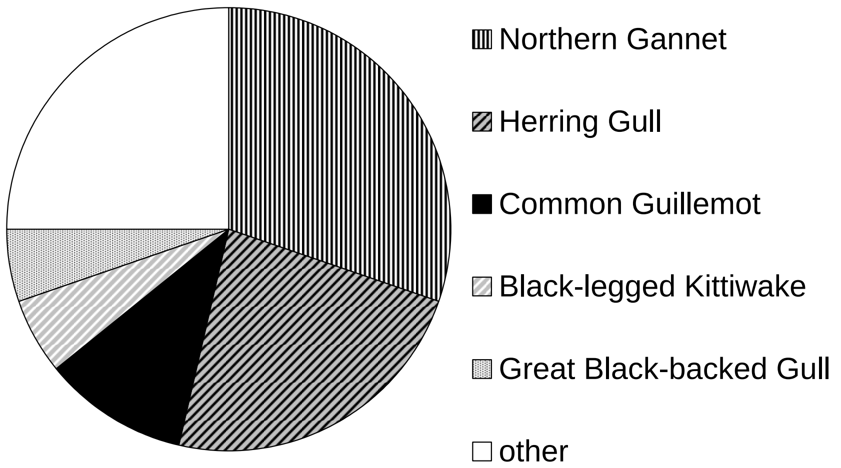

Figure 17: Species composition of the 56 birds found beached and entangled on the Belgian coast from 1992 to 2010. The Northern Gannet was the main species retrieved entangled.

Having a closer look at the sensitivity to entanglement (i.e. the percentage of a certain species found entangled), Northern Gannets pop out again (Table X). Out of the 13 species found entangled about half of them are deep diving seabirds (marked with * in Table X), namely: Northern Gannet, Great cormorant, Red-throated Diver, Common Guillemot, Great-crested Grebe and Razorbill.

The birds were essentially entangled in fishery gear with rope, lining and net consisting more than half of the entanglements (Figure 18). Birds were also found entangled in six-pack rings, plastic bags, sheets and plastic cups.

Table X: Sensitivity to entanglement: percentage of beached birds found entangled of a certain species. The Northern Gannet was the most sensitive in the Belgian case. Half of the birds found were deep-diving species (*).

Species	**Number of beached birds**	**Number of entangled birds**	**Percentage of beached individuals that were found entangled**
Northern Gannet*	189	17	9%
Brent Goose	16	1	6.5%
Great Cormorant*	33	1	3%
Red-throated diver*	67	1	1.5%
Great Black-backed Gull	240	3	1.3%
Herring Gull	1148	13	1.1%
Lesser Black-backed Gull	186	2	1.1%
Common Guillemot*	2994	6	<1%
Black-legged Kittiwake	623	3	
Great Crested Grebe*	306	3	
Northern Fulmar	713	3	
Razorbill*	572	2	
Eurasian Oystercatcher	788	1	
Other species	2385		
Total	**10260**	**56**	**0.6%**

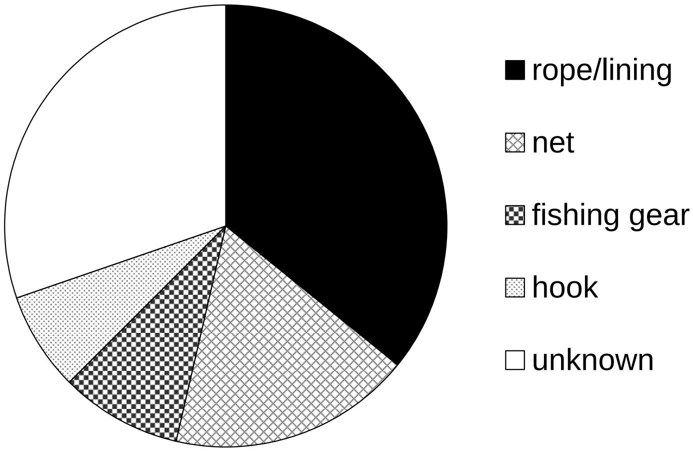

Figure 18: Types of entanglement: fishing gear was the type affecting the most entangled birds.

2.3.1.3 Discussion

If comparing the percentage of beached birds retrieved entangled (0.6% in Belgium) this figure is twice as high as in the Netherlands during the period 2008-2009 (Camphuysen 2009) and even three times higher than in the Netherlands during the period 1970-2007 (Camphuysen 2008a; compare Table XI), suggesting that the problem is more pronounced in Belgium. Particularly high incidences of entanglement were found in Northern Gannets (9.0%). Schrey and Vauk (1987) report even higher proportions in Germany between 1976 and 1985, where 13 % was entangled.

Table XI: Sensitivity to entanglement comparison between this study, Camphuysen (2009) and Camphuysen (2008). The sensitivity is expressed as the percentage of entanglement (%ent.) of beached birds (Nbeach.) of a certain species. The Northern Gannet is the most impacted by entanglement in all studies as well as the other deep-diving birds (*).

Study		**THIS STUDY**		**Camphuysen 2009**		**Camphuysen 2008**	
Monitoring period		1992 – 2010 (oct – march)		2008 - 2009		1970 - 2007	
Species		%ent	Nbeach.	%ent	Nbeach.	%ent	Nbeach.
Northern Gannet*	*Morus bassanus*	9.0%	189	4%	50	6.5%	6.5%
Brent Goose	*Branta bernicla*	6.5%	16	-	10	-	-
Great Cormorant*	*Phalacrocorax carbo*	3.0%	33	3.1%	65	1.1%	1.1%
Red-throated diver*	*Gavia stellata*	1.5%	67	100%	1	0.9%	0.9%
Great Black-backed Gull	*Larus marinus*	1.3%	240	1.7%	60	1.1%	1.1%
Herring Gull	*Larus argentatus*	1.1%	1,148	0.2%	519	0.6%	0.6%
Lesser Black-backed Gull	*Larus fuscus*	1.1%	186	-	91	0.3%	0.3%
Common Guillemot*	*Uria aalge*	0.2%	2,994	-	136	0.1%	0.1%
Black-legged Kittiwake	*Rissa tridactyla*	0.5%	623	-	44	0.1%	0.1%
Great Crested Grebe*	*Podiceps cristatus*	1.0%	306	2.3%	27	0.3%	0.3%
Northern Fulmar	*Fulmarus glacialis*	0.4%	713	-	23	0.2%	0.2%
Razorbill*	*Alca torda*	0.3%	572	-	16	-	-

Eurasian Oystercatcher	*Haematopus ostralegus*	0.1%	788	-	241	0.1%	0.1%
Eider	*Somateria molissima*	-	-	-	617	0.2%	0.2%
Black headed gull	*Larus ridibundus*	-	-	-	303	0.2%	0.2%
Common gull	*Larus canus*	-	-	-	101	0.2%	0.2%
Merganser	*Mergus serrator*	-	-	-	0	0.6%	0.6%
Common shag*	*Phalacrocorax aristotelis*	-	-	100%	1	-	-
Total		**0.6%**	**10,260**	**0.3%**	**2,830**	**0.2%**	**215,347**

Plastic in Northern Fulmars has been recorded since the 1970s (Day 1980) when it was found in 57.9% (N = 38) of the birds collected in the Subarctic North Pacific. In the late 1980s in the same region, the plastic occurrence in Fulmar stomachs had apparently increased to 84.2% (N = 19) (Robards et al. 1995). Between 1975 and 1989, 44 Fulmars were shot in the Western North Atlantic, 86.4% of them contained plastic (Moser & Lee 1992). Three drowned Fulmars recovered from a driftnet in august 1987 in the Eastern North Pacific, had all a stomach loaded with plastic (Blight & Burger 1997). If looking at the European situation van Franeker et al. (2004) described the stomach content of Northern Fulmars beached in the Netherlands: in several years since 1982 all the birds contained plastic (1982, 1983, 1985,1988, 1989,1991,1995, 1996 and 2000). Even if the examples used here are from different regions there seem to be a general and strong increase in incidence of plastic ingestion by Fulmars since the 1970s (Figure 19). The detailed study of van Franeker et al. (2004) showed that there is no apparent change in the occurrence of plastics in Northern Fulmars found in the Netherlands between 1982 and 2003, with 95% of the Dutch birds collected in 2003 (N = 39) containing plastic and with a peak in 1997-1999. Our results showing an incidence of 95% is coherent with van Franeker et al (2004).

