

Photo: Martin Stock / LKN-SH. Litter washed on shore.

Wadden Sea Quality Status Report

Marine litter

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1. Introduction

Pollution with litter in the marine and coastal environment is a global problem, which does not stop at the border of the Wadden Sea. It causes harm to the Wadden Sea through enhanced economic costs, e.g., for beach cleaning, cleaning of nets, ships propellers etc. and through its effects on wildlife, mainly through entanglement, ingestion and smothering. The sources of marine litter are manifold. Litter enters the marine environment at sea, from land or can be transported there by rivers. It can originate from local or distant sources. Marine litter is defined as all synthetic or processed items or fragments of items that have been discarded or lost either directly into the coastal and marine environment or transported from land to the sea e.g., by rivers or effluents, wind and land run-off (Figure 1).

Marine litter is included as a descriptor in the Marine Strategy Framework Directive. At present, indicators with associated reference levels, thresholds and targets, as well as monitoring programmes, assessments and measures to reduce litter levels are being developed for this descriptor. For marine litter in the Wadden Sea, this process is taking place at the OSPAR regional seas level. OSPAR indicators are under development for litter on the coast, on the seabed, on the water surface, litter ingested by organisms and for microplastics (i.e., plastic items < 5 mm). As this is an ongoing process, there is currently no information available for publication in this report for all these aspects of the marine litter problem. Long-term monitoring data are available from OSPAR programmes for beach litter and litter ingested by fulmars *Fulmarus glacialis*. Initial information is available for litter on the seabed and for microplastics. Data from some research and development (R&D) projects on litter at the sea surface, in marine mammal and fish stomachs could not be included in this report. The information on microplastics in sediments is taken directly from sampling in the Wadden Sea. The data for beach litter origin from beaches on islands, which face the North Sea. The seabed data is from surveys off the coast outside the Wadden Sea. Similarly, the litter recorded in fulmar stomachs is generally an indication of the level and type of litter pollution in offshore waters. However, as litter is permanently exchanged between offshore waters and the Wadden Sea, litter pollution recorded in the offshore area reflects the pressure on the Wadden Sea itself.



Figure 1. Plastic nets and containers are abundant litter items on Wadden Sea shores (M. Stock / LKN-SH).

No recent information on the sources of marine litter are available, however, the review "Identifying Sources of Marine Litter" on appropriate methods to assess sources has been published by the EU Technical Group on Marine Litter (Veiga et al., 2016), which could be applied to Wadden Sea data in the future. There is no indication that the sources of marine litter in the Wadden Sea region have changed since the last QSR report.

Targets are available for the OSPAR programmes. A quantitative target exists for the amount of litter recorded in fulmar stomachs and a qualitative target for beach litter, i.e., the number of litter items recorded on survey sites should be decreasing.

2. Status and trends

2.1 Macrolitter on beaches (OSPAR Beach Litter Monitoring)

The results of counts of the number of litter items on 100 m stretches of beach on the islands of Sylt, Scharhörn, Juist, Minsener Oog and Terschelling, carried out within the OSPAR Beach Litter Monitoring programme, are used for the assessment of litter on the coast for the period 2009-2014. The survey sites have been monitored since spring 2002 and the results for the period 2009-2014 are compared with the results published in the QSR 2009 for the period 2002-2008. The analysis software "Litter Analyst" (Baggelaar & van der Meulen, 2014) was used to assess trends in the abundance of litter items recorded on the OSPAR survey sites. Trend analyses were performed applying Mann-Kendall tests together with Sen-Theil slope estimations. Trends were calculated for items, sources and materials of beach litter.

As in the period 2002-08 plastic and polystyrene is the major component of litter on the coast, making up over 80 % of all litter items recorded in the period 2009-14. All other material or use categories are each only responsible for 4.5 % or less of total litter recorded in the period 2009-2014 (Table 1). The use categories "Sanitary" and "Medical" also often include items made of plastics, e.g., cotton-bud-sticks.

The only large difference in composition between the two time periods is in the category processed wood. The high percentage of wooden items in total litter in the period 2002-2008 is due to exceptionally high numbers of unidentifiable wooden items recorded during the surveys on Sylt in July 2002 and January 2008. The abundances of the top 15 litter items are presented in Table 2. The top items recorded on the survey sites were plastic nets and ropes, which, together with tangled nets and ropes, make up over 42 % of all items recorded. Plastic fragments smaller than 50 cm are the second most common item with 12.8 % of all items recorded. Rubber balloons, often released in large numbers during public events, are on the top 15 items list as are a number of packaging items.

Litter items from shipping including fishing make up 47.4 % of all litter items. Packaging items are the second major litter fraction recorded (21.6 % of all litter items). Small and large plastic bags make up 3.4 % of all litter items recorded. The average total number of litter items recorded per 100 m survey site was 247.4 (median 166) in the period 2009-2014 in comparison to 236 (median 158) in 2002-2008. The increase in the total number of items is not significant. The only significant trend recorded in the period 2009-2014 is a decrease in the number of paper/cardboard items (Table 3). Items recorded in this category are mainly cigarette butts and TetraPak packaging (36 % and 39 %, respectively, of all paper/cardboard items). This material category, however, only makes up a minor part of total litter recorded. No other significant increases or decreases in the number of litter items recorded on the five beaches were identified in the period 2009-2014.

Table 1. Composition of litter according to material or use type.

Material/Use type	Total no. of items recorded 2006-2014	Share 2009-2014 (in %)	Share 2002-2008 (in %)
Plastic/polystyrene	23,191	82.3	75.3
Metal	1,268	4.5	2.4
Glass	1,163	4.1	5.4
Rubber	897	3.2	3.0
Wood	838	3.0	8.3
Paper/cardboard	365	1.3	3.2
Sanitary	193	0.7	0.6
Cloth/textile	147	0.5	1.4
Pottery/ceramic	94	0.3	0.2
Medical	27	0.1	0.1

Table 2. Abundances (items/100 m of beach) of the top 15 litter items recorded on beaches bordering the Wadden Sea in the years 2009-2014 (calculated with Litter Analyst).

Item name [OSPAR ID]	Median	Average	St. dev.	Percentage of total beach litter (in %)	Change in average no./year within the period 2009-2014	p-value
Plastic all nets and ropes	76.1	98.3	109.2	39.3	-9.3	0.230
Plastic polystyrene pieces <50 cm	28.2	30.6	19.7	12.2	0.9	0.673
Plastic caps and lids [15]	9.4	9.9	5.0	4.0	-0.7	0.242
Metal other items <50 cm [89]	1.3	8.1	18.8	3.2	-0.5	0.162
Plastic tangled ropes and nets [33]	9.0	7.7	4.6	3.1	-0.9	0.217
Glass other items [93]	6.1	6.5	3.9	2.6	-0.3	0.721
Rubber balloons [49]	6.3	6.5	2.9	2.6	0.1	0.897
Plastic industrial packaging, plastic sheeting [40]	5.2	6.5	4.1	2.6	0.4	0.496
Plastic other items [48]	4.4	6.4	6.0	2.5	-0.6	0.183
Plastic crisp/sweet packets and lolly sticks [19]	5.6	6.3	4.1	2.5	-0.6	0.256
Plastic bags small [3]	4.6	4.8	2.5	1.9	-0.3	0.514
Plastic foam/sponge [45]	3.6	4.8	4.5	1.9	0.0	1.000
Plastic drink bottles & containers [4]	4.1	4.6	2.2	1.8	0.5	0.104
Plastic bags (shopping) [2]	2.5	3.7	2.9	1.5	-0.7	0.059
Wood: other items <50 cm [74]	3.1	3.6	2.2	1.4	0.0	0.948

Table 3. Abundances (items/100 m of beach) of litter items according to material/use categories recorded on beaches bordering the Wadden Sea in the years 2009-2014 (calculated with Litter Analyst).

