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Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea

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A B S T R A C T

The abundance of plastics in stomachs of northern fulmars from the North Sea is used in the OSPAR Ecological Quality Objective (EcoQO) for marine litter. The preliminary EcoQO defines acceptable ecological quality as the situation where no more than 10% of fulmars exceed a critical level of 0.1 g of plastic in the stomach. During 2003–2007, 95% of 1295 fulmars sampled in the North Sea had plastic in the stomach (on average 35 pieces weighing 0.31 g) and the critical level of 0.1 g of plastic was exceeded by 58% of birds, with regional variations ranging from 48 to 78%. Long term data for the Netherlands since the 1980s show a decrease of industrial, but an increase of user plastics, with shipping and fisheries as the main sources. The EcoQO is now also used as an indicator for Good Environmental Status in the European Marine Strategy Framework Directive.

1. Introduction

Marine debris can have serious economic and ecological consequences. Even on a local scale, such as the Shetland Islands in Scotland, the economic damage can exceed a million Euro's annually (Hall, 2000; Lozano and Mouat, 2009; Mouat et al., 2010). The ecological damage from marine litter is sometimes dramatically illustrated by entangled wildlife. Less apparent are the consequences of the ingestion of plastics and other types of litter, common among a wide range of marine organisms (Laist, 1987, 1997; Derraik, 2002). Plastics gradually break down to microscopic sizes and there is a growing concern that 'micro-plastics' may enter the base of marine food webs via sediment- or filter-feeding organisms (Thompson et al., 2004, 2009; Browne et al., 2008; Graham and Thompson, 2009). These concerns are exacerbated by evidence that plastics, in addition to having many embedded chemicals, also adsorb toxic pollutants from the surrounding water, thus potentially boosting bioaccumulation of dangerous contaminants in the food web by ingestion (Endo et al., 2005; Hale et al., 2010; Teuten et al., 2007; Moore, 2008; Arthur et al., 2009; Teuten et al., 2009). The potential toxic danger of plastic ingestion thus affects the higher food web levels not only

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directly, but also indirectly through the consumption of contaminated prey.

Several early international policy measures attempted to reduce input of litter into the marine environment, such as the 1972 London Dumping Convention, the MARPOL Convention 73/78, and the 1992 Oslo and Paris Conventions for the protection of the marine environment of the northeast Atlantic (OSPAR). In the absence of significant improvement, new policy initiatives were developed by, for example, the EC Directive 2000/59/EC on Port Reception Facilities (EC, 2000), the Bergen Declaration of the North Sea Ministerial Conference (2002) and most recently by the inclusion of litter in the European Marine Strategy Framework Directive (EC, 2008, 2010). Emphasizing the need for policy aims to be quantifiable, the North Sea Ministers decided to establish a system of Ecological Quality Objectives for the North Sea (EcoQO's) to be implemented by OSPAR and ICES (International Council for the Exploration of the Sea). For marine litter, ICES had proposed an EcoQO based on the abundance of plastics in stomachs of seabirds (e.g., ICES-WGSE, 2001). Studies from the North Atlantic and North Pacific had shown that the northern fulmar (*Fulmarus glacialis*) commonly ingests litter and accumulates plastic in the stomach (Bourne, 1976; Baltz and Morejohn, 1976; Day et al., 1985; Furness, 1985; van Franeker, 1985; Moser and Lee, 1992; Robards et al., 1995; Blight and Burger, 1997). Synthetic debris may sometimes be ingested because it somehow resembles prey (Derraik, 2002), but in many instances it is unclear what triggers the ingestion of plastic objects. Unlike many other seabird species, for example gulls, fulmars feed only at sea, never on land and normally do not regurgitate hard prey remains. Indigestible food parts accumulate in the muscular part of the stomach to be slowly ground down to a size that may pass into the gut. Consequently, the abundance of hard prey remains in the stomach, including plastics, provides an integrated picture of ingestion over a period of time before death. Different quantities of plastic in stomachs of fulmars from the North Sea and from the Arctic (van Franeker, 1985), and differences among related species in the Antarctic (van Franeker and Bell, 1988; Ainley et al., 1990) provided early evidence for this basic assumption. In combination with the fulmar's high abundance and wide distribution (Del Hoyo et al., 1992; Hatch and Nettleship, 1998) these features make the species an optimal candidate for the ecological monitoring of litter in the marine environment.

Since the initial identification of the 'Seabird-Plastic-EcoQO' by ICES and the North Sea Ministers, close co-operation has grown between researchers around the North Sea. The work started with a pilot study in the Netherlands, investigating the usage of beached fulmars as an indicator of the effectiveness of Dutch shipping and harbor policies to minimize waste disposal at sea (van Franeker and Meijboom, 2002). The pilot project assessed potential sources of bias influencing stomach contents, adequate sample size and the most appropriate metric to use. Internationally, monitoring of plastics in fulmars started as a part of the 'Save the North Sea' campaign (Save the North Sea, 2004; van Franeker et al., 2005). In a number of research reports (most recent: van Franeker and the SNS Fulmar Study Group, 2008) and policy documents (most recent: OSPAR, 2008) the metrics, data presentation and target definition of the Fulmar-Plastic-EcoQO have gradually been evaluated and matured to a level ready for formal implementation. Although formally still a 'proposed' EcoQO, OSPAR (2010a,b) presents it as being implemented. The EcoQO is based on the mass of plastics in fulmar stomachs, with the preliminary target for acceptable ecological conditions defined as:

"There should be less than 10% of northern fulmars having 0.1 g or more plastic in the stomach in samples of 50–100 beached fulmars from each of 5 different regions of the North Sea over a period of at least 5 years".

The OSPAR target level is an arbitrary political choice, matching pollution levels in environments where anthropogenic influence is expected to be low. Data are lacking to identify a target that represents a no-effect level for fulmars or any other ecosystem component.

The purpose of this article is to disseminate the concept of the Fulmar-Plastic-EcoQO as a tool to quantify trends and geographic patterns in marine litter, which will provide a sound basis for policy decisions in combination with increased public awareness. Similar tools are required for implementation of the 'Good Environmental Status (GES)' requirement in the Marine Strategy Framework Directive (MSFD) (EC, 2008).

2. Materials and methods

In the Netherlands, volunteers of the Dutch Seabird Group (Nederlandse Zeevogelgroep NZG) involved in Beached Bird Surveys have collected dead fulmars for this study since the early 1980s. Other organizations such as coastal bird rehabilitation centers also assist in collecting. Similar sampling began in all countries bordering the North Sea following the start of the Save the North Sea project in 2002, with participating groups in Shetland, Orkney, eastern England, the French Channel, Belgium, Germany, Denmark, Norway and Sweden. These groups ranged from volunteer birders to governmental research institutes and municipal beach cleaning projects. The Faroe Islands have participated in the project as a reference area outside the North Sea. Sampling locations were grouped into the following North Sea regions: Scottish Islands, eastern England, Channel area, southeast North Sea (Belgium, Netherlands, Germany) and Skagerrak area (Denmark, Sweden, Norway).

Fulmar corpses were stored frozen until processed in batches in the laboratory. Standard dissection methods structured the recording of a broad range of data needed to assess sex, age, breeding status, body condition, probable cause of death, origin, and other potentially relevant issues. Thorough attention was given to age-related characters because age was the only variable previously found to influence the quantity of litter in stomachs (van Franeker and Meijboom, 2002). Assessments used developmental stages of sexual organs (size, shape, color) and the presence and size of the Bursa of Fabricius (a gland-like organ near the end of the gut involved in immunity systems of young birds, but disappearing within the first year of life or shortly after). Supporting information on age was derived from plumage details and timing of moult. Complete information on dissection methods and forms used is provided in the project dissection manual (van Franeker, 2004; plus addenda in Online supplement).