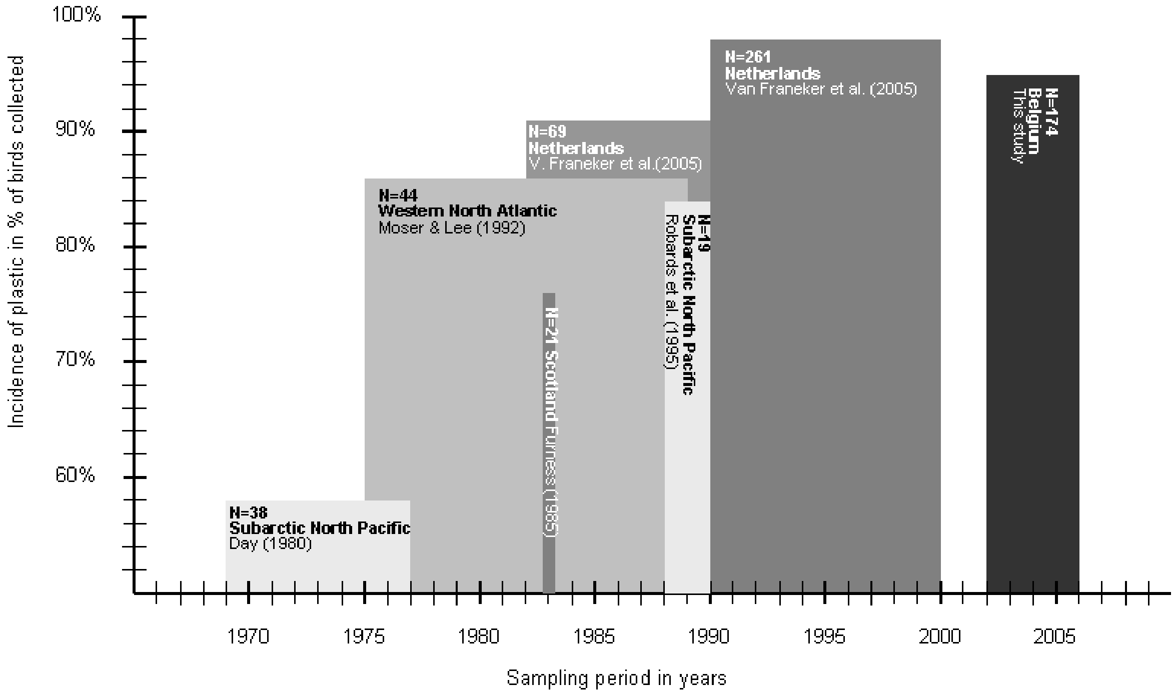

Figure 19: Incidence of plastic (% of individuals that contained plastic) in Fulmars from the period 1969 to 2006. Less than 60% of the Fulmars ingested plastic in the 1970s (Day 1980); this percentage increases heavily to get above 90% in the late 1980s – 1990s (van Franeker et al. (2005) and our study).

Van Franeker (1985) reported that in the early 1980s on average twelve pieces of plastics were found in Dutch Fulmars, with user and industrial pieces occurring in equal numbers. This situation was confirmed by Moser & Lee (1992) in the Western North Atlantic and Blight & Burger (1997) in the Eastern North Pacific. In the late 1980s Robards et al. (1995) described the stomach content of Fulmars in the Subarctic North Pacific with slightly more user plastics (± 60% of all items) than industrial. The Fulmars of this study contained almost 50 pieces of plastic on average with industrial pellets only representing 6% (or 3 pellets) of the total number of plastic items in the stomach. The decrease of industrial pellets in the Fulmars stomach mirrors the situation in the environment where the amount of industrial pellets is also diminishing (Ryan et al. 2009, van Franeker et al. 2004). The numerical decrease in industrial plastics is fully countered by an enormous increase of user debris ingested by Northern Fulmars (van Franeker et al. 2004, van Franeker et al. 2005).

If comparing the GMM of plastic in birds found in Belgium with those found in other parts of Europe, the Belgian situation is amongst the highly polluted areas (Figure 20). The only areas where Fulmars had less of both types of plastic were the Faeroes and the Scottish Isles. van Franeker et al. (2005) supposed a high incidence in the south-eastern North Sea due to the high shipping density in the English Channel.

In Belgium 51% of the Fulmars had more than 0.1 gram of plastic in their stomachs, being way above the level of 10% fixed to qualify the North Sea as clean (Ospar Ecological Quality Objective). However, presently this objective is not even met by the Faeroes which is supposed to be the reference - zero pollution – area (Figure 21).

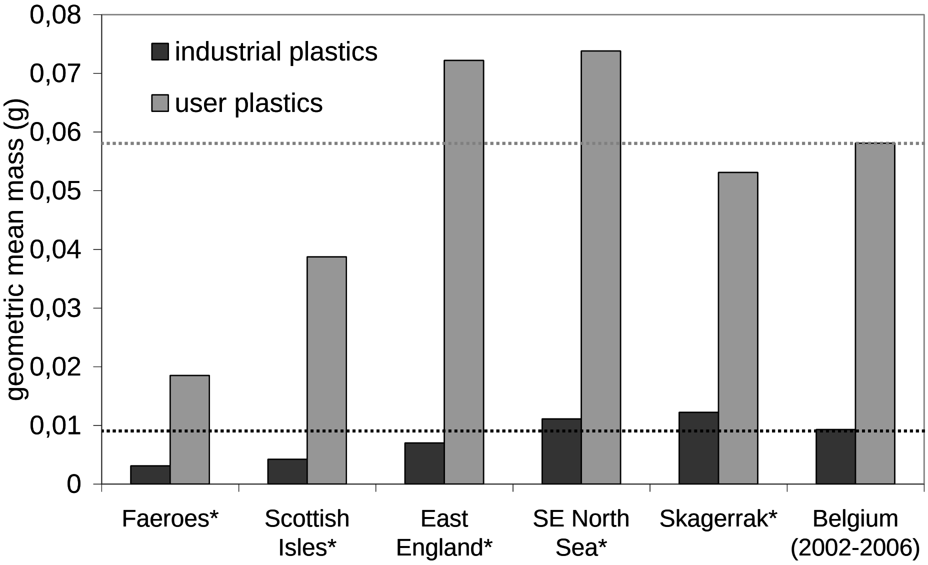

Figure 20: Geometrical mean mass of user plastics and industrial pellets in the North Sea. The data with a * originates from IMARES (van Franeker et al. 2005); the SE North Sea region is inclusive Belgium. Belgian fulmars were loaded with industrial plastic than those from East England, the Scottish Isles and the Faeroes. The fulmars from East England had more user plastic than the Belgian Fulmars.