Materials	Median	Average	St. Dev.	Percentage of total beach litter (in %)	Change in average no./year within the period 2009-2014	p-value
Plastic/polystyrene	187.7	204.1	123.4	81.5	-17.0	0.163
Metal	6.2	12.1	18.7	4.8	-0.8	0.330
Glass	9.1	10.6	6.0	4.2	0.4	0.871
Rubber	7.7	8.1	3.4	3.2	0.1	0.897
Wood	6.5	7.7	3.6	3.1	-0.4	0.456
Paper/cardboard	3.0	3.5	2.1	1.4	-0.6	0.003
Sanitary	1.2	1.7	1.6	0.7	-0.2	0.143
Cloth/textile	1.3	1.3	0.9	0.5	-0.1	0.416
Ceramic/pottery	0.5	0.9	1.0	0.4	0.1	0.357
Medical	0.0	0.3	0.4	0.1	0.0	0.186

2.2 Litter on offshore seafloor (macrolitter IBTS-Data)

Few studies have investigated spatial distribution and trends of benthic macrolitter in the North Sea. Galgani et al. (2000) and Schulz et al. (2015) found that sampling procedures differed between studies, making comparison of data difficult. The ICES protocol (ICES, 2012), however, which is currently applied within the ICES International Bottom Trawl Survey (IBTS), provides standardized sampling procedures and allows for a comparison of data over extensive areas such as the southern North Sea.

A detailed description of sampling methods used during IBTS surveys is given in ICES (2012). German IBTS data from the years 2011 to 2013 were provided by TI-SF (Germany). In addition, German, Dutch and Danish IBTS data from 2011 to 2015 (Figure 2) were obtained from the online database DATRAS of ICES. All data were analysed statistically and partly geo-statistically (see Annex).

The material composition by weight was dominated by plastic, which is in good agreement with previous studies on marine litter on beaches of the North Sea (Table 4; Schulz et al., 2013). The most abundant items were clothing/rags, fishing net, sheet, fishing line and processed wood, which hints at fisheries as a major source of benthic litter for the southern North Sea.

In the cluster, which was analysed geo-statistically, the removal of outliers considerably reduced spatial variability. Mean litter densities were 1.39 and 29.4 kg km^{-2} for cleaned and non-cleaned datasets, respectively (Figure 3). In the entire southern North Sea, mean densities of benthic litter were in the same range as those reported by Schulz et al. (2015) and amounted to 6.35 ± 11.5 kg km^{-2} and 15.2 ± 102.7 kg km^{-2} for cleaned and non-cleaned data, respectively. From a statistical point of view, it is recommended to consider only cleaned data. Densities tended to increase from 2011 to 2015 (Figure 4), but this is probably due to the small number of hauls carried out in 2011 and 2012 rather than to a real trend. Even though extreme outliers were removed the spatial and temporal variability of litter densities was considerable.

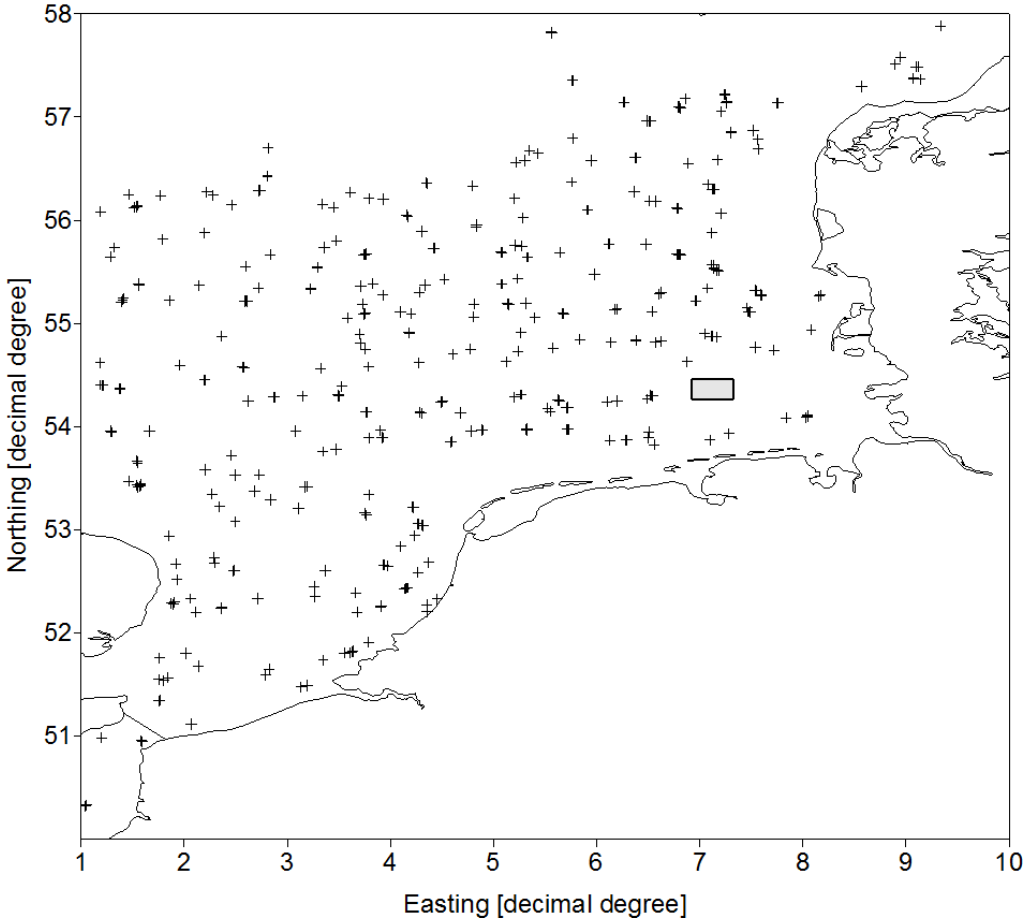


Figure 2. Sampling positions within the ICES International Bottom Trawl Survey (IBTS) programme in the southern North Sea from 2011 to 2015. A cluster considered for geo-statistical data evaluation is marked with a rectangle (data source: DATRAS).

The pollution of the seafloor of the North Sea with litter is persistent, because benthic litter is only episodically re-suspended during storm events and exported to neighbouring areas, if the seafloor lies above the storm wave base (Schulz et al., 2015). Benthic litter could be used as an indicator for descriptor 10 of the Marine Strategy Framework Directive if the same sampling protocol and data analyses are continuously applied. At present the sampling period is too short for the identification of trends.

Table 4. Left: The ten most abundant macrolitter items; right: Composition of benthic macrolitter according to material (data source: DATRAS).

Item	Percentage of total benthic litter (in %)
Clothing/rags	32.1
Fishing net	12.5
Sheet	11.8
Fishing line (monofilament)	8.4
Wood (processed)	7.4
Sanitary towels/tampons	4.6
Fishing line (entangled)	4.3
Plastic: other	2.6
Bag	2.3
Synthetic rope	1.6

Material class	Percentage of total benthic litter (in %)
Plastic	45.5
Sanitary waste	4.7
Metal	2.8
Rubber	1.8
Glass/ceramics	2.0
Natural products	9.1
Miscellaneous	34.1

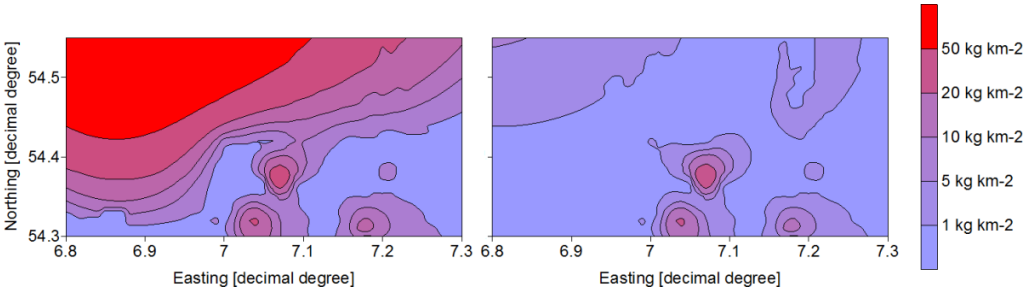


Figure 3. Interpolated densities of total benthic macrolitter in a spatial cluster in the German Bight. The left plot is based on data including outliers, the right plot is based on data cleaned from outliers (data source: Thünen Institute of Sea Fisheries).