After removal of the stomach, contents were carefully rinsed in a sieve with a 1 mm mesh and then transferred to a petri dish for sorting under a binocular microscope. The 1 mm mesh was used because smaller meshes become clogged with mucus from the stomach wall and with food-remains. Analyses using smaller meshes were found to be extremely time consuming and particles smaller than 1 mm seemed rare in the stomachs, contributing little to plastic mass. Plastic items were categorized into industrial- or user plastics. Industrial plastics are the raw granular stock from which all sorts of user objects can be made by melting the granules and adding different substances to give the plastic its desired characteristics. User plastics are the debris of all sorts of consumer products. User plastics and non-plastic rubbish are described in further subcategories (see Online supplement) that are not a part of the formal EcoQO but do play a role in assessments of sources of litter. After sorting, the plastic and rubbish were left to become completely air-dry in open petri-dishes for a number of days. Then, for each individual stomach, the precise number of items and their combined mass was recorded for each subcategory of plastic and litter. Weights were recorded using electronic Sartorius weighing scales to an accuracy of 0.0001 g. Further details of procedures are provided in the Online supplement. Data from dissections and stomach content analysis were initially recorded in Excel spreadsheets and then stored in Oracle relational database. The stomach data allow analyses for subcategories of litter or higher groupings by i) the percentage of birds having the litter in the stomach (incidence or frequency of occurrence) or ii) number of items or iii) mass. As proposed in the Dutch pilot study (van Franeker and Meijboom, 2002) and the international EcoQO (OSPAR, 2008), the main interpretation of data and statistical analyses were based on mass of plastic. The following conventions and definitions apply:

- The 'current situation' is defined as the most recent 5-year period, 2003–2007 for the purposes of this article, in which data are calculated from all individuals within that period (i.e., not from annual averages)
- EcoQO compliance or performance is defined as the percentage of birds in a sample that had 0.1 g or more plastic mass in the stomach
- Statistical tests for significance of temporal trends are conducted by linear regressions fitting ln-transformed plastic mass values for individual birds on the year of collection
- 'Recent trend' is defined as the trend over the past 10 years
- 'Long term trend' refers to the full dataset (for the Netherlands from the first individual in 1979)

For evaluation of regional differences, data from individual birds over the most recent 5- year period were fitted in a negative binomial generalized linear model and tested by likelihood ratio test (Venables and Ripley, 2002).

Annual averages are of limited use because small sample sizes, short-term variations and individual outliers can have a strong effect on results. Thus, as in the EcoQO target definition, 5-year periods are used as the basic unit for data presentation in tables and figures. Time related changes are illustrated by running 5-year averages, each time shifting one year and thus overlapping for four years. Where needed, short-term inter-annual comparisons are based on geometric means, derived from logarithmically transformed data. See the Online supplement for details illustrating the skewed distribution of mass data and the relation to arithmetic averages, geometric means and the critical level of 0.1 g used in the EcoQO.

3. Results

3.1. Long term litter trends based on Dutch data

The incidence of plastic in stomachs of fulmars from the Netherlands averaged 91% in the 1980s, increased to about 98% around the year 2000 and has since stabilized at a level slightly below 95% (Table 1). The average number of plastic particles per bird was c. 15 in the 1980s, increased to over 30 around the turn of the century and currently averages 26. Greater differences exist in average mass of plastic: initially, as with the number of items, mass of plastic doubled from 0.34 g in the 1980s to 0.64 g in the late 1990s. However, whereas the number of particles decreased only slightly in subsequent years, the mass of plastic in the stomachs halved to a now fairly stable level of 0.28 g of plastic per beached fulmar, slightly below the 1980s level. A similar but more dampened time trend may be seen in geometric mean masses for 5-year periods, and in gradual changes in the EcoQO percentage of birds exceeding the critical limit of 0.1 g of plastic in the stomach. Remarkably, the EcoQO percentage did not reveal an obvious change from the 1980s to the late 1990s despite the marked changes in numbers of particles and mass. This is probably related to the size and mass differences between industrial and user plastics and their changing proportions (see below). However, after the mid-1990s the percentage of birds exceeding the critical level of 0.1 g did show a 10% decrease although this has not continued in the most recent periods. (Table 1, Fig. 1 and Online supplement Table 2 for statistical details).

For the overall mass of plastics (industrial plus user) in the stomachs of Dutch fulmars, the regressions for long term trends show no significant change as linear tests do not take the initial increase and subsequent decrease into account. Restricted to the period after the mid-1990s, the short-term (10-year) trends for mass of plastic were initially significantly downwards (e.g., $p < 0.001$ for 1996–2005), but have stabilized and are no longer significant in the most recent test for 1998–2007. Trends in abundance for the two major types of plastic were very different (Fig. 2). Measured over the full time frame of 1979–2007, industrial plastic has decreased significantly. User plastics have increased but not with consistent significance in all age groups of birds (Online supplement Table 2). The main change occurred from the 1980s to 1990s: when industrial plastic mass in stomachs decreased by half (decrease1979–2000 $p < 0.001$) but user plastics tripled (increase 1979–2000 $p < 0.001$). Both categories showed decreases after the mid-1990s that were significant initially (1996–2005 decreases $p = 0.007$ for industrial and $p < 0.001$ for user plastic) but currently show no further change (both not significant for 1998–2007).

3.2. Current litter levels in the wider North Sea

Analyses of time related trends for North Sea areas other than the Netherlands are not yet available as data collection in most of those areas began in 2002 and 2003 and the minimum period for trend analysis is taken as 10 years. Data presented here are for the 'current' 5-year period in our analysis, i.e., 2003–2007. The fulmar stomachs reveal clear spatial patterns of litter pollution in the North Sea (Table 2 and Fig. 3 and Online supplement). The Likelihood ratio test of the negative binomial model for the five regions indicated significant differences (LR stat 11.1832; df = 4; $p = 0.025$). The abundance of plastics was highest in fulmars from the Channel area, and gradually decreased northwards along both the eastern and western coasts of the North Sea. The Channel area differed significantly from the neighboring regions of East England (LR Stat 4.7074; df = 1; $p = 0.030$) and the SE North Sea (LR Stat 5.0886; df = 1; $p = 0.024$). The decreases from East England to the Scottish Islands and from the SE North Sea to the Skagerrak were not significant.

4. Discussion

Initial evaluation of the time series of Dutch fulmars (van Franeker and Meijboom, 2002) found that only the age composition of samples of beached birds might cause bias in analyses for trends over time, with younger birds having more plastic in the stomach than older birds. Data added after the pilot study showed that the age difference is consistent to a level that all different age groups can be combined into a single monitoring unit. The annual geometric mean mass of plastics shows the same long-term pattern, and the same short-term annual fluctuations for adults and non-adults, in spite of the substantial difference between these groups (Fig. 4). Thus, as long as age composition of samples is considered, any risks of age-related bias can be controlled for and policy reports may use simple "all age" derived graphs such as in Fig. 1. The details of, and reasons for the higher loads of plastics in younger birds are unclear. Preliminary data from

Table 1
Incidence, number of particles and mass of plastics in stomachs of fulmars beached in the Netherlands in the 1980's and 'running' 5-year periods since 1995. Mass data are also shown as geometric mean mass, and as percentage of stomachs with more than 0.1 g of plastic (EcoQO performance).

5-year period	*n*	Incidence %	Average number $n \pm$ se	Average mass g $\pm$ se	Geometric mean mass (g)	Over 0.1 g EcoQO %
1980s	69	91%	14.6 ± 2.0	0.34 ± 0.06	0.11	67%
1995–1999	222	97%	32.7 ± 3.7	0.64 ± 0.13	0.15	67%
1996–2000	258	98%	31.3 ± 3.2	0.60 ± 0.12	0.15	67%
1997–2001	304	97%	29.9 ± 2.8	0.55 ± 0.10	0.14	63%
1998–2002	329	98%	33.1 ± 3.3	0.52 ± 0.10	0.13	62%
1999–2003	294	98%	33.5 ± 3.6	0.37 ± 0.06	0.11	59%
2000–2004	318	95%	28.8 ± 2.9	0.30 ± 0.04	0.09	59%
2001–2005	331	95%	27.9 ± 2.7	0.29 ± 0.04	0.09	57%
2002–2006	304	94%	29.3 ± 3.0	0.30 ± 0.04	0.09	61%
2003–2007	309	93%	26.5 ± 2.1	0.28 ± 0.02	0.09	61%

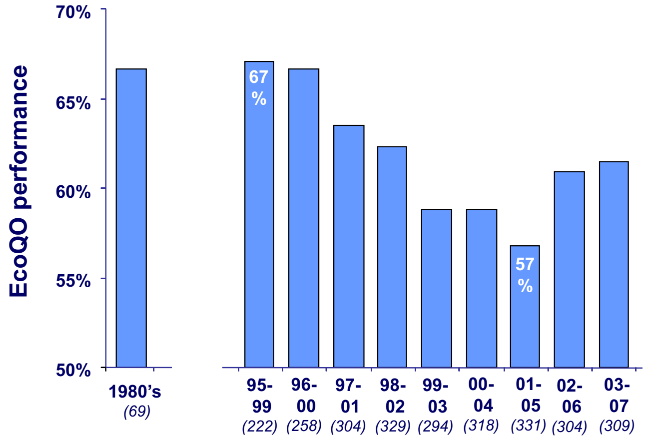

Fig. 1. EcoQO performance in the Netherlands 1980–2007 – Trend in the percentage of beached fulmars having more than 0.1 g of plastic in the stomach (running average over 5-year periods, each bar shifting one year; number of birds in brackets below each bar). Note that the *Y*-axis only shows the 50–70% range whereas the OSPAR target for the EcoQO is that less than 10% of birds should have more than 0.1 g of plastic in the stomach.

an ongoing study on seasonal changes on the Faroe Islands suggest that breeding adults may lose part of their plastics burden by feeding it to chicks, but the effects are short-term and insufficient to fully explain the differences between age groups.