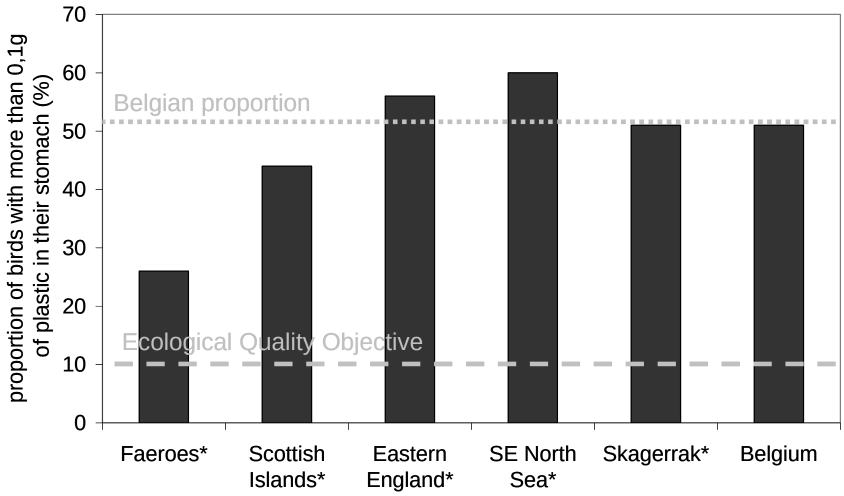

Figure 21: Proportion of Fulmars (%) with more than 0.1 grams of plastic in their stomachs. The data with a * originates from IMARES (Van Franeker et al. 2005), the SE North Sea region is inclusive Belgium. The EcoQO being 10%, even the Faeroes (supposed to be the 0% area) were above that level, with 26% of the birds having more than 0.1grams. Twice as many Fulmars (51%) were above the critical level in Belgium than in the Faeroes.

2.3.2 Impact/effects of microlitter

Laboratory experiments were conducted to examine the possible effects of microplastics on marine invertebrates. Two model species were used: the blue mussel *Mytilus edulis*, as a representative of a filter feeding species (filtering plankton from the water column), and the lugworm *Arenicola marina,* as a representative of a benthic species feeding on food associated with sediment particles. In a series of separate laboratory experiments it was assessed whether:

i. these model species take up and accumulate microplastics;
ii. these microplastics affect the health of the organisms;
iii. microcontaminants (e.g. persistent organic pollutants) adsorbed to the microplastics are transferred to (and affect) the organisms.

Short-term experiments (14 days) were performed at high particle concentrations (110 particles.mL^{-1}), with mussels and lugworms exposed to different sizes of polystyrene spheres, more specifically 10, 30 and 90μm diameter. These spheres are commercially available, already in suspension.
After exposure to the particles, uptake and accumulation were studied. Uptake or ingestion of the microplastics was examined by microscopic analysis of the faeces of the exposed organisms. Accumulation or translocation (transport of ingested particles to the tissue of the organisms) was studied by microscopic analysis of hemolymph/coelom fluid samples and acid destructed tissue. The possible adverse effects on both model organisms were evaluated by assessing physiological responses (sub-organismal endpoint: e.g. cellular energy allocation) and behavioural responses (organismal endpoint: e.g. time for burying in *A. marina*).

After these studies, more experiments were planned to investigate whether PAHs absorbed by microplastics can be transferred to the organism and whether this causes any adverse effect. To this end, mussels (and lugworms) will be exposed to microplastics in four different scenarios:

i. exposure to uncontaminated plastics in a clean environment;
ii. exposure to contaminated plastics in a clean environment;
iii. exposure to contaminated plastics in a contaminated environment;
iv. exposure to uncontaminated plastics in a contaminated environment.

These exposure scenarios will allow the assessment of the relative contribution of contaminants absorbed on microplastics to the effects caused by the contaminants already present in a contaminated environment.
Possible biotransfer from the microplastics to the test organisms will be assessed through tissue analysis using GC-MS. The effects will be quantified by determining EROD-activity.

These experiments have not been completed yet, since some issues arose with the protocol for the EROD-biomarker. These are still being dealt with.

2.3.2.1 Effects on *Arenicola marina*

Lugworms ingested the microplastics while feeding: on average 43.3 ± 16.1 particles were found per gram faeces. Performing microscopic analysis on destructed tissues showed that part of the ingested particles translocates to the tissue: on average 19.9 ± 4.1 particles were detected per destructed worm (Figure 22). While particles of all sizes (i.e. 10, 30 and 90μm) were present in the faeces of the exposed animals, only the smaller particles were detected in the tissue and coelom samples. 10μm-particles were present in the tissue and circulatory system of a lugworms at 18.8 ± 4.2 particles per worm. 30μm-particles, however, were present in much smaller quantities: only 1.1 ± 0.9 particles per worm.

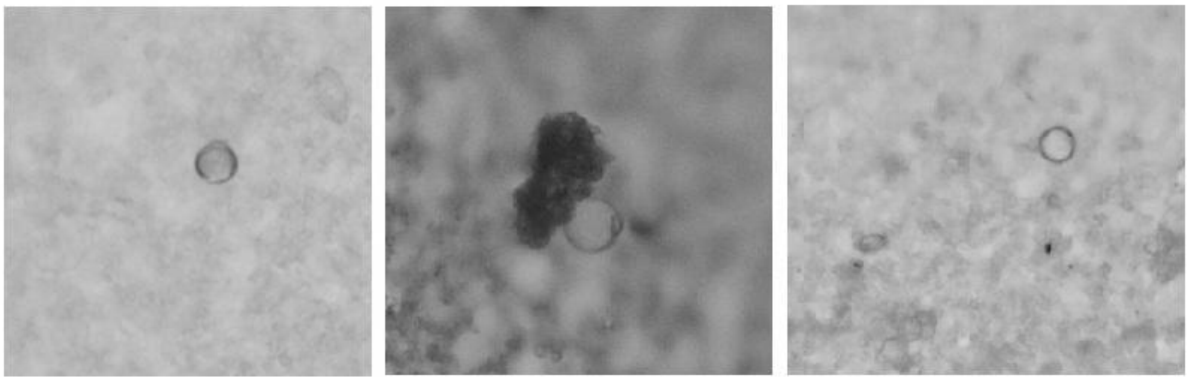

Figure 22: Examples of 10μm particles retrieved from tissue of exposed animals.

Concerning the effects of this ingestion and translocation, no significant effects were observed.

The results of the biomarker analysis (sub-organismal endpoint) are represented in Table XII. Cellular Energy Allocation (De Coen & Janssen, 1997) comprises several measurements to determine the energy available (protein, carbohydrate and lipid content) and energy consumed (electron transport system (ETS)), to ultimately calculate the energy reserve – energy consumption ratio, also known as *time to survive*. Exposure to microplastics only resulted in a significant increase in protein content of lugworms. However, looking at the energy reserve – energy consumption ratio (time to survive in Table XII), this increase in protein content did not result in an overall significant difference between exposed and control organisms.

The behavioural assay executed on the lugworm involved the measurement of the time needed by the animals to burry themselves in the sediment. This was measured at the start of the experiment (day 1) and halfway (day 8) when the sediment the lugworms were kept in was replaced. Results of the statistical analysis of the measured burial time are represented in Table XIII.

Table XII: Results of the statistical analysis (Wilcoxon-Mann-Whitney test) of the biomarker Cellular Energy Allocation, for the lugworm *Arenicola marina* (Control N=7; Exposed N=9) (* is significant).