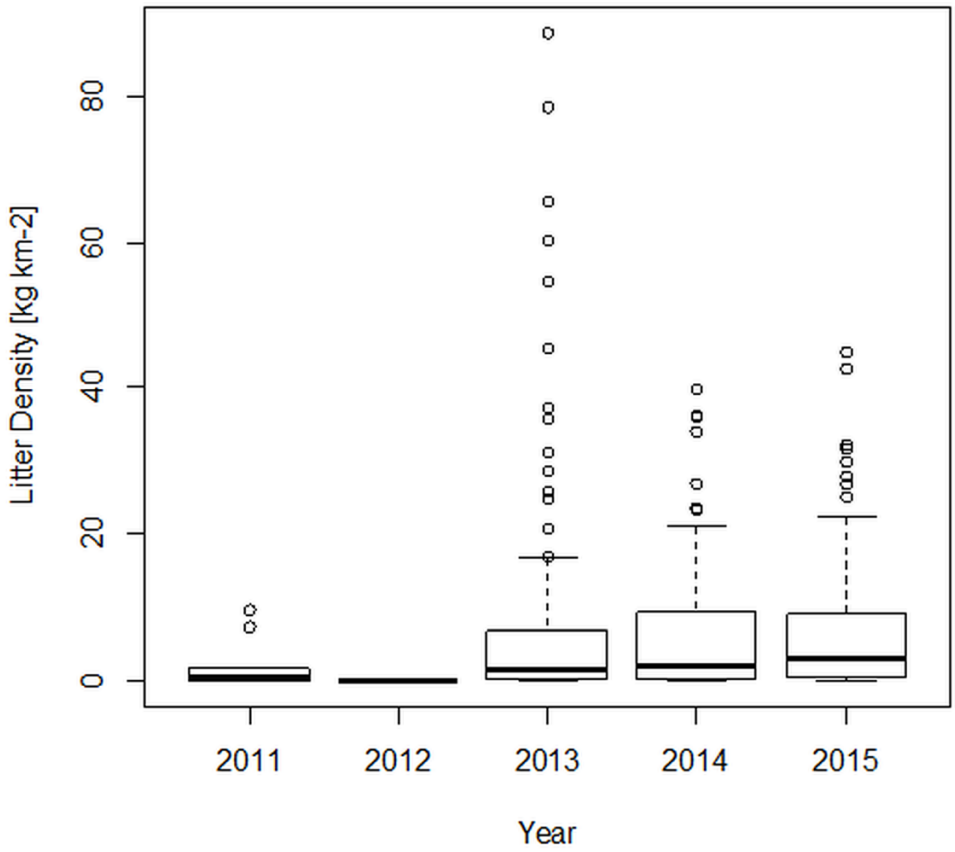


Figure 4. Benthic litter densities in the southern North Sea in the years 2011-2015. Horizontal lines in boxes give the three quartiles. Whiskers give standard deviations, empty dots mark outliers (data source: DATRAS).

2.3 Macro- and microlitter in marine organisms - an overview

Ingestion of marine litter by marine organisms, in particular of plastic debris, has been widely documented (Kühn et al., 2015). Ingestion of plastics by free living zooplankton has only been shown in the Pacific (Desforges et al., 2015), but plastic ingestion by animals in the wild in and around the Wadden Sea has been found at all levels of the food-web (Table 5). This includes benthic worms (Van Cauwenberghe et al., 2015), shrimps (Devriese et al., 2015), shellfish (De Witte et al., 2014), fish (Lusher et al, 2013; Foekema et al., 2013; Rummel et al., 2016; Collard et al., 2015), seabirds (Van Franeker et al., 2011; Van Franeker & Law, 2015), Eider ducks (Ens et al., 2002), seals (Bravo Rebolledo et al., 2013) and cetaceans, from small porpoises (Unger et al., 2015) to the largest baleen (Besseling et al., 2015) and toothed whales (Table 5). Globally, 40

% of seabird species (164 of 406) and 50 % of marine mammal species (62 of 123) have been documented as ingesting plastic. The number of records of plastic ingestion by invertebrates and fish is increasing rapidly (Kühn et al., 2015). Models predict that ultimately all species will be affected (Wilcox et al., 2015). Individual suffering and death as a consequence of ingested litter is sometimes evident. Negative impacts on populations are hard to quantify (Browne et al., 2015; Rochman et al., 2016), and concerns exist even for impact on humans (Galloway, 2015). Most studies in and around the Wadden Sea have an incidental character, but do provide a general impression of the status.

Table 5. Records for frequency of occurrence (FO) of plastic ingestion and, if available, average number and mass of plastic litter per individual (population average, including individuals with zero plastics) in wild animals living in or near the Wadden Sea.

Species	FO (in %)	Average number	Average mass (in g)	Notes	Source
Fish, North Sea (n=1203; 7 species)	2.6	0.03	-	Up to 33 % for cod in Channel; fibres not included	Foekema et al., 2013
Fish, Channel (n=504; 10 species)	36.5	0.70	-	68 % of these fibres	Lusher et al., 2013
Fish, German North Sea (n=148; 5 species)	6.1	0.09	-	Most fibres not included	Rummel et al., 2016
Northern Fulmar, Dutch and German wadden Sea (n=281)	94	38	0.32	60 % of birds had more than 0.1 g in stomach	This analysis (2010-2014)
Eider duck, Dutch Wadden Sea	~ 6	-	-	Preliminary data (dissections 2000-2002)	Ens et al., 2002; unpublished data Van Franeker
Harbour seal, Dutch Wadden Sea (n=107)	11.2	0.26	0.024	Plastics in stomach (intestines additional 1 %)	Bravo Rebolledo et al., 2013
Harbour porpoise, Berman Baltic (mainly) North Sea (n=533)	~1	~ 0.01	-	Plastics, fishing line, hook, bracelet	Unger et al., 2015
Sperm whale, German and Dutch Wadden Sea (n=19; beached 2016)	37.0	-	-	7 of 19 beached sperm whales on Wadden Sea islands contained plastic debris, some of them large, e.g., fishing nets or car bumper	pers. comm. B. Unger (Germany) and E. Bravo Rebolledo (Netherlands)

2.4 Macro- and microlitter in fulmar stomachs

For the evaluation of trends of abundance of marine litter ingested by animals, the only long-term monitoring study is that of the OSPAR Common Indicator on plastic particles in fulmars' stomachs (OSPAR, 2015). This monitoring approach has also been adopted in the EU Marine Strategy Framework Directive (EC 2008, 2010). Data on plastics in stomachs of fulmars beached in the combined German and Dutch Wadden Sea area are available from year 2000 onwards. The Common Indicator considers the proportion of beached fulmars that have more than 0.1 g of plastic in the stomach. OSPAR has set its Ecological Quality Objective (EcoQO) as the situation where no more than 10 % of beached birds exceed the 0.1 g threshold (OSPAR, 2009a) as measured over periods of five years. The current status (2010-2014) is that 60 % of fulmars found in the Dutch/German Wadden Sea region exceed this threshold (Figure 5, Table 6). Trends are tested for statistical significance by linear regression of individual data for mass of plastics over the most recent 10 years. No significant change can be observed (2005-2014; n=676 p=0.364). Longer data series for the Netherlands (Van Franeker & Law, 2015) showed significant increase in ingested plastic from the 1980s to 1990s, followed by similar decrease into the early 2000s and stability since then. The proportion of industrial plastics (industrial plastic resin pellets), about 50 % by mass in the 1980s, has decreased to about 20 % in recent years. Currently, consumer waste (all non-industrial remains of plastic objects such as fragments of plastic items and packaging material) is the main plastic found in fulmar stomachs.