Insights into the temporal aspects of fulmar monitoring data can be derived from Fig. 4. An aberrant peak in plastic abundance occurred in 2002 but the consistency of the pattern between age groups indicates a real event rather than an accidental outlier. Such consistency often persists even for smaller sample sizes, which might suggest that the power analyses in van Franeker and Meijboom (2002) and the OSPAR (2008) recommendations for an annual sample size of c. 40 birds per location, the use of 5-year averages and a minimum of 10 years for statistical tests for trends over time may be overly cautious. However, we emphasize that caution must be maintained in information that is used for long-term policy decisions, especially when short-term events such as that in 2002 are not properly explained: possibly flooding in central Europe caused increased riverine input of litter into the North Sea in 2002, but we found no way to substantiate this quantitatively. Thus, although we believe that annual geometric means will generally reflect true developments, management decisions should only rely on longer-term data evaluations. For the long term, there are no comparative datasets in the North Sea area. However, for the period after 2002, results from beach surveys around the North Sea confirm the finding from the Fulmar monitoring in showing that there is no change in the amount of beached debris (OSPAR, 2010a).

Questions concerning the spatial resolution of fulmar plastic monitoring are gradually being clarified. Starting with the Save the North Sea project in 2002, monitoring was expanded to a wide range of locations around the North Sea. In theory, the flying abilities of fulmars allow them to travel over much or all of the North Sea in a single or in a very few days. This led to the expectation that local differences of pollution within the North Sea area were unlikely to be clearly reflected in fulmar stomach contents. However, even though we only have 5–6 years of data, and less for some locations, data combined into regions reveal a clear pattern in mass of plastics in the fulmar stomachs in the North Sea. Highest levels occur in the English–French Channel area, and these decrease northwards, reaching a minimum for the North Sea around the Scottish Islands (Fig. 3 and Table 2). Such a pattern shows that the bulk of debris in the North Sea must be of relatively local origin, and cannot be attributed to a 'background noise' of litter drifting in from distant sources such as the western Atlantic. Warm Gulf Stream water flows into the North Sea around both the north and south of the UK, and elevated levels of litter in the Channel and southern North Sea compared to the Scottish Islands provide evidence for litter sources that are predominantly local. The geographic pattern and variations in subcategories of litter indicated that shipping and fisheries play a major role in the pollution of the North Sea with plastic (van Franeker et al., 2005), a conclusion confirmed by a large inventory of litter on the beaches

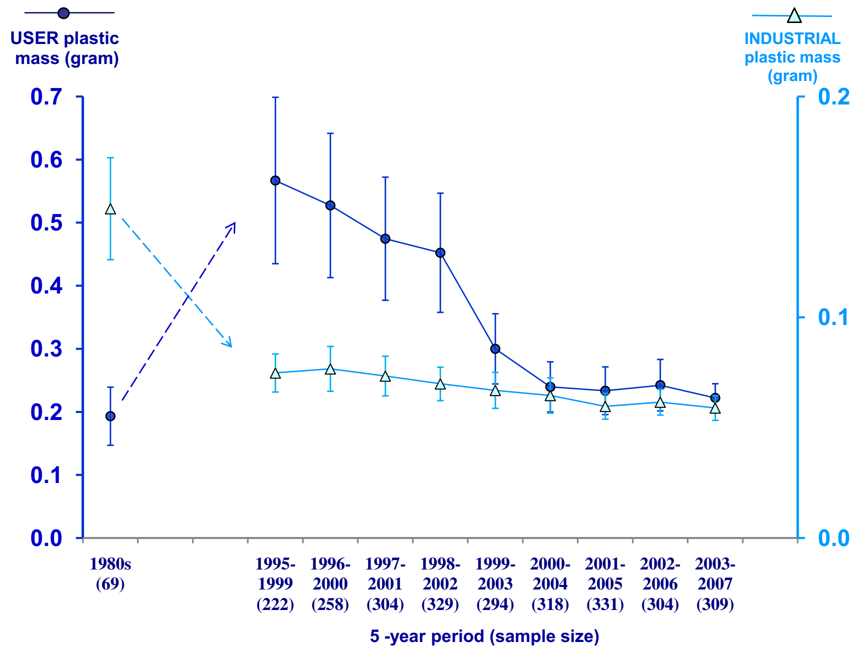

Fig. 2. Trends for industrial and user plastics in the Netherlands 1980–2007 – Running 5-year average mass ± standard error for the two main categories of plastic in stomachs of beached fulmars from the Netherlands.

Table 2
Incidence, number of particles and mass of plastics in stomachs of fulmars beached in different North Sea regions during the 5-year period 2003–2007. Mass data are also shown as geometric mean mass, and as percentage of stomachs with more than 0.1 g of plastic (EcoQO performance).

Region	*n*	Incidence %	Average number *n* ± se	Average mass g ± se	Geometric mean mass (g)	Over 0.1 g EcoQO %
Scottish Islands	95	92%	18.9 ± 3.0	0.20 ± 0.03	0.06	48%
East England	60	95%	35.0 ± 6.9	0.23 ± 0.03	0.11	60%
Channel area	107	100%	56.7 ± 8.3	0.44 ± 0.06	0.23	78%
SE North Sea	842	94%	30.4 ± 3.0	0.30 ± 0.02	0.09	58%
Skagerrak area	191	95%	47.7 ± 8.6	0.36 ± 0.11	0.08	50%
North Sea total	1295	95%	34.5 ± 2.5	0.31 ± 0.02	0.09	58%

of Texel in the Netherlands in 2005 (van Franeker, 2005). These findings for the North Sea conflict with an opinion that globally most marine debris has a land-based origin (MEPC, 2009).

The spatial differentiation of stomach contents over relatively small scales implies that, despite potentially high mobility, the average fulmar in the average situation spends ‘prolonged’ periods of time within a restricted sea area, enough time to accumulate a (on average) characteristic level of litter in the stomach. Of course if storm-driven winter movements or synchronous returns to colonies are followed by sudden mortality, stomach contents may incidentally not reflect local conditions. Such incidents may distort the occasional annual value, but not the average multi-year picture.

Concerning the aspect of stomach contents not always reflecting the ‘local’ situation, it is relevant to know how long it takes a fulmar to accumulate an amount of plastic characteristic for the foraging area. We have no way to determine this directly, but can make a rough assessment of time scales from the rate of disappearance of plastics from stomachs. Early publications indicated long residence times for plastics in seabird stomachs, Day et al. (1985) suggesting an average of 6 months or more for plastic particles to disappear through wear in the gizzard and subsequent passage through the gut, while Ryan and Jackson (1987) estimated a half-life of at least one year for plastic granules in the stomachs of White-chinned Petrels *Procellaria aequinoctialis*. However, these are probably serious overestimates. van Franeker and Bell (1988) observed that Cape Petrels *Daption capense* returning to clean Antarctic waters after wintering in northern, more polluted environments lost 80–90% of plastics from their stomachs in just over a month. As described in the Online supplement, disappearance rates for squid beaks in several species of Antarctic fulmarine petrels (van Franeker et al., 2001) and datasets on plastics in high Arctic Canadian fulmars (Mallory, 2008) and thick-billed murres *Uria lomvia* (Provencher et al., 2010) accord with such rapid rates of disappearance. From these data, disappearance rates of plastics from stomachs can be conservatively estimated at over 75% per month. In the North Sea, where soft foamed and sheet-like plastics are commonly ingested, disappearance may be considerably faster, and it is reasonable to assume that fulmars lose or accumulate characteristic local pollution levels within time frames of at most a very few weeks or even a number of days.

The main purpose of this paper was to provide insight into the reliability of the Fulmar EcoQO approach as a scientific instrument for policy decisions concerning marine litter. Nevertheless, major conclusions on trends, regional patterns, sources of litter and potential meaning for policy decisions should be discussed here too.