	Control ± SD	**Exposed ± SD**	**Z-Statistic**	**p-value**
Proteins ($kJ.g^{-1}$ tissue)	0.595 ± 0.082	0.700 ± 0.069	-2.2229	0.0131*
Carbohydrates ($kJ.g^{-1}$ tissue)	0.011 ± 0.005	0.010 ± 0.003	0.1059	0.4579
Lipids ($kJ.g^{-1}$ tissue)	0.278 ± 0.023	0.297 ± 0.025	-1.1644	0.1221
ETS ($kJ.h^{-1}$ g^{-1} tissue)	$6.71\ 10^{-6}$ ± $7.26\ 10^{-7}$	$6.71\ 10^{-6}$ ± $8.74\ 10^{-7}$	0.5293	0.2983
Time to survive (h)	**150.0 ± 29.4**	**167.7 ± 28.6**	**-1.4819**	**0.0692**

Table XIII: Results of the statistical analysis (Wilcoxon-Mann-Whitney test) of burial time for the lugworm *Arenicola marina* (Control N=9; Exposed N=19)

	Control ± SD	**Exposed ± SD**	**Z-Statistic**	**p-value**
Day 1 (s)	164.6 ± 35.3	143.9 ± 35.8	1.2792	0.1004
Day 8 (s)	135.2 ± 75.6	113.3 ± 36.0	0.3937	0.3469
Day 8 – Day 1 (s)	-29.3 ± 56.7	-30.6 ± 43.8	-0.7628	0.2228

2.3.2.2 Effects on *Mytilus edulis*

With these experiments it was shown that the blue mussel (*M. edulis*) filters microplastics from the water column, and hence ingests them: on average 633.2 ± 111.2 particles were detected in the faeces produced by one mussel per day. Three different particle sizes (10, 30 and 90μm) were offered at a total concentration of 110 particles.mL^{-1}. Mussels did not discriminate between particle sizes, since it was noticed that all sizes disappeared at an equal rate from the water column and were eventually recovered from the faeces.

Microscopic analysis of destructed tissue showed that the ingested particles can actually translocate to the tissue of the mussel, be it only the smallest size particles (i.e. 10μm). More specifically 4.5 ± 0.9 particles were detected in the tissue of destructed mussels (Figure 22). Additional analysis of hemolymph samples showed that these particles can be translocated to the circulatory system of the exposed organism: for 100μl of hemolymph extracted 5.1 ± 1.1 microplastics were detected.

Effects of the ingestion and translocation to the tissue of the mussels was examined by analysing the Cellular Energy Translocation biomarker (see also § 3.3.2.1) and by quantifying the clearance rate, which the rate at which particles (algae) are filtered from the water column, i.e. the feeding rate of the mussels.

Mussels exposed to microplastics exhibited a significant increase of 25% in their energy consumption compared to the control organisms (Table XIV). However, this increase in metabolism wasn't accompanied by any other in- or decreases in the energy reserves, and hence no significant overall effect on the energy reserve – energy consumption ration, or time to survive, was detected (Table XIV).

Clearance rate, which is a measurement for the food intake of mussels, was measured on three different days. As can be noticed in Table XV, no significant differences exist between the clearance rate of exposed and control organisms on different days.

Table XIV: Results of the biomarker analysis (Cellular Energy Allocation) for the mussel *Mytilus edulis* (Control N = 15; Exposed N = 15) (Wilcoxon-Mann-Whitney test) (* is significant).

	Control ± SD	**Exposed ± SD**	**Z-Statistic**	**p-value**
Proteins ($kJ.g^{-1}$ gland)	0.655 ± 0.182	0.674 ± 0.206	-0.0415	0.4835
Carbohydrates ($kJ.g^{-1}$ gland)	0.134 ± 0.078	0.143 ± 0.093	0.0243	0.4903
Lipids ($kJ.g^{-1}$ gland)	3.518 ± 1.243	4.068 ± 1.499	0.8510	0.1974
ETS ($kJ.h^{-1}$ g^{-1} gland)	0.012 ± 0.004	0.015 ± 0.003	-3.1642	0.0008*
Time to survive (h)	**387.6 ± 146.7**	**328.2 ± 119.1**	**-1.1151**	**0.1324**

Table XV: Results of clearance rate measurements for the mussel *Mytilus edulis* (Control N = 5; Exposed N = 4) (Wilcoxon-Mann-Whitney test).

	Control ± SD	**Exposed ± SD**	**Z-statistic**	**p-value**
Day 0 ($L.h^{-1}$)	0.97 ± 0.11	1.13 ± 0.14	1.3472	0.0890
Day 14 ($L.h^{-1}$)	0.67 ± 0.30	0.69 ± 0.22	0.1225	0.4513
Day 14 – Day 0 ($L.h^{-1}$)	-0.30 ± 0.36	-0.45 ± 0.17	-0.1225	0.4513

2.3.2.3 Discussion

These experiments, performed on two marine organisms representing different feeding strategies, demonstrate that microplastics present in the water column and sediment can be ingested by the mussel (*Mytilus edulis*) and lugworm (*Arenicola marina*), respectively. Ingestion of microplastics has already been confirmed for an array of marine organisms (Table XVI). Translocation to the tissue of exposed organisms, however, has only been demonstrated once, by Browne et al (2008). They exposed *Mytilus edulis* to two sizes of polystyrene spheres (i.e. 3.0 and 9.6μm) at 43 particles of each per mL. After three days microplastics were found in the hemolymph and hemocytes. With these experiments, translocation of ingested microplastics to the circulatory system of mussels was confirmed and, for the first time ever, demonstrated for the polychaete *Arenicola marina*.

Translocation to the tissue of organims, however, is restricted by the size of the particles. As Browne et al (2008) already demonstrated, small particle sizes translocate to the circulatory system of mussels, but smaller 3.0μm particles occurred in consistently greater abundances (60% more) than the larger particles of 9.6μm. Mussels exposed to different sizes of microplastics in this experiment only had the smallest particles in their tissue and circulatory system. This particle size (i.e. 10μm) is comparable to the largest particle detected by Browne et al (2008) (i.e. 9.6μm). The size limit of particles able to be transported through the wall of the digestive tract of mussels hence is located between 10 and 30μm diameter. In contrast to mussels, particles of two sizes were detected in the tissue and coelom samples of lugworms. But, as with the mussels of Browne et al (2008), the smallest were present in greater abundances: 17 times more 10μm particles were detected compared to 30μm particles. The size limit for particles available for translocation to the tissue and circulatory system of lugworms seems to be larger than that for mussels, and is located between 30 and 90μm.

Table XVI: Experimentally demonstrated ingestion of microplastics by marine organisms of different phyla.

Organism	**Species**	**Particle size (μm)**	**Reference**
Copepod	*Acartia tonsa*	7 – 70	Wilson, 1973
Echinoderm larvae	*Dendraster excentricus* *Ophiopholis aculeata* *Dermasterias imbricata* *Parastichopus californicus*	10 – 20	Hart, 1994
Amphipod	*Orchestia gammarellus*	20 – 2,000	Thompson et al, 2004
Polychaete	*Arenicola marina*	3 – 9.6	Thompson et al, 2004
Barnacle	*Semibalanus balanoides*	3 – 9.6	Thompson et al, 2004
Bivalve	*Mytilus edulis*	3 – 9.6	Browne et al, 2008
Echinoderm	*Holothuria floridana* *Holothuria grisea* *Cucumaria frondosa* *Thyonella gemmata*	250 – 15,000	Graham & Thompson, 2009

The presence of microplastics in the circulatory system may pose a potential health risk to these organisms. By restricting the blood flow, damage to the vascular tissues and changes in cardiac activity may be induced. Different endpoints (sub-organismal and organismal) were tested to verify whether ingestion and translocation of microplastics had significant effects on the exposed animals.