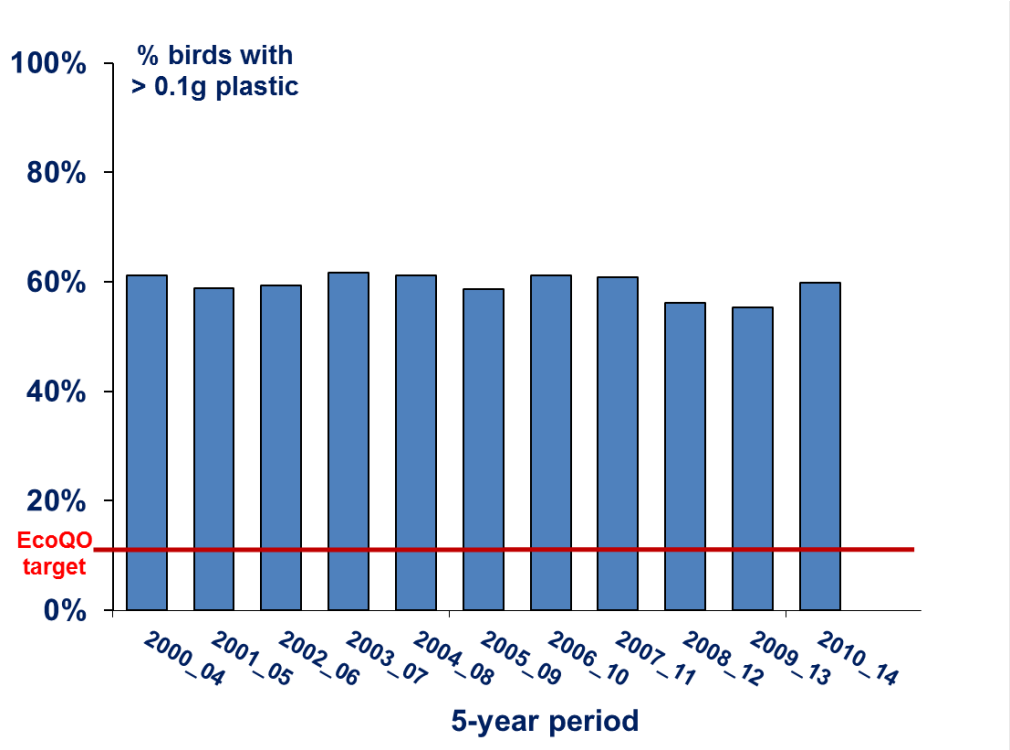


Figure 5. Trends in the proportion of northern fulmars having more than 0.1 g plastic in the stomach (EcoQO performance) in the Wadden Sea area since the year 2000. Data are shown as running five-year averages with full details given in Table 6. The red line reflects the OSPAR target for acceptable ecological quality, defined as the situation that no more than 10 % of fulmars have more than 0.1 g of plastic in the stomach for a continuous period of at least five years in any subregion of the North Sea.

Data were evaluated for potential differences between fulmars found from 2005 to 2014 on the Wadden Sea islands (n=389), and those found on the mainland coasts (n=278). The latter group may have spent more time within the Wadden Sea. As might be expected considering the massive daily water exchange between the North Sea and Wadden Sea, no differences were observed (p=0.905).

Table 6. Trends in abundance of plastic litter in stomachs of fulmars collected from the Dutch and German Wadden Sea areas as investigated in the OSPAR Common Indicator. Shown as running five year averages are the sample size of stomachs investigated, their EcoQO performance (the percentage of birds having more than 0.1 g of plastics in the stomach); Incidence (frequency of occurrence of any plastic in the stomachs); arithmetic averages ± standard error (SEM) for number of particles and mass of ingested plastic, and their geometric mean mass.

Wadden Sea total		Total plastics				
5-year period	Sample n	EcoQO (in % over 0.1 g)	Incidence (in %)	Average no. [n ± SEM]	Average mass [g ± SEM]	Geometric mean mass (in g)
2000-2004	306	**61**	94	27.7 ± 4.3	0.31 ± 0.04	0.094
2001-2005	381	**59**	94	25.6 ± 3.5	0.29 ± 0.03	0.088
2002-2006	387	**59**	94	26.4 ± 3.5	0.29 ± 0.03	0.091
2003-2007	476	**62**	94	27.2 ± 2.9	0.34 ± 0.03	0.101
2004-2008	479	**61**	94	27.6 ± 3.0	0.36 ± 0.03	0.103
2005-2009	395	**59**	97	24.1 ± 1.7	0.33 ± 0.04	0.110
2006-2010	340	**61**	97	29.0 ± 2.6	0.37 ± 0.05	0.121
2007-2011	373	**61**	96	27.5 ± 2.4	0.38 ± 0.06	0.114
2008-2012	402	**56**	96	32.4 ± 7.1	0.31 ± 0.05	0.097
2009-2013	388	**55**	96	32.4 ± 7.3	0.28 ± 0.04	0.094
2010-2014	281	**60**	94	37.9 ± 10.1	0.32 ± 0.06	0.093

2.5 Macrolitter in the stomachs of beached harbour porpoises (*Phocoena phocoena*)

The harbour porpoise is the most common cetacean occurring in the Wadden Sea. The Institute for Terrestrial and Aquatic Wildlife Research (ITAW) of the University of Veterinary Medicine Hannover has collected data on stranded harbour porpoises on the German North Sea coast since 1990. In 2015, findings of marine litter were evaluated in the frame of a PhD. Between 1990 and 2014, 2,299 carcasses of stranded harbour porpoises were found on the North Sea coast of Schleswig-Holstein (including four in the Elbe River). In 404 porpoises the decomposition state allowed for an examination of the gastro-intestinal tract. Marine litter was recorded in four of these porpoises (Unger et al., 2017).

The litter recorded in the four individuals comprised three plastic pieces, one piece of fishing line and one plastic piece, one piece of monofilament net and one bracelet. Only one of these records, the bracelet found in the mouth of one individual, was from the period 2009-2014, where necropsies were performed on a total of 104 carcasses. None of the findings caused the death of the animals.

2.6 Microplastics in Wadden Sea sediments

Three peer-reviewed publications (Liebezeit & Dubaish, 2012; Fries et al., 2013; Dekiff et al,. 2014), two technical reports (Derksen et al., 2012; Leslie et al., 2013) and one conference poster (Strand et al., 2014) provided quantitative information on microplastics in sediments from 12 sites along the entire Wadden Sea from Denmark to the Netherlands. Sediments were collected in dunes, on beaches and tidal flats and from the subtidal seafloor (Figure 6). Samples were taken between 2010 and 2013. This time span is too short to allow for an analysis of temporal trends. No historical information exists on microplastics in sediments of the Wadden Sea.

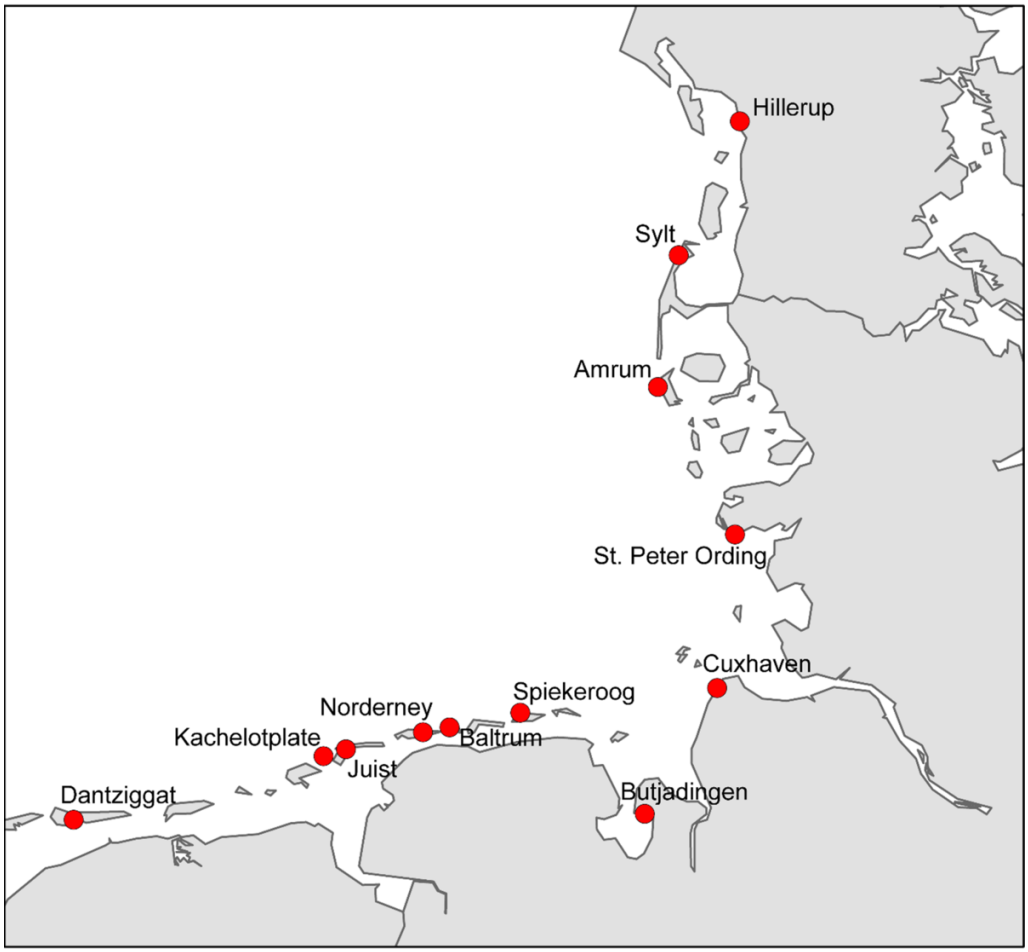


Figure 6. Sediment sampling sites in the Wadden Sea (Author: Jan Beermann).