Within the Dutch time series, the pattern of plastic litter, peaking in the 1990s followed by a sharp downward trend back to earlier levels, appears dominated by a high figure for 1997 (Fig. 4). Nevertheless if in the standard 10-year analysis (1997–2006 decrease $p < 0.001$) all 1997 data are left out, the trend remains significant (1998–2006 decrease $p = 0.003$). In arithmetic annual averages for mass of plastics (Supplement Table 1) the value for the large 1998 sample exceeds that for 1997, indicating that the pattern is not caused by a single odd year.

The most remarkable change in the long term dataset concerns the reduced pollution by industrial plastic, unfortunately compensated for by an increase in user plastic debris (Fig. 2.). This phenomenon was previously documented by van Franeker and Meijboom (2002) and has also been observed in the north Pacific (Vlietstra and Parga, 2002), and in the south Atlantic and southwest

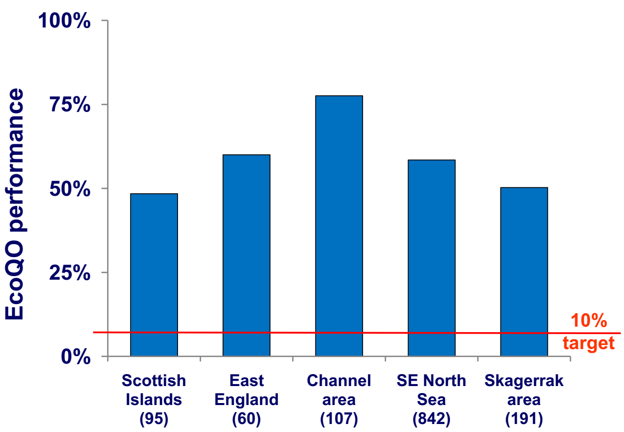

Fig. 3. EcoQO performance in North Sea regions 2003–2007 – Percentages of beached fulmars having more than 0.1 g of plastic in the stomach over the 2003–2007 5-year period in different regions around the North Sea.

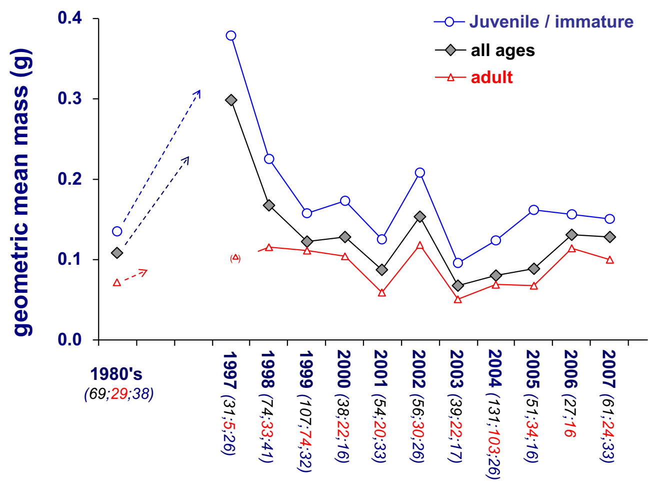

Fig. 4. Annual geometric means for mass of plastics in stomachs of beached fulmars from the Netherlands 1982–2007 for all age groups combined (including birds of unknown age), adult birds and non-adults, with sample sizes (all ages; adults; non-adults) in brackets in the *x*-axis labels. Data-points are shown for sample sizes of 10 stomachs or more.

Indian Ocean (Ryan, 2008). The economic value of raw industrial plastic may have been an incentive to reduce losses from industrial processing plants and during transport. Increased container transport as well as improved waste water treatment will have reduced loss of granules to the environment. Unfortunately, economic incentives are largely lacking as a stimulus to reduce the discarding of consumer plastics. Consequently, the current overall plastic pollution level may be similar to that in the 1980s, but its composition and origin have changed markedly. Such findings stress the importance of recording subcategories of plastics, even if the EcoQO considers all plastics together.

Being aware of the role of shipping, the European Commission decided that global rules for ships in MARPOL Annex V were insufficiently effective, and introduced a Directive to enhance proper waste disposal at harbors (EC, 2000). In the Netherlands, the fulmar monitoring has been financed as a tool to evaluate the effectiveness of this Directive after its implementation in 2004. As yet, fulmar data from the Netherlands show no significant improvements in the marine litter situation in the North Sea since implementation of the Directive, a finding corroborated by the OSPAR Beach Litter Surveys (OSPAR, 2010a). An evaluation of the effectiveness of the Directive should, however, take into account increases in shipping traffic and in the proportion of plastics in wastes.

The EcoQO target for 'acceptable ecological quality' has been defined by OSPAR as the situation where less than 10% of fulmars carry more than 0.1 g of plastic (OSPAR, 2008). In the North Sea, currently 58% (48–78% depending on area) of fulmars exceed this level (Table 2). The considerable gap between the current situation and the target is of concern and raises the question of whether the EcoQO target is realistic, even in the long term (no target date was set by OSPAR). The Save the North Sea study has used stomachs of fulmars from the Faroe Islands as an outside reference; currently 44% of Faroe birds exceed the critical level of 0.1 g of plastic (Fig. 5 and details in Online supplement). At present, the EcoQO target is only approached by fulmars in the eastern Canadian Arctic, where data suggest regional averages of 40% incidence, 2.5 particles and 0.03 g per bird, and 14% of birds exceeding 0.1 g of plastic in the stomach (Mallory et al., 2006; Mallory, 2008; Provencher et al., 2009). The true local pollution level is probably lower, because some birds were sampled early in the breeding season and probably contained plastics from wintering areas further south (see Discussion on disappearance rates in Online supplement).

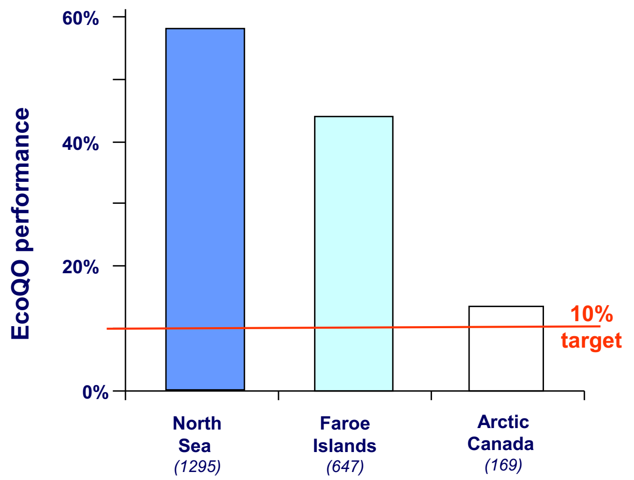

Fig. 5. EcoQO performance in North Sea 2003–2007 and reference areas in relation to the OSPAR EcoQO target. Canadian data calculated from Mallory et al. (2006), Mallory, (2008), Provencher et al. (2009) and personal information from these authors.

Increased pollutant loads have been observed in soils below high arctic breeding colonies of fulmars (Choy et al., 2010), in which a contribution from excrement containing digested plastics seems a reasonable assumption. The long term OSPAR EcoQO target for the North Sea can be seen as realistic, because the target level already exists in relatively clean areas of the North Atlantic.

The EcoQO approach for the North Sea has also been adopted as an indicator for Good Environmental Status (GES) in the European Marine Strategy Framework Directive (MSFD) (EC, 2008; Galgani et al., 2010; EC, 2010). In some European marine areas the Fulmar EcoQO is directly applicable, although copying the undated OSPAR target to the MSFD date of 2020 could be considered too ambitious. If so, an alternative target such as a 'significant' or 'fixed percentage' decrease could be formulated for the short-term. Fulmars do not inhabit all the regions covered by the MSFD and feasibility studies of plastic ingestion by other seabird species, marine mammals, sea-turtles, fish or invertebrates will be needed to establish a Europe-wide monitoring system for the impacts of marine litter.

Marine organisms like the fulmar continuously integrate litter levels in their environment in a way that is virtually impossible to replicate by direct physical measurements (Ryan et al., 2009). EcoQO trends (Fig. 1) and patterns (Fig. 3) provide policy makers with a statistically robust basis for urgently needed management decisions aiming at improving the quality of European marine environments.

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Beached fulmars are mainly collected by volunteers, too many to be named individually, but without whom a project such as this would have been impossible. This publication is therefore dedicated to all our helpers around the North Sea.

Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.envpol.2011.06.008.

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ONLINE SUPPLEMENT

to

Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea.