For A*renicola marina* no significant effect was observed on the behaviour of exposed organisms (Table XIII). Time needed by lugworms to burry themselves is an ecologically relevant parameter, because by doing so they avoid predation and hence burying time is directly related to survival of the animal. No significant effect on burying time of exposure to microplastics was observed. Within both treatments (control and exposure to microplastics) there seemed to be an decrease in time needed for an animal to completely burry itself. In a previous study, burying time of lugworms in PAH and PCB contaminated sediments was tested (Morales-Caselles et al, 2009). They found a significant increase in burying time, suggesting a chemosensory response to the contamination. For contamination of sediments with microplastics, lugworms do not suffer physically, since they are still able to burry themselves quickly, and they do not 'sense' that the sediment is contaminated with microplastics, since there was no hesitance to burry themselves in the sediment.

Clearance rate, or feeding rate, in *Mytilus edulis* also showed no significant effect of exposure to microplastics (Table XV). Both control mussels and exposed mussels, however, showed a decrease in clearance rate over time. A decrease in clearance rate was previously observed in mussels that had high concentrations of contaminants, such as metals and PAHs, in their tissues (Wang, 2001; Toro at al, 2003). Also a sudden thermic shock will result in a decrease of the feeding rate in mussels (Cusson et al, 2005). Increased stress thus appears to decrease the clearance rate in mussels. Not the exposure to microplastics but the experiment itself seemed to result in stress for the animals, explaining the decrease in clearance rate observed with time.

Biomarkers are used to quantify the physiological response of organisms exposed to a specific stressor. When organisms inhabit a suboptimal environment, they will only be able to cope with this stress by investing part of the available energy in their survival. The remaining energy can than be used for growth. Determining the energy budgets of animals is hence an appropriate method for measuring the stress the organisms experience (Kooijman & Bedaux, 1996). Here, the energy reserves measured were proteins, lipids and carbohydrates, energy consumption was determined by measuring the electron transport system. Overall time to survive was measured as the energy reserve – energy consumption ratio. Exposed mussels showed an increased energy consumption compared to the control organisms (Table XIV). Simply put, animals exposed to microplastics burned up their energy faster, i.e. respired faster, than control organisms. Increased respiration can be linked, again, to increased stress. Organisms exposed to stress will try to cope with the metabolic cost of retaining a physiological balance by increasing their respiration (Smolders et al, 2002). This, however, was not observed in the measurements of the energy reserves: no significant decrease in proteins, lipids or carbohydrates was observed. As a consequence, no significant effect of exposure to microplastics on time to survive was observed.

Similarly, in the lugworm no overall adverse effect of exposure to microplastics was observed: time to survive between control and exposed animals did not differ significantly. What did however differ between treatments was the concentration of proteins per worm: exposed animals had higher concentrations of protein (Table XII). This is unexpected, since it was expected that under stressful conditions, energy reserves of exposed animals would drop. What could explain this unforeseen increase, is the production of stress protein in exposed worms, increasing the entire protein concentration (Smolders et al, 2003).

Even though the test organisms were exposed to very high concentrations of microplastics, over a thousand times the natural environmental concentrations, no significant adverse effects were observed. These experiments, however, were only short-term (14 days). In their natural environment mussels and lugworms will be exposed over their entire lifetime. Consequently, further research is still needed to examine the toxicological consequences of long-term exposure of organisms to microplastics. In addition, fragments of plastic found in marine habitats worldwide (Mato et al, 2001; Rios et al, 2007; Heskett et al, 2011) have shown high concentrations of persistent organic pollutants, such as PAHs, PCBs and DDT. Recent laboratory work has shown that sorption of phenanthrene to microscopic particles of polyethylene, polypropylene, and polyvinvylchloride was up to an order of magnitude higher than that to natural sediment (Teuten et al, 2007). Although the experiments performed in the context of the As-MADE project do not provide evidence for uptake of these chemicals sorbed to microplastics, they do show that ingested particles can translocate to the tissues and circulatory system of the exposed animals. Therefore, this could provide a possible route for transport of these contaminants to various tissues.

2.4 Financial impact assessment

Taking Hall's (2000) OSPAR project as a starting point, the methodology adapted here focuses on the economic impact of marine litter on human activities and uses a sector-based approach to investigate the increased costs and potential loss of revenue associated with marine litter for key industries. This approach does not include an evaluation of the economic cost of degradation of ecosystem goods and services due to marine litter. The findings presented in this report are therefore likely to significantly underestimate the total economic costs of marine litter (Mouat, 2010).

Marine litter can directly cause numerous economic impacts, particularly in terms of litter clearance and removal. Marine litter can also result in a wide range of indirect economic impacts, which are associated with the environmental, social, and public health and safety impacts of marine litter (Mouat, 2010). Estimating the full economic impact of marine litter is therefore complex as many impacts are challenging to quantify in economic terms.

As a result, "to date, very little information has been reported on the economic impacts of marine litter" (UNEP 2009b: 10) and Hall's (2000) project remains one of the few studies to investigate the economic cost of marine litter. During 2009-2010 a new estimation of the economic impact of marine litter was conducted by KIMO based on the approach adopted by Hall (Mouat 2010). The approach adopted by Hall focused on establishing how marine litter affected the economic value of human activities that relied upon a healthy marine environment.

In practice, this was applied in terms of the increased costs or potential loss of revenue incurred due to marine litter by various key industries. It was decided to follow a similar approach in this assessment for several reasons. Firstly, research focusing on the economic value of human activities has a strong theoretical basis and has been applied previously in a marine litter context. This approach was similarly attractive due to its relative simplicity and, as it is based on actual expenditure, the increased likelihood that data would be available.

Putting this approach into practice firstly involved identifying the key sectors of human activity that could be affected by marine litter. The sectors involved in this project are:

- Fisheries
- Harbours
- Marinas
- Municipalities
- Touristic organisations

Each sector was then assessed individually to determine how marine litter could affect them and the ways in which it could result in increased costs and/or a loss of revenue. The questionnaires developed by Hall were then adapted for each sector based on these issues to made them suitable for the Belgium situation and these were distributed to organisations along the Belgian coast. Questionnaires were identified as the most suitable method for collecting data as the project focused on a wide variety of sectors and persons.

2.4.1 Data collection

The project began in 2010 and was conducted over a 6 month period. The project focused on the Belgian coast and was carried out in conjunction with the network of the coordination centre on ICZM. The majority of questionnaires were sent out via post or email. The main project questionnaires were distributed in May 2010.

In total 134 questionnaires were distributed and Table XVII below shows how these were divided between the different sectors. Responses were received from a total of 26 individuals and organisations overall, which represents a 19.4% response rate on average.

Table XVII: Number of questionnaires send out and received

Sector	Number of questionnaires distributed	Responses
Tourism	11	4
Municipalities	11	4
Harbours and marinas	15	5
Fisheries	97	13
Total	134	26

2.4.2 Limitations

While the methodology adopted in other projects has largely been successful, it is important to acknowledge several key limitations. This approach can only provide a partial insight into the economic cost of marine litter because it excludes the economic cost of the environmental and social effects of marine litter from the analysis. Establishing the costs of marine litter is further complicated by a lack of data recording mechanism, which means that costs may often go unreported. The limited area en responses will only sketch a part of the true costs of marine litter.

2.4.3 Results

2.4.3.1 Municipalities

The principle economic impact of marine litter on municipalities is the cost of keeping beaches clean and free of litter. The costs associated with removing marine litter include the collection, transportation and disposal of litter as well as hidden costs such as contact management, program administration and volunteer time. A questionnaire was developed to find out more about beach cleansing activities and this was distributed to the local government organisation.

All municipalities remove marine litter from their coastline. They were asked to select the main reason(s) why they undertake beach cleans. Figure 23 shows that ensuring beaches are clean, attractive and safe for tourists are key priorities for municipalities and justify the cost of removing marine litter. Protecting tourism also appears to provide a powerful incentive for removing marine litter.