In the Netherlands, microplastics were found in subtidal sediment from Dantziggat at a density of 770 particles kg_{DW}^{-1} (Leslie et al., 2013) (Table 7). Liebezeit & Dubaish (2012) reported exceptionally high microplastic densities in intertidal sediments on the German islands of Kachelotplate, Juist and Spiekeroog with a maximum density of 62,100 particles kg_{DW}^{-1}. However, minute granules, which constituted the vast majority of the material in that study, were not specifically mentioned in any other study. In addition to granules, Liebezeit & Dubaish (2012) recorded abundances of microplastic fibres. The densities of fibrous material varied between 100 and 1,400 items kg_{DW}^{-1} and were within the range of microplastic densities recorded from other sites along the Wadden Sea. Apart from the exceptionally high records reported by Liebezeit & Dubaish (2012), microplastic densities in sediments of the German Wadden Sea varied between 245 and 648 particles kg_{DW}^{-1}. Comparatively low but still considerable densities of about 100 microplastic particles kg_{DW}^{-1} were recorded at Hillerup in the Danish Wadden Sea (Strand et al., 2014). Derksen et al. (2012) suggested that microplastic densities along the Dutch and the Eastern Frisian coast were generally higher than in sediments of the North Frisian and the Danish coast because of the intense shipping traffic off the southern coast of the North Sea. Additionally, discharge from large rivers may contribute to the high microplastic concentrations in sediments.

A proper verification of the polymer type by spectroscopic or chromatographic procedures is mandatory in scientific quantifications of microplastics in field samples, because the rate of misidentification of microplastics, when only using visual inspection, can be high (70-98 %), even when using a microscope (Hidalgo-Ruz et al., 2012; Löder & Gerdts, 2015). However, only two publications performed adequate polymer verification (Fries et al., 2013; Dekiff et al., 2014). Microplastic densities

reported in these studies were two orders of magnitude lower than in studies with simple visual particle identification.

In summary, microplastics were found in sediments from beaches, dunes and the seafloor along the entire Wadden Sea coast. Microplastic densities were similar to densities reported from sediments in the Belgian part of the North Sea (Claessens et al., 2011). However, a proper polymer verification resulted in substantially lower densities (Fries et al., 2013; Dekiff et al., 2014), indicating a potential overestimation of microplastic densities in most studies due to erroneous identification of particles. Methodological inconsistencies and missing information on the lower size limit of the particles recorded hamper the comparison of quantitative data from different studies.

Table 7. Densities of microplastics in sediments of the Wadden Sea. n.i. = no information available.

Site	Year	Habitat	Type of microplastics	Density [n · kg_{DW}^{-1}]	Verification of polymer type	Reference
Netherlands						
Dantziggat	2012	subtidal sediment	spheres, fibres, fragments	770	no	Leslie et al., 2013
Germany						
Kachelotplate	2011	beach	fibres	100-1400	no	Liebezeit & Dubaish, 2012
Kachelotplate	2011	beach	granules	0-62100	no	Liebezeit & Dubaish, 2012
Juist	2011	tidal flat	fibres	500-600	no	Liebezeit & Dubaish, 2012**
Juist	2011	tidal flat	granules	3500-10500	no	Liebezeit & Dubaish, 2012**
Norderney	2011	beach	particles	1.3-2.3	yes	Dekiff et al., 2014
Norderney	2010	beach	particles	1.5-2.1*	yes	Fries et al., 2013
Norderney	2010	beach	particles	372-408	no	Derksen et al., 2012
Baltrum	2010	beach	particles	245	no	Derksen et al., 2012
Spiekeroog	2011	dune	granules	1500-5800	no	Liebezeit & Dubaish, 2012**
Spiekeroog	2010	beach	particles	159-648	no	Derksen et al., 2012
Butjadingen	2010	beach	particles	509	no	Derksen et al., 2012
Cuxhaven	2010	beach	particles	268-300	no	Derksen et al., 2012
St. Peter-Ording	2010	beach	particles	112-646	no	Derksen et al., 2012
Amrum	2010	beach	particles	320	no	Derksen et al., 2012
Sylt	2010	beach	particles	386	no	Derksen et al., 2012
Denmark						
Hillerup	2012/13	n.i.	flakes, granules, fibres	100	no	Strand et al., 2014**

* unit: n · kg_{WW}^{-1}

** densities estimated from bar charts

2.7 Results from “Fishing for Litter”

Fishing for Litter is an environmental initiative, internationally coordinated by KIMO and OSPAR, aiming to reduce the amount of litter in the sea and to highlight the problem of marine litter among the public and the fishing sector. Fishermen are provided with large hardwearing bags to collect the marine litter that accumulates in their nets, as part of their usual fishing activity. Facilities are offered in the participating harbours to deposit the litter at no cost to the fishermen. In the year 2015 the initiative took place in 20 harbours in the Wadden Sea area with more than 200 vessels participating. In the Netherlands the initiative has been running since the year 2000 (M. Mannaart, KIMO the Netherlands and Belgium, pers. comm.), on the German North Sea coast since 2012 (Dau et al., 2015)), whereas in Denmark, as yet, no harbour is involved (R. Metcalfe, KIMO Denmark, pers. comm.). From 2009 until 2014, between 70 and 190 tons of marine litter were removed annually from the seabed in the North Sea and brought to the harbours of the Wadden Sea to be disposed of.

In Germany, where the initiative is coordinated by the NGO NABU, the composition of a subsample of the litter is assessed each year according to the OSPAR beach litter sampling protocol (see sub-chapter 2.1). From 2013 to 2015 a total of 27,972 items were counted and categorized. Up to 95 % of the litter items were made of plastic and polystyrene. The percentage of plastic items collected is higher than for the coastline and for other participating harbours (Fleet et al., 2009; OSPAR, 2009b; KIMO, 2014).

We attribute the large number of plastic items to the small mesh sizes of 16-31 mm used in the North Sea shrimp fishery, from which the litter was obtained. The most common items were plastic and polystyrene fragments of unidentifiable origin which accounted for 39 % of the total number of litter items (Figure 7). Fishing nets accounted for 26 % of the total number of items, whereas ropes and strings together made up to 8 % of the total. 7 % were plastic food bottles and containers. The top ten items further included plastic bags, plastic crisps and sweets packets, plastic cups, textiles, plastic drink bottles, containers and drums, as well as plastic industrial packaging/sheeting.

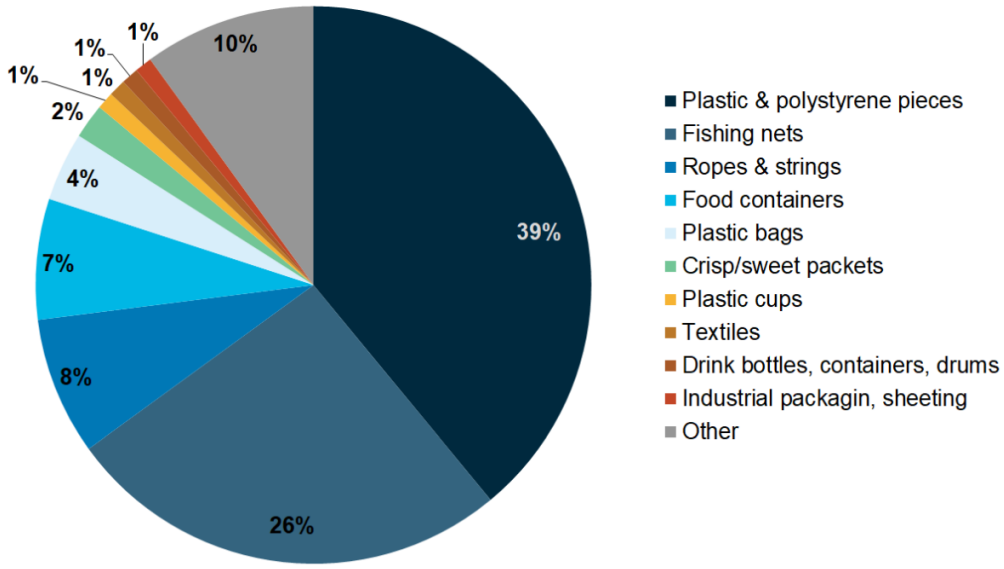


Figure 7. Composition of litter analysed within the Fishing for Litter programme in German harbours from 2013-2015.