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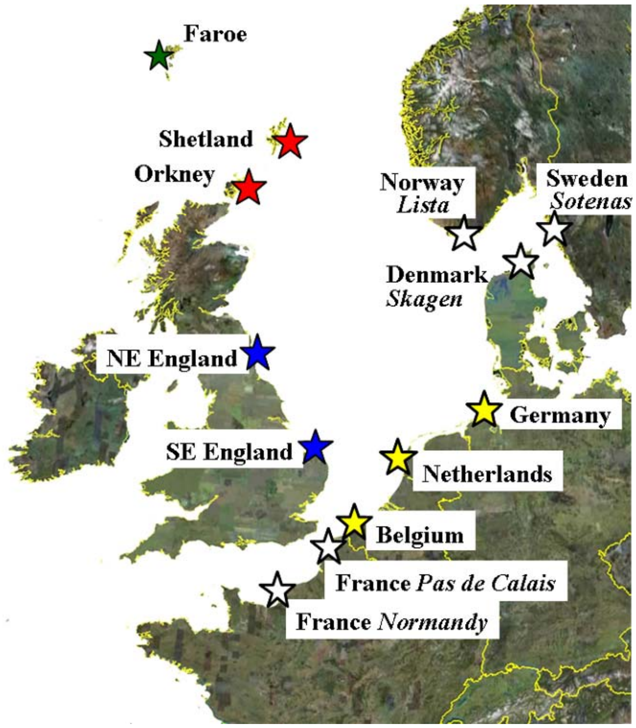
Relevant webpages
Downloadable pdf files of all earlier reports and other material of this fulmar study are most easily available at www.zeevogelgroep.nl. More general information on the plastic pollution issue can be found at: www.imares.wur.nl/UK/research/dossiers/plastic/

Contents of online supplement

1. Locations and contact details of partners in the Fulmar EcoQO study



Supplement-Fig. 1.
Fulmar-Litter-EcoQO study sites (colour of symbol indicates regional grouping)

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Save the North Sea

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Chevron Upstream Europe

2. Addenda to the Fulmar EcoQO dissection manual

Two new data fields have been added to the standards presented in the dissection manual (van Franeker 2004; available at www.zeevogelgroep.nl under downloads).

The additions are:

Body Moult Internal:
This is checked on the feather-fields on the breast, to the left and right of where we open the bird

- blank = not recorded
- 0 = no internal moult (no feather-shafts growing = growing feathers have soft, white, broad open ended shafts)
- 1= yes or yes weak (1 to 5 new shafts as above in one of the breast fields)
- 2 = yes specified strong (more than 5 new shafts in one breast feather-field)

(in very fat birds, some subcutaneous fat has to be scraped off to be able to assess the score)

condition of DOWN on belly plus breast (check both)

- blank = not recorded
- 0 = down virtually absent (i.e. bare skin or with few bare "pins)
- 1 = poor (some down may be present, but clearly insufficient to cover whole skin)
- 2 = moderate (not as complete as possible, but more or less covering skin)
- 3 = down ok (nice thick coverage of the whole skin)
- ? = checked, but can not decide (corpse too old or too wet ......)

When the down is wet, care should be taken to make an estimate of what it looks like when dry. Care must be taken with older decaying corpses, where down on belly can easily be wiped off. Also be aware of the 'incubation patch' in the breeding season (from about May to late July), The skin on brood patch looks different, is more pinkish in colour, and often a bit wrinkled. Sometimes, down condition can differ substantially between breast and belly: in those cases take average score for the two.

A pdf file of the currently used forms may be requested from jan.vanfraneker@wur.nl

3. Methods for stomach analysis in the Fulmar EcoQO

The stomachs of dissected birds are opened by scissors or scalpel. Stomachs of fulmars have two 'units'. The first large glandular stomach (the proventriculus) is used to store food and initiate digestion. From here, the food passes into a second smaller muscular stomach (the gizzard) where harder prey remains can be processed through mechanical grinding before contents can pass into the gut. If ingestion rates of hard items (like plastics) are too high, they accumulate not only in the gizzard but also take up space in the proventriculus. In some older data-series, data on contents of the two stomachs were recorded separately, but this is time consuming and without major benefit for monitoring: thus for efficiency reasons, proventriculus and gizzard contents are combined in the EcoQO.

If at the initial opening of the stomachs, oil or chemical types of pollutants appear to be present, these are sub-sampled and weighed before further processing. Greasy substances, often similar to palm-oil or paraffin, but sometimes containing toxic mixtures (Camphuysen et al. 1999) are common at sea and on beaches and also seen regularly in fulmar stomachs. Recording the details of such substances is unfortunately not a standard component of the funding for the Dutch ‘graadmeter’ nor the international EcoQO because the authorities do not classify such wastes as marine litter as defined in MARPOL Annex V.

Stomach contents are carefully collected in a sieve with 1 mm mesh and thoroughly rinsed with cold running water to remove mucus from the proventricular walls and digested soft food components. If sticky substances hamper further processing of the litter objects, hot running water and if needed detergents are used to clean them.

After rinsing, remaining elements of the stomach contents are transferred to a petri-dish for sorting under a binocular microscope. The following categorization (acronyms in brackets) is used for sorting litter items found in the stomachs:

1. PLASTICS (PLA)
    - 1.1. Industrial plastic pellets (IND). These are small, often cylindrically-shaped granules of ± 4 mm diameter, but disc and rectangular shapes also occur. Various names are used, such as pellets, beads or granules. They can be considered as “raw” plastic or a half-way product of the form in which plastics are usually first produced (mostly from mineral oil). The raw industrial plastics are then usually transported to manufacturers that melt the granules and mix them with a variety of additives (fillers, stabilizers, colourants, anti-oxidants, softeners, biocides, etc.) that depend on the user product to be made. For the time being, included in this category is a relatively small number of very small, usually transparent spherical granules, also considered to be a raw industrial product.
    - 1.2. User plastics (USE) (all non-industrial remains of plastic objects) differentiated in the following subcategories:
        - 1.2.1. sheetlike user plastics (she) as in plastic bags, foils and clingfilm etc., usually broken up in smaller pieces;
        - 1.2.2. threadlike user plastics (thr) as in (remains of) ropes, nets, nylon line, packaging straps etc. Sometimes ‘balls’ of threads and fibres form in the gizzard;
        - 1.2.3. foamed user plastics (foa), as in foamed polystyrene cups or packaging or foamed polyurethane in matresses or construction foams;
        - 1.2.4. fragments (fra) of more or less hard plastic items as used in a huge number of applications (bottles, boxes, toys, tools, equipment housing, toothbrushes, lighters etc);
        - 1.2.5. other (oth), for example cigarette filters, rubber, elastics etc., i.e. items that are ‘plastic-like’ or do not fit into a clear category.
2. RUBBISH (RUB) other than plastic:

2.1. paper (pap) which besides normal paper or cardboard includes laminated packaging materials in which paper appears to dominate (e.g. tetra-pack), silver paper, aluminum foil etc, i.e. various types of non-plastic packaging material;
2.2. kitchen-food (kit) for human food wastes such as fried meat, chips, vegetables, onions etc, probably mostly originating from ships' galley refuse;
2.3. various rubbish (rva) is used for e.g. pieces of timber (manufactured wood); paint chips, pieces of metals etc.;
2.4. fish hook (hoo) from either sport fishing or long lining.

These sub-categories go into more detail than is the basic requirement for quantifying plastic litter in the OSPAR EcoQO. However, the refined categorization is considered essential as background information in the EcoQO to identify regional differences or temporal changes in types and sources of litter that may require dedicated policy decisions.
After sorting, the plastic and rubbish contents are left in open petri-dishes to become completely air-dry. Two days drying time is the usual minimum, but certain types of material e.g. larger pieces of foamed material, may take longer to become completely dry. After drying, for each individual stomach content and each subcategory of plastic and litter, the precise number of items and their combined mass in the subcategory is recorded. Weights are taken using electronic Sartorius weighing scales to an accuracy of the 4th decimal of a gram (= tenth of milligram). Weights of items below this level are recorded at the minimum of 0.0001 gram.
These records then allow analyses for litter subcategories or higher groupings by i) percentage of birds having the litter in the stomach (incidence or frequency of occurrence) or ii) number of items or iii) mass. Analyses using incidence and numbers of items are not part of the requirements of the EcoQO definition (which uses mass), but add valuable information on (changes in) litter characteristics and allows comparison with published literature which has largely focused on incidence or number of particles rather than mass.

All plastic samples from this project are kept in dry storage to allow further analyses if warranted. For example, in the EcoQO approach, many details of plastic objects, including plastic type, colour or individual particle size or mass are not recorded, but may be relevant for other later analyses (e.g. Shaw & Day 1994).