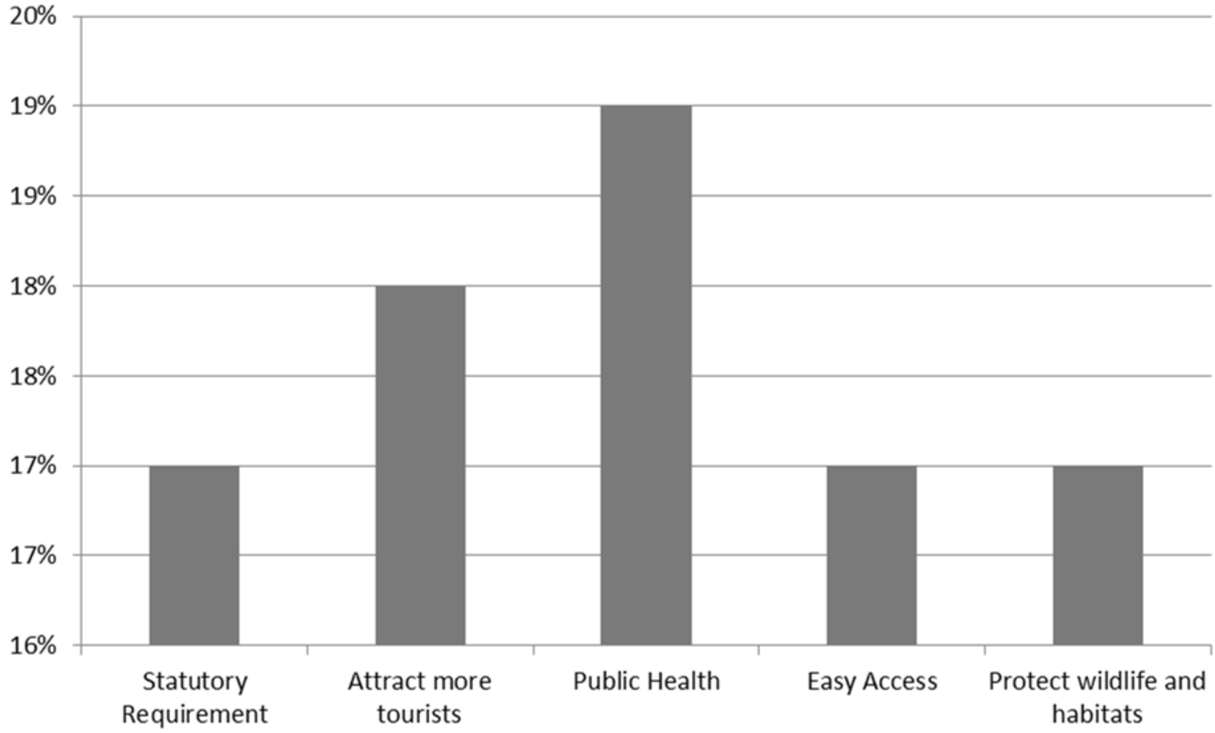

Figure 23: Reasons why municipalities undertake beach cleans.

Municipalities were asked to identify several key characteristics of the beaches they cleaned, and provide information about the methods and frequency at which clean ups occur.

All municipalities removed marine litter from high usage beaches. The majority of municipalities used a combination of manual and machinal cleaning methods. This was the case for 90% of participating municipalities. There is a high use of machinery for beach cleansing because the beaches are generally sandy in nature.

The frequency of clean-up operations often varied to match the season and this made it difficult to draw any conclusions in terms of how regularly clean ups occurred. Overall, most municipalities operated a variable cleaning regime, by removing litter on daily basis in summer and only when necessary in winter.

Municipalities found it more difficult to give details about the weight of litter they removed from their coastlines. The quantity of litter removed by one municipalities can go up to 88 ton in one summer season.

Litter bins are the most common prevention method. Two municipalities were also taking additional action to prevent litter such as:

- raising awareness by newsletters, talks, exhibitions, leaflets;
- providing specific recycling bins and facilities on beaches;
- tin can catcher;
- a clean beach-team called Beach Busters.

Only two municipalities were able to supply figures regarding the total cost of removing beach litter. No one was able to provide a breakdown of these costs. The total cost of beach litter removal reported was €89,000 with an average cost of €32,375 per municipality per year. 3 municipalities also reported that their beach cleaning costs had increased by an increase of the labour cost, increased disposal costs and the occurrence of a wider beach.

2.4.3.2 Harbours and marinas

Marinas and harbours make important contributions to many coastal communities by attracting tourists and generating income and employment. The primary economic impact of marine litter on harbours and marinas is the cost of removing marine litter in order to ensure that these facilities remain clean, safe and attractive for users.

All harbours and marinas surveyed took action to remove marine litter. The manual removing of marine litter tended to occur on a monthly basis from 1-5 hours per month to 10-15 hours per month. The majority of organisations spend between 1 and 5 hours per month manually removing marine litter. On average, this was part of the duty of 1 member of the staff in each harbour and marina.

To get an idea of the extent to which marine litter affects vessels, harbours and marinas were asked whether their users had experienced any incidents with marine debris over the last year. 80% of harbours and marinas reported that their users had experienced cases of fouled propellers, fouled anchors and blocked intake pipes and valves.
Fouled propellers were by far the most commonly reported type of incident with 80% of harbours and marinas stating that their users had experienced this type of incident. Harbours and marines most commonly reported between 1 and 15 fouled propellers among their users per year. The two marinas of Nieuwpoort reported between 11 and

15 fouled propellers. The most common types of marine litter causing fouled propellers are shown in Figure 24. Rope was the most frequently identified cause of fouled propellers with 80% of organisations reporting that this type of litter caused entangled propellers among their users. Nets and plastic were also identified as a cause by 60% of the organisations. These findings suggest that derelict fishing debris, such as ropes and nets, can pose high health and safety risks in the marine environment.

All harbours surveyed meet the EU Directive on Port Waste Reception Facilities (EC200/59) and encourage vessels to dispose of waste, particularly old ropes and nets, using harbour facilities. In total 80% of harbours have also set up recycling facilities for vessels' waste. The most common types of recycling facilities are for glass, paper, plastic, oil, batteries,...
60% of harbours and marinas give information to the users about dealing with litter at sea and in the marina. This is typically done through posters, letters and pamphlets. 80% of the marinas surveyed held some form of award. The most popular was the Blue Flag award, only one marine had participated in the Golden Anchor award scheme and held 5 Golden Anchors.