3. Assessment

3.1 Water and sediment

The Wadden Sea Plan (WSP) refers explicitly to marine litter pollution only in the report on *Water and Sediment*. It is acknowledged that marine litter "is a constant threat to wildlife, a hindrance to human activities, incurs high economic costs, is unsightly and reduces the recreational value of our coasts" (CWSS, 2010). The WSP further recognizes the continuous increase in marine litter concentrations in the southern North Sea. According to the WSP the targets defined for water and sediment are consistent with the definitions of "good chemical status" according to WFD. Among other things, the targets require "concentrations of human-made substance as resulting from zero-discharges" as well as "improvement of habitat quality for conservation of species". Marine litter items are not human-made contaminants in the narrowest sense. However, if applied to marine litter the above targets for man-made chemical contaminants are at risk of not being reached, because marine litter occurs consistently and in considerable densities in the Wadden Sea and in connected offshore areas.

The results presented in this QSR reveal that macrolitter occurs on the seafloor and on beaches of the southern North Sea and the Wadden Sea. Additionally, microplastics are common in Wadden Sea sediments, including beaches, dunes and tidal flats. Litter

is constantly captured by fishermen during trawling, as indicated by the considerable amounts of litter recorded by the Fishing for Litter programme. The persistent occurrence of litter in the marine environment indicates that substantial amounts of litter are still entering the North Sea, from either terrestrial or sea-based sources. Although litter pollution occurs to some extent in the Wadden Sea itself, considerable amounts of litter are being transported into the Wadden Sea from the adjacent North Sea by wind and currents, and by rivers entering the Wadden Sea area.

The OSPAR beach monitoring programme allowed for an evaluation of the temporal development of beach litter densities. It clearly shows that densities of macrolitter on beaches of the Wadden Sea have not decreased since the last Wadden Sea QSR in 2009. The vast majority of litter items on Wadden Sea beaches were plastics. Nets and ropes were commonly recorded on beaches but also on the seafloor, indicating that fisheries and other maritime activities are an important source of marine litter in the Wadden Sea.

Litter items and fragments pose a physical threat to marine organisms through entanglement, ingestion or smothering. Additionally, chemicals, which are added to plastics during the manufacturing process, are known to have deleterious health effects for marine organisms and humans (Rochman, 2015). However, it is as yet unknown how marine plastic litter contributes to the overall chemical load of water and sediments in the oceans. The transfer of chemical additives from ingested plastic items to consumers is currently subject to intensive research. Kühn et al. (2015) emphasize that ingested litter items have a long residence time in the intestines of animals, especially of larger vertebrates, which allows for a transfer of chemicals from the plastic litter items into animal tissue.

3.2 Birds

The Birds Targets of the Wadden Sea Plan (WSP) do not specifically refer to marine litter. They address more generally the status of bird populations and of habitats, which are used by birds for breeding, feeding, moulting and roosting (see reports on breeding birds, migratory birds and East Atlantic Flyway). The long-term monitoring of the OSPAR Common Indicator on plastic particles in fulmars' stomachs does not allow for direct inference on the health effects of ingested marine litter on fulmars. It does, however, allow for an evaluation of litter densities in the foraging areas of fulmars on the North Sea coast. A number of studies have, however, clearly shown that the ingestion of litter items causes serious damage to seabirds and that ingested litter is a common source of mortality in fulmars (reviewed by Kühn et al., 2015). Accordingly, the amount of litter and its long-term temporal development is an indicator of the population status of fulmars in the southern North Sea.

OSPAR has set its Ecological Quality Objective (EcoQO) for litter in fulmar stomachs as the situation where no more than 10 % of beached birds exceed the 0.1 g threshold (OSPAR, 2009) as measured over periods of five years. Monitoring revealed that for the period 2010-2014 an average of about 60 % of the fulmars found in the Dutch/German Wadden Sea region clearly exceeded this threshold. The average amount of litter recorded inside a fulmar stomach was 0.32 g. The average amount of litter in the stomachs as well as the proportion of dead fulmars with litter in their stomachs has not changed significantly over the past 14 years and not since the last Wadden Sea QSR from the year 2009. These results indicate that the status of the Wadden Sea with regard to pollution with potentially harmful litter has not improved. Furthermore, no long-term trend was apparent in the data that would indicate a future improvement of the situation. Unfortunately, no comparable monitoring data are

available for the Danish part of the Wadden Sea. However, since the foraging area of fulmars collected in the German and Dutch part of the Wadden Sea is not restricted to those countries it must be assumed that the data reliably reflect the situation in the Danish part as well (Van Franeker & the SNS Fulmar Study Group, 2013).

3.3 Marine mammals

The Marine Mammals Targets of the Wadden Sea Plan (WSP) do not specifically refer to marine litter (see report on marine mammals). The targets address more generally the viability of the stocks and the survival potential of juveniles. Examinations of the intestines of stranded harbour porpoises from the Wadden Sea indicate that only a small proportion (< 2 %) of the population ingests marine litter. However, unpublished data from similar investigations in the Dutch Wadden Sea showed a considerably higher frequency of occurrence of litter in the intestines of Harbour Porpoises of about 7-12 % (pers. comm. J.A. Van Franeker). Additionally, a certain amount of ingested litter is probably constantly evacuated from the intestines by egestion, which would lead to an underestimation of the incidence of litter ingestion when using necropsies.

There is no evidence that ingested litter led to the death of the stranded porpoises found in the Schleswig-Holstein Wadden Sea. Kühn et al. (2015) also doubt that ingestion of litter causes mortality in marine organisms at a frequency that is relevant at the population level. However, the authors refer to sub-lethal effects, which are assumed to be more relevant for marine vertebrates. Accordingly, current litter quantities in the southern North Sea do not seem to directly compromise the viability of harbour porpoises and, thus, the implementation of the Marine Mammals Targets of the Wadden Sea Plan for harbour porpoises.

Marine litter was found in a considerable proportion of the sperm whales (*Physeter macrocephalus*) stranded in the German and Dutch Wadden Sea in early 2016. These findings are not necessarily indicative for the litter pollution of the Wadden Sea. However, they demonstrate that marine litter is available for ingestion by large marine mammals in the North Sea and connected marine regions.

Information on ingested litter in pinnipeds is not available for the period 2009-2014. However, an inspection of intestines of harbour seals (*Phoca vitulina*), which died from the epidemic Phocine Distemper Virus (PDV) in 2002, revealed that 11 % of the individuals had marine litter in their stomachs (Bravo Rebolledo et al., 2013). The study indicated that particularly younger animals of up to three years of age ingest litter, raising concern about potential effects on the survival of juveniles, which might compromise the Wadden Sea Plan targets.

A proper estimation of the effects of marine litter on mammals should not only consider ingestion of litter and direct mortality but also other types of interaction such as entanglement and direct injury. Information on these types of interaction is currently not available for North Sea mammals from the Wadden Sea region.

4. Recommendations

4.1 Recommendations for monitoring and research

Current knowledge on macro- and microlitter in the Wadden Sea is still fragmentary. Only two OSPAR monitoring programmes – Beach Monitoring and Monitoring of Fulmars' Stomachs – are available to evaluate the long-term development of litter pollution in the region. A higher spatial coverage of these programmes by establishing OSPAR beach litter survey sites and the collection of beached fulmars in the Danish part of the Wadden Sea would be beneficial.

The Fishing for Litter programme will be able to provide some additional and useful information on seafloor litter composition. The fishing for litter data could be made more valuable if fishing effort and the fishing grounds are recorded along with the amount of litter caught in the nets. Additionally, an improved coordination of beach cleaning events would make the data collected more valuable, especially for the identification of sources of marine litter.

Data on marine macrolitter on the seafloor of the North Sea are obtained from routine programmes such as the ICES International Bottom Trawl Survey (IBTS), which cover extensive offshore areas and are repeated regularly in a standardized way. The results presented here indicate a substantial temporal and spatial variation in density and distribution of litter on the seafloor. The routine collection of data as part of the IBTS surveys is planned and will provide information on trends in the future.

The examination of litter in the stomachs of stranded marine mammals should be continued. The assessment of the incidence of marine litter interactions with harbour porpoises and seals directly addresses species, which are explicitly considered in the Wadden Sea Plan.