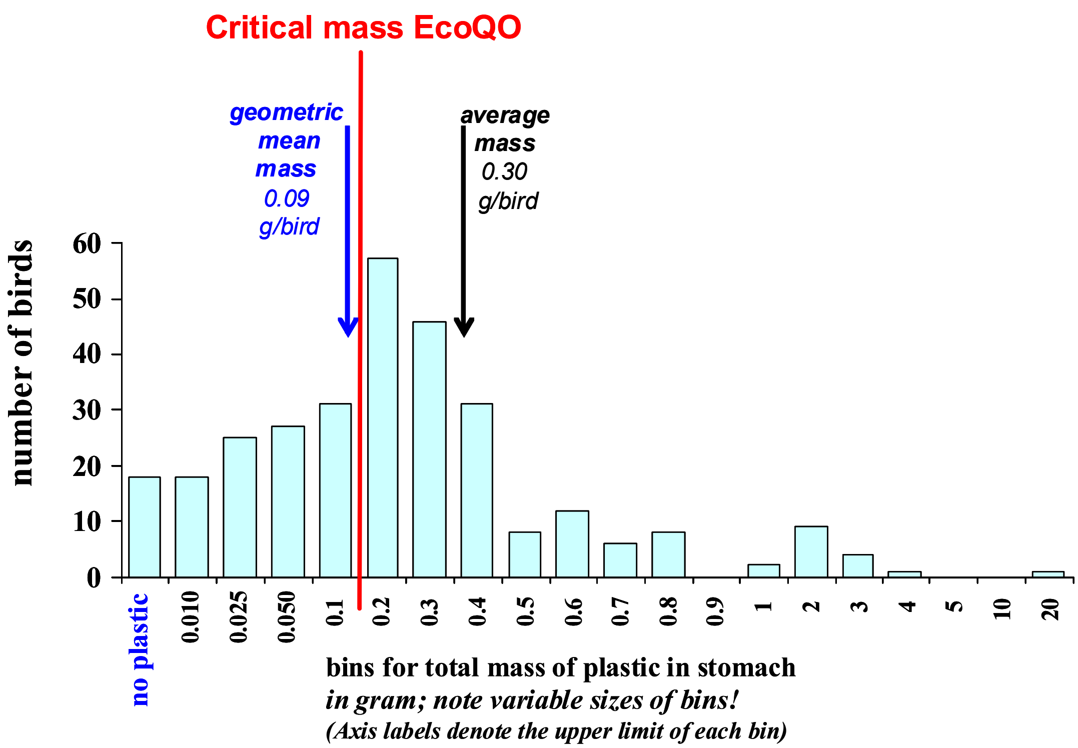
During the stomach sorting, materials other than plastic and rubbish have to be separated out anyway, and depending on other aims of project participants, these may be categorized and processed as:

3. POLLUTANTS (POL) for materials of industrial or chemical origins in subcategories of: coal or slag (remains of ore after extraction of metals); tar-lumps (remains of mineral oil); chemical (lumps or 'mud' of paraffin-like materials or sticky substances arbitrarily judged to be unnatural and of chemical origin) and feather-lumps (indicating excessive preening by the bird of feathers sticky with oil or chemical pollutants).
4. NATURAL FOOD REMAINS (FOO) in which numbers of specific items may be recorded in separate subcategories (fish otoliths, eye-lenses, squid-jaws, crustacean remains, jelly-type prey remains, scavenged tissues including feathers, insects, other).
5. NATURAL NON-FOOD REMAINS (NFO) for e.g. remains of plants, seaweeds, pumice, stones and other natural items that can not be considered as normal food.

In addition to acronyms used for the above (sub)categories, further acronyms describe datasets: logarithmic transformed data 'ln'; mass data by 'G' (gram); numerical data by 'N' (number). For example lnGIND refers to the dataset that uses ln-transformed data for the mass of industrial plastics in the stomachs; acronym NUSE refers to a dataset based on the number of items of user plastics.

4. Skewedness of data in relation to EcoQO metrics

Fluctuations in year to year comparisons in ingested plastic and differences in EcoQO performance are easier to understand with some insight in the frequency distribution of data. Supplement-Fig. 2. shows numbers of birds falling in categories ('bins') of plastic mass for the Netherlands over the period 2002-2006 (304 birds). The labels on the x-axis show the upper limit of each bin, i.e. the bin labeled 0.2 g represents the category for all birds with plastic masses in the stomach between 0.1g and 0.2g. In reading the graph, be aware that bin sizes are arbitrarily chosen representing ranges of a few mg at the left end of the scale to several grams at the right end of the scale.



Supplement-Fig. 2. Skewed frequency distribution of plastic mass in stomachs of Dutch fulmars 2002-2006 (304 birds) in relation to average mass, geometric mean mass and critical value in the EcoQO definition (van Franeker, J.A. and SNS Fulmar Study Group 2008). NB: note unequal bin sizes on x-axis used to compress large data range!

Incidence of plastic can be read from the graph by comparing the first bar (no plastic; 0 gram) to the sum of all other bars.
The (arithmetic) average mass of plastic is well above the most frequently occurring values because it includes extreme cases of over 10 grams of ingested plastic, 2 orders of magnitude above the most common type of stomach contents. In small samples (e.g. annual figures) the presence or absence of such an extreme may cause significant fluctuations in the average.

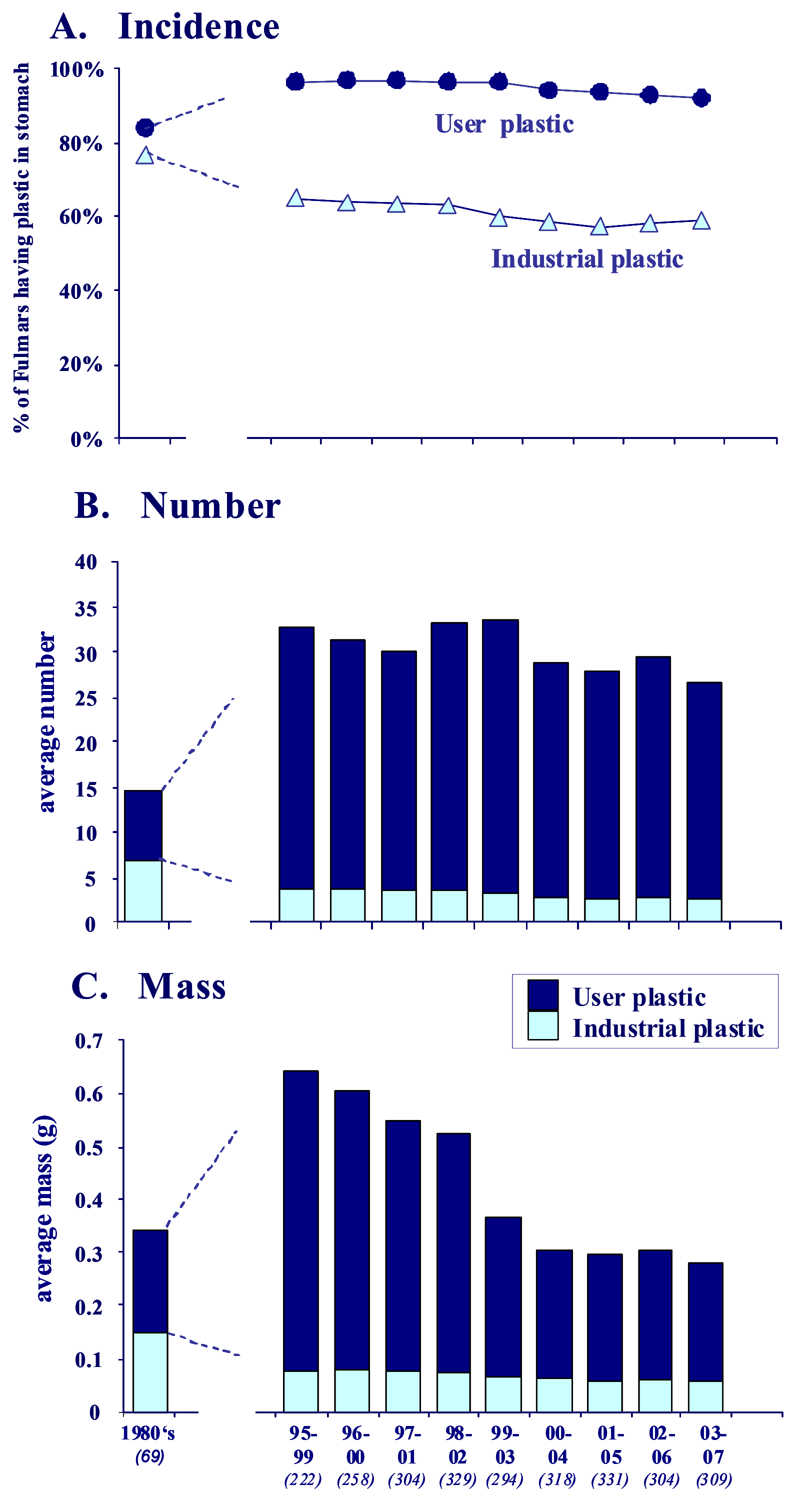
The geometric mean mass reduces such strong fluctuations by logarithmic transformation of data (which reduces high values and results in a mean closer to the most commonly occurring values). Thus, the geometric mean mass is a more appropriate basis to compare smaller samples between years or between locations. The disadvantage is that many people will read it as an 'average' which it is not, and it even underestimates the most abundantly occurring stomach contents.
The definition of the EcoQO uses another approach to reduce the influence of extreme values by comparing the number of birds having less than 0.1 g of plastic to those above that critical value. In that system, a bird with 0.2g of plastic is no different from the extreme bird with 20 grams of plastic. The fact that this report showed sudden interannual fluctuations is thus not attributable to extremes, but has a different background in the fact that currently, a very large proportion of the birds is very close to the critical value. In small samples (annual or regional), this may lead to sudden fluctuations in the EcoQO result. Such instability of the EcoQO figure will disappear when the most commonly occurring mass of plastics shifts away from the critical value.
In conclusion, the above implies that (changes in) normal average data and EcoQO performance are best viewed over longer periods and larger sample-sizes. Where interannual or regional comparisons do require usage of smaller sample-sizes, geometric means give the best guidance for interpretation of data.