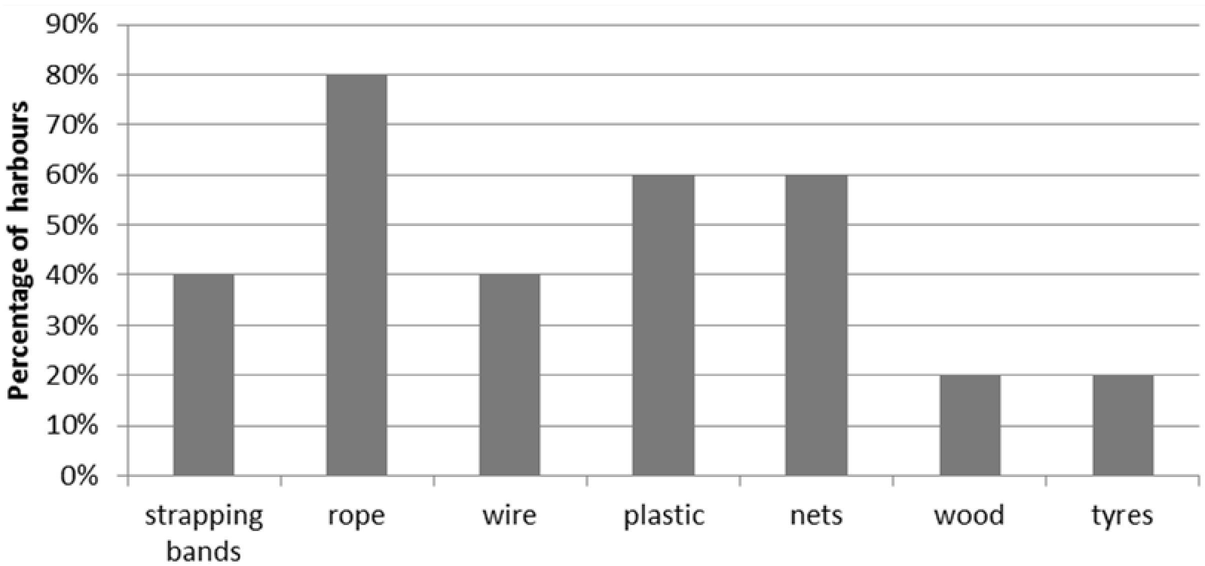

Figure 24: Commonly reported types of marine litter which cause fouled propellers.

The total cost of marine litter removal reported by the 6 harbours and marinas is €21,313 with an average of €4,262.6. The cost for removing marine litter varies between €250 and €10,000 per harbour per year. Based on this average, marine litter costs the ports and harbour industry more than €51,144 each year (calculated based on 12 ports and 3 harbours along the Belgian coast (Goffin et al, 2007)). The large difference in costs between harbours is in part due to the differing size and use of the marina's and harbours.

2.4.3.3 Sea fisheries

The fishing industry is often highlighted as a source of marine litter but less attention has been paid to the negative impact that marine litter has on fishing vessels. Marine litter affects the fishing industry in a variety of ways, which can result in both additional costs and reduced revenue for fishing vessels.

The vast majority of questionnaire responses received came from trawlers. The fishermen were asked to identify the types of litter that commonly accumulated in their nets. The most common types of litter was plastic and nets, with over 70% of fishermen experiencing these types of litter accumulating in their nets. Ropes and wood were also very common, with over 50% of fisherman finding these types of debris in their nets (Figure 25).
The fishermen were also asked to identify in which areas the changes on collecting litter are highest. 69% of the fisherman also identified that the risk on marine litter in their nets is bigger closer to the shore.

Various types of marine litter can also contaminate a vessels' catch resulting in the fish having to be dumped, additional costs to clean the vessels and equipment, and loss of fishing time. Approximately 31% of vessels surveyed had discarded fish due to contamination. This occurs between 1 to 4 times a year. Contamination is mostly caused by oil filters (23%) or paint (31%).

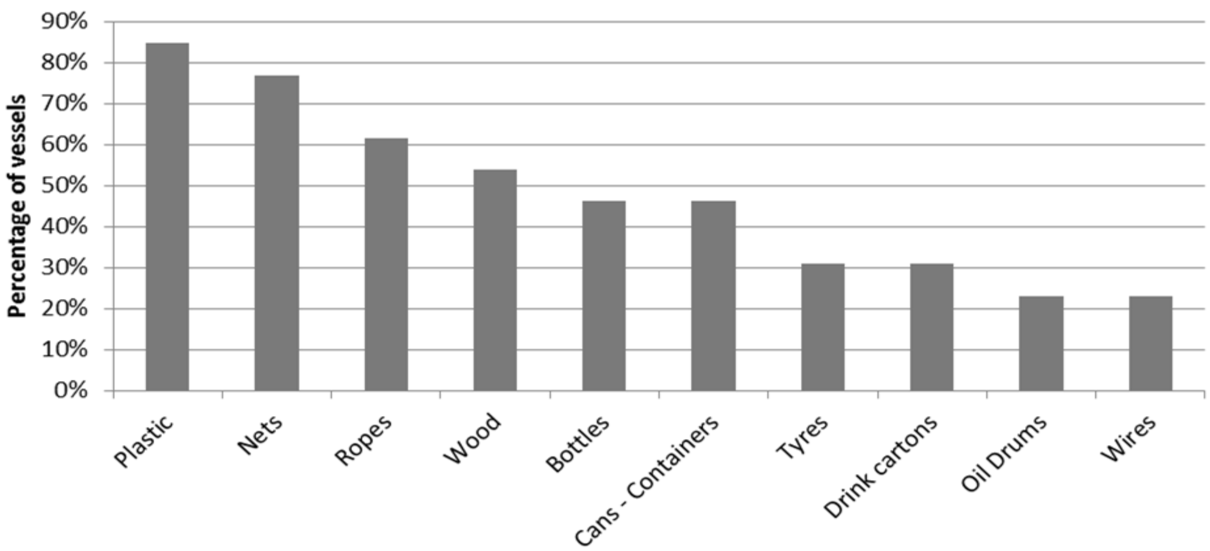

Figure 25: Types of debris most commonly retrieved in the nets of sea fisheries.

Marine litter can pose navigational hazards for fishing vessels and potentially result in vessel damage. The types of incidents involving marine litter include mainly fouled propellers: 62% of the responders reported that they have one or more fouled propellers per year. On average 2.25 fouled propellers were reported.

This project concentrated on the direct economic impact of marine litter on fishing vessels. This includes the overall cost of fouling incidents, calculated as the cost of a fouling incident as reported by each vessel, and the loss of earnings as a result of reduced fishing time due to clearing litter from nets, calculated using the average value of one hour fishing time as estimated by vessels surveyed during this project.

The loss of fishing time due to clearing nets of marine litter accounts for the majority of costs experienced by fishing vessels as result of marine litter. On average, each vessel spends 101.69 hours per year clearing litter from their nets, at a cost of approximately €22,779 per vessel per year. The average effect cost per fouling incidents is €471, but these costs do not take into account the loss of fishing time due to marine litter.

Based on these average figures, marine litter costs the fishing industry around €2.16 million each year. This is calculated using the average cost of marine litter per vessel and the number of vessels involved in fisheries. The number of vessels is based on the official list received from the 'Dienst Zeevisserij' on 20/03/2012. Within this number the value of dumped catch because of contamination and the cost of repairs to fishing gear and nets is not included.

Given the continuing restrictions on the number of days fishing vessels can spend at sea, the large amount of lost fishing time due to marine litter is an area of particular concern. In general only very few vessels received any assistance to cover costs incurred due to marine litter. Only 7% of vessels have claimed insurance for incidents involving marine litter, no one had claimed income support.

The fishing industry has adopted a number of positive measures to tackle marine litter and reduce its environmental impact. 46% of the respondents are referring to the Fishing for Litter scheme. Several fisherman suggest that the facilities to bring litter to the shore should be approved and should be free of charge.

Marine litter poses numerous issues for fishing vessels and there are number of actions the industry could take to reduce its own contribution to marine litter. Environmental awareness training incorporating marine litter issues could be implemented. Also the waste reception facilities could be improved and expanded.

3. POLICY SUPPORT

Results from this research project were and will be transferred to relevant policy makers at different levels and through various channels. Marine pollution is mainly regulated at the European scale, via the **Marine Strategy Framework Directive** (**Directive 2008/56/EC)** as part of the EU's Integrated Maritime Policy. Litter in the marine environment is one of the elements incorporated into the issue of 'Good Environmental Status' of the Marine Strategy Framework Directive. Colin Janssen is one of the **experts involved** in the **international Task Group** that reviewed relevant knowledge and provided advice on possible approaches to a **Good Environmental Status** in the context of marine litter (Galgani et al., 2010).