Only very few studies presented here applied appropriate methodology for the identification and quantification of microplastics from environmental samples. Microplastics will be an environmental issue of increasing importance in the future, because microplastics are mainly the product of degradation of larger plastic items, which are predicted to increase in abundance in the upcoming decades (Jambeck et al., 2015). The development of appropriate monitoring programmes for microplastics in invertebrates and vertebrates (e.g., fish) should be considered for the Wadden Sea. Additional investigations on microplastics in intestines or faeces of top consumers, such as porpoises and seals, would provide an understanding of how synthetic particles progress through the marine food web.

Regular assessments of the socio-economic problems arising from marine litter within the Wadden Sea should be developed in order to provide reliable data on the societal aspects of the litter problem. Monitoring programmes for the marine litter descriptor of the Marine Strategy Framework Directive are presently under development and diverse research projects will produce proposals for standardized monitoring. This work is also being supported by the EU Technical Group on Marine Litter, which provides guidance on monitoring marine litter in European seas (MSFD-TSGML, 2011; Galgani et al., 2013). The results of ongoing research and the guidance of the TGML should be taken into consideration when planning future monitoring, in order to achieve optimal and standardized monitoring procedures for marine litter in the Wadden Sea region.

4.2 Recommendations for management

Measures to combat the marine litter problem are currently being developed to achieve a “Good Environmental Status” according to the European Marine Strategy Framework Directive. For the Northeast Atlantic an OSPAR regional action plan has been developed to reduce marine litter. The measures proposed in the plan address all main aspects of the marine litter problem. The plan provides a basis for national initiatives required by the MSRL. The prime aim of the action plan is to prevent litter entering the marine environment, however, measures aiming at reducing litter already present in the marine environment, such as Fishing for Litter initiatives and beach cleanups, are also included. Prevention measures address sea-based and land-based sources of macrolitter as well as the input of microlitter.

The key action areas addressed in the Regional Action Plan (RAP) include the following:

- Port reception facilities for litter from shipping;
- Waste from the fishing industry;
- Fines for littering at sea;
- Fishing for litter initiatives;
- Abandoned and lost fishing gear;
- Floating litter hotspots;
- Education and outreach;
- Improved waste management;
- Sewage/stormwater run-off;
- Reduction of single use items;
- Removal of microplastics from products/zero pellet loss;
- Redesign of harmful products.

A number of the measures are directly relevant to the Wadden Sea and, if implemented in the region, could reduce litter in the Wadden Sea considerably. These include education and awareness campaigns and improved waste management, especially in the fisheries industry, as well as measures, which address plastic packaging, such as plastic-free islands or improved regulation of litter production during events that take place in the coastal environment, e.g., through the banning of single-use items and the provision of the necessary infrastructure for the safe and easy disposal of litter. Regular campaigns informing tourists, residents and people working in the Wadden Sea and adjacent areas about the environmental, economic and health problems arising from marine litter are imperative.

5. Summary

The results from the various investigations and monitoring programmes presented in this report demonstrate the continuous and widespread occurrence of litter in the Wadden Sea and adjacent offshore waters. Marine litter of different sizes and from diverse sources occurs on dunes and beaches, in and on inter- to subtidal sediments and in marine organisms, including protected seabirds and mammals. The OSPAR Beach Litter Monitoring and Monitoring on Litter in Fulmars’ Stomachs provide an evaluation of the temporal development of litter abundance in the southern North Sea. Both programmes clearly show that litter densities have not declined since the last Wadden Sea QSR in 2009, indicating that large amounts of litter are still entering the marine environment either directly within the Wadden Sea or from adjacent waters. The amount of litter entering the marine environment is continuously increasing

(Jambeck et al., 2015). This increase is, however, not apparent in the results of the two monitoring programmes. Litter degrades in the marine environment and breaks down into ever smaller fragments. The fragmentation of plastic objects produces microplastics, which are not sufficiently assessed by current monitoring programmes. Densities of microplastics are expected to increase substantially in the future in all marine habitats. Accordingly, scientifically sound monitoring of these synthetic particles with standardized methods that allow for the comparison of results from different programmes will be indispensable.

Marine litter is not restricted to specific habitats but occurs in all compartments of the marine environment with a constant exchange between them. Accordingly, monitoring litter densities in both coastal and offshore habitats is essential for a sound evaluation of litter pollution of the Wadden Sea. Many of the investigations presented in this report are on-off events, which do not provide information on temporal trends. However, they do demonstrate that the Wadden Sea is contaminated with marine litter and that litter densities in the Wadden Sea are not lower than in other coastal regions. The litter densities presented in this report provide a valuable baseline for future evaluations of temporal trends.

The monitoring of litter in fulmars' stomachs and the examinations of carcasses of harbour porpoise, harbour seals and eider ducks revealed that litter does not simply occur in the marine environment but actually interacts in a potentially harmful way with the marine biota. It is well established that the ingestion of litter can have deleterious and often lethal effects on marine organisms. It is yet unknown whether marine litter has demographically relevant implications for marine species. For evaluating this, the effects of marine litter must not be considered in isolation but always together with the effects of other environmental stressors such as ocean warming and acidification, eutrophication and the exploitation of natural stocks (see reports on climate change, geomorphology, eutrophication and fisheries). Several Wadden Sea Plan targets are compromised by the continuous pollution of the North Sea with marine litter. A proper management of the marine litter problem will require appropriate reduction measures and extended and optimized monitoring programmes in order to evaluate future developments.

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References

Besseling, E., Foekema, E.M., Van Franeker, J.A., Leopold, M.F., Kühn, S., Bravo Rebolledo, E.L., Hesse, E., Mielke, L., IJzer, J., Kamminga, P., Koelmans, A.A. (2015) *Microplastic in a macro filter feeder: Humpback whale* Megaptera novaeangliae. Marine Pollution Bulletin 95: 248-252.

Bravo Rebolledo, E.L., Van Franeker, J.A., Jansen, O.E., Brasseur, M.J.M. (2013) *Plastic ingestion by harbour seals (*Phoca vitulina*) in The Netherlands*. Marine Pollution Bulletin 67: 200-202.

Browne, M.A., Underwood, A.J., Chapman, M.G., Williams, R., Thompson, R.C., Van Franeker, J.A. (2015) *Linking effects of anthropogenic debris to ecological impacts*. Proceedings Royal Society B 282: 20142929.

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

Collard, F., Gilbert, B., Eppe, G., Parmentier, E., Das, K. (2015) *Detection of anthropogenic particles in fish stomachs: an isolation method adapted to identification by Raman spectroscopy*. Archives of Environmental Contamination and Toxicology 69: 331-339.

CWSS (2010) *Wadden Sea Plan 2010*. Eleventh Trilateral Governmental Conference on the Protection of the Wadden Sea. Common Wadden Sea Secretariat, Wilhelmshaven, Germany. 102 pp.

Dau, K., Millat, G., Abel, C., Zwoch, I., Möllmann, N. (2015) *Fishing for Litter Niedersachsen*. pp 15. www.umwelt.niedersachsen.de/aktuelles/fishing-for-litter-140821.html.

Dekiff, JH., Remy, D., Klasmeier, J., Fries, E. (2014) *Occurrence and spatial distribution of microplastics in sediments from Norderney*. Environmental Pollution 186: 248-256.

Derksen, D.M., Kindermann, O., Schweikart, A., Steinecke, K. (2012) *Belastung mariner Lebensräume durch Mikroplastik: Stand der Wissenschaft sowie erste Ergebnisse einer Vorstudie zur Erfassung und Bewertung des Vorkommens von Mikroplastikgranulat im Sediment von Küsten der deutschen Nordsee*. In: M Flitner, I Mossig, M Rosol, J-F Venzke, B Zolitschka (eds.) Bremer Beiträge zur Geographie und Raumplanung, Heft 44, pp. 96-107.

Desforges, J.-P.W., Galbraith, M., Ross, P.S. (2015). *Ingestion of microplastics by zooplankton in the Northeast Pacific Ocean*. Archives of Environmental Contamination and Toxicology 69: 320-330.

Devriese, L.I., Van der Meulen, M.D., Maes, T., Bekaert, K., Paul-Pont, I., Frère, L., Robbens, J., Vethaak, A.D. (2015) *Microplastic contamination in brown shrimp (*Crangon crangon*, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area*. Marine Pollution Bulletin 98:

179-187.

De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., Robbens, J. (2014) *Quality assessment of the blue mussel (*Mytilus edulis*): Comparison between commercial and wild types*. Marine Pollution Bulletin 85: 146-155.