5. Data details on fulmars from the Netherlands

Supplement-Table 1
Annual details for plastic abundance in fulmars from the Netherlands
For separate and combined plastic categories, incidence (%) represents the proportion of birds with one or more items of that litter present; number (n) abundance by average number of items per bird; and mass (g) abundance by average mass per bird in grams. The column on the far right indicates level of performance in relation to the OSPAR EcoQO, viz. the percentage of birds having more than the critical level of 0.1 gram of plastic in the stomach. The bottom line of the table shows the 'current' situation as the average over the past 5 years. *Note sample sizes (n) to be very low for particular years implying low reliability of the annual averages for such years, not to be used as separate figures. Also note erratic variability in age proportions of birds in samples, where age is known to influence amount of litter in the stomach. Trend analyses (Supplement-Table 2) are not based on annual averages, but on values from all individual birds, together and in age-groups, to overcome problems of years of poor sample size or variable age composition.*

			INDUSTRIAL PLASTICS			USER PLASTICS			ALL PLASTICS (industrial + user)			EcoQO
YEAR	*n*	% adult	%	n	g	%	n	g	%	n	g	> 0.1 g
1979	1	0%	100%	2.0	0.07	100%	3.0	0.17	100%	5.0	0.24	100%
1980												
1981												
1982	3	0%	100%	5.0	0.11	67%	6.0	0.50	100%	11.0	0.61	100%
1983	19	37%	84%	8.8	0.19	89%	7.2	0.31	100%	16.0	0.49	89%
1984	20	40%	70%	9.6	0.19	90%	8.4	0.17	90%	17.9	0.35	55%
1985	3	33%	100%	5.3	0.14	100%	5.0	0.14	100%	10.3	0.28	100%
1986	4	25%	50%	0.8	0.02	75%	4.8	0.06	75%	5.5	0.08	25%
1987	15	67%	80%	3.9	0.11	67%	8.9	0.09	80%	12.7	0.20	53%
1988	1	0%	0%	0.0	0.00	100%	2.0	0.04	100%	2.0	0.04	0%
1989	4	50%	75%	5.3	0.14	100%	11.0	0.16	100%	16.3	0.29	75%
1990												
1991	1	0%	0%	0.0	0.00	100%	11.0	0.14	100%	11.0	0.14	100%
1992												
1993												
1994												
1995	2	50%	100%	1.5	0.02	100%	3.5	0.03	100%	5.0	0.06	0%
1996	8	63%	75%	2.9	0.07	100%	24.5	0.19	100%	27.4	0.26	63%
1997	31	16%	74%	5.9	0.13	97%	29.8	0.60	97%	35.8	0.73	84%
1998	74	45%	69%	3.1	0.07	95%	25.9	0.88	96%	29.0	0.95	72%
1999	107	69%	58%	3.4	0.06	97%	31.8	0.38	98%	35.3	0.44	61%
2000	38	58%	61%	3.4	0.08	100%	18.6	0.27	100%	22.0	0.35	61%
2001	54	37%	63%	2.6	0.06	96%	20.4	0.18	96%	22.9	0.24	48%
2002	56	54%	68%	4.6	0.09	96%	47.2	0.41	98%	51.8	0.50	68%
2003	39	56%	51%	2.3	0.05	92%	26.3	0.12	95%	28.5	0.17	54%
2004	131	79%	54%	2.6	0.06	91%	20.8	0.22	91%	23.4	0.27	60%
2005	51	67%	53%	2.0	0.05	96%	15.8	0.22	98%	17.8	0.27	47%
2006	27	59%	78%	3.5	0.08	93%	30.4	0.23	93%	33.9	0.30	85%
2007	61	39%	70%	3.1	0.07	90%	32.5	0.30	92%	35.6	0.37	70%
03-07 *	309	64%	59%	2.6	0.06	92%	23.8	0.22	93%	26.5	0.28	61%

* Five-year data were averaged over all individual birds in the five year period (so not from annual averages)



Supplement-Fig. 3. Visual summary of fulmar-Litter monitoring results in the Netherlands 1982-2007, comparing average data for incidence, number of items and mass in the 1980s with running 5-year averages for the more recent period. The different trends in number of items compared to mass indicates a change in the characteristics of user plastic, favouring rapid break-up into small particles.

Supplement-Table 2
Details of linear regression of trends in plastic abundance in stomachs of fulmars from the Netherlands 1979-2007.
Analysis of trends was conducted by linear regression, fitting ln-transformed litter mass values for individual birds on the year of collection. Tests were conducted over the full time period 1979-2007 (Table A) and the most recent 10 years of data (Table B). *The regression line ('trend') is described by y = Constant + estimate*x in which y is the calculated value of the regression-line for year x. When the t-value of a regression is negative it indicates a decreasing trend in the tested litter-category; a positive t-value indicates increase. A trend is considered significant when the probability (p) of misjudgement of data is less than 5% (p<0.05). Significant trends in the table have been labeled with positive signs in case of increase (+) or negative signs in case of decrease (-). Significance at the 5% level (p<0.05) is labeled as - or + ; at the 1% level (p<0.01) as -- or ++; and at the 0.1% level (p<0.001) as --- or +++.*

A. **LONG TERM TRENDS 1979-2007**
for plastics in Fulmar stomachs, the Netherlands

INDUSTRIAL PLASTIC (lnGIND)	n	Constant	estimate	s.e.	t	p	
all ages	750	103.9	-0.0540	0.0137	-3.94	**<0.001**	- - -
adults	418	63.6	-0.0341	0.0208	-1.64	0.103	n.s.
non adults	320	102.9	-0.0534	0.0186	-2.88	**0.004**	- -
USER PLASTICS (lnGUSE)	**n**	**Constant**	**estimate**	**s.e.**	**t**	**p**	
all ages	750	-31.6	0.0145	0.0126	1.15	0.249	n.s.
adults	418	-22.6	0.0099	0.0186	0.53	0.596	n.s.
non adults	320	-77.6	0.0377	0.0155	2.43	**0.016**	+
ALL PLASTICS COMBINED (lnGPLA)	**n**	**Constant**	**estimate**	**s.e.**	**t**	**p**	
all ages	750	27.5	-0.0148	0.0115	-1.29	0.198	n.s.
adults	418	9.4	-0.0059	0.0184	-0.32	0.748	n.s.
non adults	320	10.7	-0.0063	0.0143	-0.44	0.662	n.s.

B. **RECENT 10-year TRENDS (1998-2007)**
for plastics in Fulmar stomachs, the Netherlands

INDUSTRIAL PLASTIC (lnGIND)	n	Constant	estimate	s.e.	t	p	
all ages	638	-1.4	-0.0015	0.0300	-0.05	0.960	n.s.
adults	378	-30.6	0.0130	0.0407	0.32	0.750	n.s.
non adults	250	43.5	-0.0237	0.0444	-0.53	0.594	n.s.
USER PLASTICS (lnGUSE)	**n**	**Constant**	**estimate**	**s.e.**	**t**	**p**	
all ages	638	66.9	-0.0347	0.0255	-1.36	0.174	n.s.
adults	378	102.8	-0.0527	0.0363	-1.45	0.147	n.s.
non adults	250	23.3	-0.0127	0.0347	-0.37	0.714	n.s.
ALL PLASTICS COMBINED (lnGPLA)	**n**	**Constant**	**estimate**	**s.e.**	**t**	**p**	
all ages	638	82.3	-0.0422	0.0249	-1.69	0.091	n.s.
adults	378	94.3	-0.0483	0.0358	-1.35	0.177	n.s.
non adults	250	68.3	-0.0350	0.0329	-1.07	0.287	n.s.