At the official launch in November 2011 of 'Waste Free Oceans – Belgium', a project from the plastics industry, supported by NGOs and politicians, Colin Janssen has presented the main findings of this project in a platform presentation. This was attended by **EU commissioner for fisheries and maritime affairs Maria Damanaki** and by **member of the European parliament Anna Rosbach**, who is steering Waste Free Oceans – Europe. These important policy makers have received a copy of the presentation. Also the current **Belgian Federal Minister of the North Sea**, **Johan Vande Lanotte,** was in the audience. In May 2012, Colin Janssen will present results of the project at a special meeting of the **Environment Council** of the city of **Oostende**, for an audience of more than 200 people.

The project and its results have been presented to members of the Belgian and European **Plastics Industry** consortia (Plastics Europe, EuPC, Federplast) at several occasions. This has been instrumental in the creation of a **Joint Declaration for Solutions on Marine Litter** by the Global Plastics Associations in March 2011.

Finally, the results of this project will be discussed at meetings of the **Coordination Centre for Integrated Coastal Zone Management.** This Centre is a subcontractor in this project. Partners from all relevant Belgian policy levels are involved in the Centre: the **Provincial Government of West Flanders;** The **Ministry of Flanders; Agency of Nature and Forests, Coastal Management Region and Maritime Service & Coast;** and the **Federal Public Service Health, Food Chain Safety and Environment**.

Specific **policy tools and guidance** regarding monitoring, effects evaluation, cost-efficient cleanup and prevention of marine debris will be proposed after further interaction among the different project partners. These will be transferred to the relevant policy levels through the Coordination Centre for Integrated Coastal Zone Management.

4. DISSEMINATION AND VALORISATION

A key tool for the dissemination and valorisation of project results is the dedicated **website**, http://www.vliz.be/projects/as-made/. This website for the general public is developed and hosted by VLIZ. It gives an overview of the performed research activities, popularised reports of data and results, a photo gallery, a summary of the project partners and a list of interesting links and scientific papers.
Moreover, the **integrated database** that has been developed as described in section 2.1 will be made available through this website in May 2012, upon final validation of the most recent data. That database contains all data collected and created during the project and will be an invaluable source for further research on marine debris. It will be searchable through simple online questions.

Project partners have participated in different workshops and symposia, in which research products were disseminated. VLIZ annually hosts a '**Young Marine Scientists' Day**', at which several posters and flash presentations related to this project have been presented, both by the Laboratory of Environmental Toxicology and Aquatic Ecology and by INBO. At meetings of the **Society for Environmental Toxicology and Chemistry**, project findings have been presented and discussed with the scientific community as well as with industrial and governmental partners. The project and its result have been **presented to the European plastics industries** at workshops and special meetings in Switzerland, Belgium and the Netherlands, to support the industry actions to prevent plastic marine litter. The presentation of the project results at the launch of Waste-Free Oceans Belgium has been widely covered in **popular media**, e.g. Ter Zake, La Libre Belgique...:

- Waste Free Oceans Website
  http://www.wastefreeoceans.eu/news;
- Ter Zake (08/11/2011)
  http://www.deredactie.be/cm/vrtnieuws/mediatheek/programmas/terzake/2.18622/2.18623/1.1150965
  http://www.deredactie.be/cm/vrtnieuws/mediatheek/programmas/terzake/2.18622/2.18623/1.1150966
- De Morgen (08/11/2011)
  http://www.demorgen.be/dm/nl/989/Binnenland/article/detail/1345335/2011/11/08/Project-Waste-Free-Oceans-moet-tot-afvalvrije -zee-leiden.dhtml
- Knack Magazine (08/11/2011)
  http://kw.knack.be/west-vlaanderen/nieuws/ algemeen/vissers-werken-mee-aan-project-voor-afvalvrije-zee/article-4000003205 667.htm
- La Libre Belgique (10/11/2011)

http://www.lalibre.be/societe/planete/article/699005/comment-deplastifier-les-mers.html
- RTBF Matin Première (15/11/2011)
- http://www.rtbf.be/info/emissions/article_planete-la-peche-aux-plastiques?id=7079043

An expert group in VLIZ is currently creating a **Compendium for Coast and Sea**. Every five years, a document will be published that gives an overview of the marine and maritime scientific landscape, a summary of the different use categories of the coast and the sea and an illustration of the interface between science and policy. This Compendium will also be disseminated via a website and different communication products of VLIZ (e-newsletters, the journal 'De Grote Rede', informative brochures...). A special section on marine litter will be incorporated in the Compendium for Coast and Sea. Also on the website **Coastal Wiki**, a section on marine litter will be incorporated.

Finally, research from this project will be submitted for **publication in high-ranked academic journals** such as Environmental Science and Technology or Marine Pollution Bulletin. This will ensure dissemination of research output to the worldwide research community.

5. PUBLICATIONS

5.1 Peer review

INBO

van Franeker, J.A.; Blaize, C.; Danielsen, J.; Fairclough, K.; Gollan, J.; Guse, N.; Hansen, P.L.; Heubeck, M.; Jensen, J-K.; Le Guillou, G.; Olsen, B.; Olsen, K.O.; Pedersen J, Stienen EWM & Turner DM. (2011) Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. Environmental Pollution 159(10): 2609-2615.

LMAE

Claessens, M.; De Meester, M.; Van Landuyt, L.; De Clerck, K. & Janssen, C.R. (2011) Occurence and distribution of microplastics in marine sediments along the Belgian coast. Marine Pollution Bulletin 62(10): 2199-2204.

5.2 Other

INBO/LMAE/VLIZ/CDK

Braarup Cuykens, A.; Claessens, M.; Maelfait, H.; Dewitte, E.; Goffin, A.; Stienen, E.W.M. & Janssen, C.R. (2011) Sea, beach and birds: plastics everywhere, in: Mees, J. et al. (Ed.) VLIZ Young Scientists' Day. Brugge, Belgium, 25 February 2011: book of abstracts. pp. 15.

Braarup Cuykens, A.; Claessens, M.; Maelfait, H.; Dewitte, E.; Goffin, A.; Stienen, E.W.M.; Janssen, C.R.(2011) Sea, beach and birds: plastics everywhere. Poster presentation. Flanders Marine Institute (VLIZ)/INBO/Laboratory of Environmental Toxicology and Aquatic Ecology/Coordination Centre for Integrated Coastal Zone Management: Oostende. 1 poster pp.

LMAE

Claessens, M.; Rappé, K.; Roose, P. & Janssen, C.R. (2010) Hoe vervuild is onze Noordzee nu eigenlijk? De Grote Rede 27: 3-11.

Claessens, M.; Janssen, C.R. (2011) Plastics on your plate? Detecting microplastics in sediments and organisms, *in*: Mees, J. *et al*. (Ed.) (2011). VLIZ Young Scientists' Day, Brugge, Belgium 25 February 2011: book of abstracts. pp. 18.

Van Cauwenberghe, L.; Claessens, M.; Janssen, C.R. (2012) Selective uptake of microplastics by a marine bivalve (Mytilus edulis), in: Mees, J. et al. (Ed.) (2012). Book of abstracts - VLIZ Young Scientists' Day. Brugge, Belgium, 24 February 2012. VLIZ Special Publication, 55: pp. 88.

Vandegehuchte, M.; Van Cauwenberghe, L.; Claessens, M.; Janssen, C.R. (2012) Plastic waste in the Belgian coastal waters: where and how much?, in: Mees, J. et al. (Ed.) (2012). Book of abstracts - VLIZ Young Scientists' Day. Brugge, Belgium, 24 February 2012. VLIZ Special Publication, 55: pp. 97.

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