EC (2008) *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)*. Official Journal of the European Union L 164: 19-40.

EC (2010) *Commission Decision of 1 September 2010 on criteria and methodological standards on Good Environmental Status of marine waters* (notified under document C(2010) 5956) (Text with EEA Relevance) (2010/477/EU). Official Journal of the European Union L232:14-24.

Ens, B.J., Borgsteede, F.H.M., Camphuysen, C.J., Dorrestein, G.M., Kats, R.K.H., Leopold, M.F. (2002) *Eidereendensterfte in de winter 2001-2002*. Alterra-rapport 521. Alterra, Wageningen, 113 pp.

Fleet, D., Van Franeker, J., Dagevos, J., Hougee, M. (2009) *Marine Litter*. Thematic Report No. 3.8. In: Marencic, H. & Vlas, J. de (eds.). Quality Status Report 2009. Wadden Sea Ecosystem No. 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany, 11 pp.

Foekema, E.M., De Gruijter, C., Mergia, M.T., Van Franeker, J.A., Murk, T.J., Koelmans, A.A. (2013) *Plastic in North Sea fish*. Environmental Science and Technology 47: 8818-8824.

Fries, E., Dekiff, J.H., Willmeyer, J., Nuelle, M.-T., Ebert, M., Remy, D. (2013) *Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy*. Environmental Science: Processes and Impacts 15: 1949-1956.

Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., Goraguer, H., Latrouite, D., Andral, B., Cadiou, Y., Mahe, J.C., Poulard, J.C., Nerisson, P. (2000) *Litter on the sea floor along European coasts*. Marine Pollution Bulletin 40: 516-527.

Galgani, F., Hanke, G., Werner, S., Oosterbaan, L., Nilsson, P., Fleet, D., Kinsey, S., Thompson, R., van Franeker, J., Vlachogianni, T., Scoullos, M., Mira Veiga, J., Palatinus, A., Matiddi, M., Maes, T., Korpinen, S., Budziak, A., Leslie, H., Gago, J., Liebezeit, G. (2013) *Monitoring guidance for marine litter in European seas*. JRC Scientific and Policy Reports, Report EUR 26113 EN, 120 pp.

Galloway, T. (2015) *Micro- and nano-plastics and human health*. In: Bergmann, M., Gutow, L., and Klages, M. (eds). Marine Anthropogenic Litter. Springer, Heidelberg, pp. 343-366.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M. (2012) *Microplastics in the marine environment: a review of the methods used for identification and quantification*. Environmental Science and Technology 46: 3060-3075.

ICES (2012) *Manual for the International Bottom Trawl Surveys*. Series of ICES Survey Protocols. SISP 1-IBTS VIII: 68 pp.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. (2015) *Plastic waste inputs from land into the ocean*. Science 347: 768-771

KIMO (2014). *Fishing for Litter Scotland*. Final Report 2011-2014, 14 pp.

Kühn, S., Bravo Rebolledo E.L., Van Franeker, J.A. (2015) *Deleterious effects of litter on marine life*. In: Bergmann, M., Gutow, L., and Klages, M. (eds). Marine Anthropogenic Litter. Springer, Heidelberg, pp. 75-116.

Leslie, H.A., van Velzen, M.J.M., Vethaak, A.D. (2013) *Microplastic survey of the Dutch environment*.

Novel data set of microplastics in North Sea sediments, treated wastewater effluents and marine biota. Final Report R-13/11. IVM Institute for Environmental Studies, University of Amsterdam, 30 pp.

Liebezeit, G., Dubaish, F. (2012) *Microplastics in beaches of the East Frisian islands of Spiekeroog and Kachelotplate*. Bulletin of Environmental Contamination and Toxicology 89: 213-217.

Löder, M.G.J., Gerdts, G. (2015) *Methodology used for the detection and identification of microplastics – a critical appraisal*. In: M Bergmann, L Gutow, M Klages (eds.) Marine Anthropogenic Litter. Springer, Heidelberg, pp. 201-227.

Lusher, A.L., McHugh, M., Thompson, R.C. (2013) *Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel*. Marine Pollution Bulletin 67: 94-99.

MSFD-TSGML (2011) *Marine litter technical recommendations for the implementation of MSFD requirements*. Luxembourg: Joint Research Centre – Institute for Environment and Sustainability.

OSPAR (2015) *Guidelines for Monitoring of plastic particles in stomachs of fulmars in the North Sea area*. OSPAR Commission Agreement 2015-03e (Source: EIHA 15/5/12 Add.1), 26pp.

OSPAR (2009a) *EcoQO Handbook - Handbook for the application of Ecological Quality Objectives in the North Sea*. Second Edition - 2009. OSPAR Biodiversity Series Publication 307/2009. OSPAR Commission London, 65 pp.

OSPAR (2009b) *Marine litter in the North-East Atlantic Region.: Assessment and priorities for response*. London, United Kingdom, 127 pp.

Rochman, C.M. (2015) *The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment*. In: M Bergmann, L Gutow, M Klages (eds.) Marine Anthropogenic Litter. Springer, Heidelberg, pp. 117-140.

Rochman, C.M., Browne, M.A., Underwood, A.J., Van Franeker, J.A., Thompson, R.C., Amaral-Zettler, L. (2016) *The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived*. Ecology 97: 302-312.

Rummel, C.D., Löder, M.G.J., Fricke, N.F., Lang, T., Griebeler, E.-M., Janke, M., Gerdts, G. (2015) *Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea*. Marine Pollution Bulletin 102: 134-431.

Schulz, M., Krone, R., Dederer, G., Wätjen, K., Matthies, M. (2015) *Comparative analysis of time series of marine litter surveyed on beaches and the seafloor in the southeastern North Sea*. Marine Environmental Research 106: 61-67.

Schulz, M., Neumann, D., Fleet, D.M., Matthies, M. (2013) *A multi-criteria evaluation system for marine litter pollution based on statistical analyses of OSPAR beach litter monitoring time series*. Marine Environmental Research 92: 61-70.

Sherrington, C., Darrah, C., Hann, S., Cole, G., Corbin, M. (2016) Study to support the development of measures to combat a range of marine litter sources. Report for European Commission DG Environment. http://ec.europa.eu/environment/marine/good-environmental-status/descrip....

Strand, J., Lassen, P., Shashoua, Y., Andersen, J.H. (2014) *Microplastics and biogeochemical relationships in sediments from Skagerrak, Kattegat and Baltic Sea*. Poster presented the NMC Conference on Plastics in the Marine Environment

Unger, B., Herr, H., Bömert, M., Hillmann, M., Schmidt, K., Siebert, U. (2015) *Marine debris findings in dead stranded harbour porpoises from German waters*. International Whaling Commission SC/66a/E/6.

Unger, B., Herr, H., Benke, H., Böhmert, M., Burkhardt-Holm, P., Dähne, M., Hillmann, M., Wolff-Schmidt, K., Wohlsein, P., Siebert, U. (2017) *Marine debris in harbour porpoises and seals from German waters*. Marine Environmental Research 130:77-84.

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M., Janssen, C.R. (2015) *Microplastics are taken up by mussels (*Mytilus edulis*) and lugworms (*Arenicola marina*) living in natural habitats*. Environmental Pollution 199:10-17.

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, E.W.M., Turner, D.M. (2011) *Monitoring plastic ingestion by the northern fulmar* Fulmarus glacialis *in the North Sea*. Environmental Pollution 159: 2609-2615.

Van Franeker, J.A., Law, K.L. (2015) *Seabirds, gyres and global trends in plastic pollution*. Environmental Pollution 203: 89-96.

Van Franeker, J.A., the SNS Fulmar Study Group (2013) *Fulmar Litter EcoQO monitoring along Dutch and North Sea coasts - Update 2010 and 2011*. IMARES Report C076/13. IMARES, Texel, 61pp.

Veiga, J.M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Galgani, F., Thompson, R.C., Dagevos, J., Gago, J., Sobral, P. and Cronin, R. (2016) *Identifying Sources of Marine Litter*. MSFD GESTG Marine Litter Thematic Report, JRC Technical Report, EUR28309, doi:10.2788/018068.

Wilcox, C., Van Sebille, E., Hardesty, B.D. (2015) *Threat of plastic pollution to seabirds is global, pervasive, and increasing*. Proceedings of the National Academy of Science 112: 11899-11904.