6. Details for locations and reference areas

Supplement-Table 3
Plastic abundance in North Sea fulmars. Location details
Current levels and EcoQO performance for the 5-year period 2003-2007 for all locations.

LOCATION	*n*	Incidence %	average number n ± se	average mass g ± se	geometric mean mass (g)	Over 0.1 g EcoQO %
Shetland	*62*	94%	15.0 ± 2.0	0.17 ± 0.03	0.06	48%
Orkney	*33*	88%	26.2 ± 7.8	0.27 ± 0.06	0.06	48%
NE England	*20*	100%	45.5 ± 13.2	0.28 ± 0.05	0.20	70%
SE England	*40*	93%	29.8 ± 8.1	0.21 ± 0.04	0.09	55%
France Normandy	*71*	100%	56.2 ± 9.7	0.54 ± 0.08	0.29	87%
France Calais	*36*	100%	57.6 ± 15.8	0.25 ± 0.04	0.14	58%
Belgium	*203*	95%	42.4 ± 10.0	0.27 ± 0.04	0.08	52%
Netherlands	*309*	93%	26.5 ± 2.1	0.28 ± 0.02	0.09	61%
Germany	*330*	94%	26.7 ± 4.0	0.34 ± 0.04	0.09	60%
Denmark Skagen	*130*	95%	49.1 ± 11.6	0.36 ± 0.16	0.07	49%
Norway Lista	*55*	98%	44.3 ± 11.8	0.35 ± 0.07	0.10	51%
Sweden Sotenas	*6*	83%	48.2 ± 28.2	0.63 ± 0.47	0.07	67%

Supplement-Table 4
North Sea data compared to reference areas Faroe and Canadian Arctic.

REGION	*n*	Incidence %	average number n ± se	average mass g ± se	geometric mean mass (g)	Over 0.1 g EcoQO %
North Sea total	*1295*	95%	34.5 ± 2.5	0.31 ± 0.02	0.09	58%
Faroe Islands	*647*	88%	14.2 ± 1.1	0.17 ± 0.01	0.05	44%
Canadian Arctic*	*169*	40%	2.5	0.03		14%

* Data for Canadian Arctic were compiled from Mallory et al., 2006, 2008, Provencher et al., 2009 plus details provided by those authors. Data format of some older material prevented calculation of standard error and geometric means.

7. Rate of disappearance of plastics from stomachs

Only indirect evidence is available for the rate by which plastic objects are processed by the stomach system of birds like the fulmar. Petrels usually do not regurgitate hard items from their diet, unless through spitting in fear or fights or when feeding chicks. Normally digestion starts by fluids in the glandular proventriculus followed by mechanical wear in the muscular gizzard, and ultimately passage through the intestines.

After wintering in northern polluted areas like the seas around New Zealand, Cape Petrels (*Daption capense*) return to breeding colonies at Ardery Island near Casey Station (66°S-110°E) by late October to early November. From very early birds, only a single Cape Petrel which accidentally collided with a research ship off Casey in late October could be investigated. However, stomach contents of this single bird compare reasonably well to a larger sample of 18 Cape Petrels collected off South Africa and investigated by Ryan (1987) which showed 83% plastic incidence and per stomach an average of 8.6 pieces of plastic weighing 0.106 gram. Supplement Table 5 shows stepwise lower levels of plastic in the Ardery Island birds when the season progressed. Between birds collected in December and a further sample in January, plastic abundance dropped by nearly an order of magnitude, and the scarce data for the earlier period suggests similar change. Mass per remaining particle had not decreased as much between December and January, suggesting that particles had worn down to a size almost suitable for transfer into the intestines.

Supplement-Table 5

Disappearance rate of plastics from stomachs of Cape Petrels from Ardery Island area (66°S-110°E) when feeding in clean Antarctic waters (derived from van Franeker and Bell 1988). The single October bird compares well to a larger sample of Cape Petrels from near South Africa

	23 **October** n=1	10 **December** n=9	20 **January** n=20	*% decrease Dec-Jan*
plastic incidence		56%	20%	*64%*
average number of items per bird	11	1.67	0.25	*85%*
average mass per bird (g)	0.290	0.027	0.003	*88%*
average mass per remaining particle (mg)	*26.7 (n=11)*	*16.1 (n=15)*	*13.4 (n=5)*	*17%*

A similar rate of decrease was observed in the number of squid beaks in these Cape Petrels, decreasing by 90% between December and January (Supplement-Table 6). Many of the beaks originated from sub-Arctic or temperate species and squid prey is apparently less available in the breeding area. The beaks are of a similar durability as hard pieces of plastic. Antarctic Petrels (*Thalassoica antarctica*) and Southern Fulmars (*Fulmarus glacialoides*) also showed substantial reductions in squid beaks from December to January. Snow Petrels (*Pagodroma nivea*) had low number of squid in their stomach at the start of the breeding season, probably related to the fact that, unlike the other species, they continue to forage within the seasonal sea-ice in winter.

The data from Antarctic species suggest that hard plastic particles disappear from stomachs of adult birds through wear and gut passage at a rate that may be roughly estimated at 75% per month. All birds discussed here were non- or failed breeders that had not lost plastics through feeding of chicks. In addition, virtually all the hard items were in the gizzards, from where it is unlikely that particles can be lost through regurgitation (Ryan and Jackson, 1986). It has to be emphasized that these figures are derived from birds within Antarctica, and most had probably already lost softer types of plastic (sheets, foams) well before the first measurement in our dataset. Soft types of plastics likely disappear from stomachs at faster rates than the estimated rate of 75% per month for the harder items.

Supplement-Table 6
Disappearance rate of squid beaks from stomachs of fulmarine petrels in the Antarctic (derived from van Franeker et al., 2001, Table 7)

	December		*January*		
	n	**avg nr of squid beaks in stomach**	*n*	**avg nr of squid beaks in stomach**	**% decrease**
Southern Fulmar	6	**9.5**	21	**3.6**	**62%**
Antarctic Petrel	5	**7.6**	6	**1.2**	**84%**
Cape Petrel	9	**11.1**	20	**1.1**	**90%**
Snow Petrel *(major)*	4	**1.5**	13	**0.9**	**40%**
Snow Petrel *(nivea)*	7	**1.6**	2	**1**	**38%**
fulmarine petrels combined	31	**6.8**	62	**1.9**	**72%**

These findings from Antarctic species were recently supported by studies of seabirds in the Canadian Arctic after their return from winter ranges. Northern fulmars collected at Nunavut in the high Arctic (n=102; data derived from Mallory 2008) showed an overall 90% decrease in number of plastic particles in the stomach over summer from 8.6 particles/bird in May, via 3.2 in June, 1.2 in July, to 0.8 in August . The June and July data represent monthly reductions of over 60%, similar to those discussed above. In a totally different species Provencher et al (in press) found that soon after their arrival at the colony 32 Thick-billed Murres *Uria lomvia* from Prince Leopold Island had, for this species, a high abundance of plastic (incidence 13%; 0.47 particles/bird) whereas none of 18 birds collected late in the season had any remaining plastic.

In conclusion it seems justified to assume that petrels that stop eating plastics lose plastics rapidly, tentatively estimated at 75% per month for harder types of plastic. It is reasonable to assume that softer sheet-like and foamed plastics disappear at faster rates. In the North Sea over the 2003-2007 period, roughly 20-30% of the mass of plastics in beached fulmars belonged to softer, more rapidly disappearing types of materials. Consequently it is likely that fulmars in the North Sea can accumulate, or lose, characteristic local pollution levels within a few weeks or even in a number of days.

8. additional citations

Camphuysen, C.J., Barreveld, H., Dahlmann, G., van Franeker, J.A., 1999. Seabirds in the North Sea demobilised and killed by polyisobutylene (C4H8)n (PIB). Marine Pollution Bulletin 38: 1171-1176.

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9. Example photographs

A.

B.

Supplement-Fig. 5. Examples of A. an approximately "average" stomach content of a North Sea fulmar and B. an extreme accumulation of plastics in the stomach content of a single bird. Industrial granules at bottom right in picture A, and top right in picture B.