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Baseline

Prevalence of marine debris in marine birds from the North Atlantic

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ABSTRACT

Marine birds have been found to ingest plastic debris in many of the world's oceans. Plastic accumulation data from necropsies findings and regurgitation studies are presented on 13 species of marine birds in the North Atlantic, from Georgia, USA to Nunavut, Canada and east to southwest Greenland and the Norwegian Sea. Of the species examined, the two surface plungers (great shearwaters *Puffinus gravis*; northern fulmars *Fulmarus glacialis*) had the highest prevalence of ingested plastic (71% and 51%, respectively). Great shearwaters also had the most pieces of plastics in their stomachs, with some individuals containing as many of 36 items. Seven species contained no evidence of plastic debris. Reporting of baseline data as done here is needed to ensure that data are available for marine birds over time and space scales in which we see changes in historical debris patterns in marine environments (i.e. decades) and among oceanographic regions.

Plastic pollution is a major emerging problem facing the environment (UNEP, 2011). Since mass production of consumer plastics began in the post-World War II era, plastic pollution has spread to almost every habitat on earth (Barnes et al., 2009). Subsequently, plastics and their persistence have become a global problem for many organisms that live in the world's oceans.

Plastic pollution has a wide range of effects on marine wildlife. Mammals, turtles, sea snakes and seabirds are susceptible to entanglement in plastics bags, canned beverage rings, and other marine pollution (Bond et al., 2012; Gregory, 2009; Laist, 1997; Udyawer et al., 2013; Votier et al., 2011). Smaller pieces of plastics are also problematic, as a wide range of marine organisms can ingest these during foraging, including fish, sea turtles, marine mammals and birds (Boerger et al., 2010; Cadee, 2002; Gomercic et al., 2006; van Franeker et al., 2011). Although most ingested pieces of plastic are small, larger pieces can puncture the gastrointestinal tract (Brandao et al., 2011; Carey, 2011). In addition to the direct effects of starvation and gastrointestinal tract damage caused by indigestible plastics, animals that ingest plastics are also susceptible to indirect effects of harmful chemicals found in and on the plastic material (Tanaka et al., 2013; Teuten et al., 2009; Yamashita et al., 2011).

In response to plastic pollution and its potential negative impacts on the economy and local wildlife, several international policy measures have been established to limit litter entering the ocean (e.g., OSPAR, 2008). Recognizing the need to quantify and monitor marine plastic pollution, a system of Ecological Quality Objectives (EcoQOs) was implemented in the North Sea, one of which measures plastic ingestion by the northern fulmar (*Fulmarus glacialis*; van Franeker et al., 2011).

Many marine birds are susceptible to plastic ingestion, particularly those that consume small prey on the surface of the water, as this is where plastics tend to float and accumulate (Moser and Lee,

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1992; Titmus and Hyrenbach, 2011). As a result, the prevalence of plastic ingestion varies among marine birds using different foraging strategies (surface feeding storm-petrels versus deep-water pursuit-diving murres, for example), even when feeding in the same area (Moser and Lee, 1992; Provencher et al., 2010). The probabilities to ingest plastics therefore are expected to vary among species and regions (i.e. Avery-Gomm et al., 2013).

Since the development of the North Sea plastic assessment protocol (van Franeker et al., 2011), a number of research programs have reported plastic ingestion by seabirds (Colabuono et al., 2009; Kuhn and van Franeker, 2012; Petry et al., 2009). Unfortunately, however, even though ingestion of marine debris has been recorded in almost half of the world's seabird species and in most oceanographic regions (Laist, 1997; Moore, 2008), standardized baselines of plastic ingestion data for many species are still lacking, or remain unpublished. This is problematic as quality baseline data are needed to assess current levels, and to facilitate future studies of changes through time. Baseline data would also enable assessment of differences among oceanographic regions and focus needed conservation action (Avery-Gomm et al., 2013). Although potentially important for conservation, plastic ingestion data with low or no prevalence may suffer from the "file drawer effect", which means it is rarely published (Calver and King, 2000; Scargle, 2000). The purpose of this manuscript is to (1) provide existing data on plastic ingestion for seabirds in the North Atlantic that have not been widely available to date and (2) compare prevalence of plastic ingestion found here to other published reports. Based on previous sampling from a variety of species in the Atlantic and Pacific Oceans, we predicted that surface-feeding species would have a greater risk of plastic ingestion than diving species.

Published and unpublished reports of ingested plastics in marine birds from the western North Atlantic from Nunavut, Canada to Georgia, USA and east to southwest Greenland, the Faroe Islands and the Norwegian Sea were collected (Table 1). Detailed collection and dissection methods can be found in the associated literature for each species (Table 1). Data from species reported here were collected as a part of dietary or parasitological studies. These analyses resulted in the recording and classification of ingested foreign objects in the gastrointestinal tract (GIT), but this was not the primary purpose of the original studies.

All ingested items were collected in one of two ways: gastrointestinal examination using carcasses, and regurgitations from live birds. Great shearwater carcasses were collected as beached birds. Long-tailed ducks (*Clangula hyemalis*), king eiders (*Somateria spectabilis*), common eiders (*S. mollissima)*, surf scoters (*Melanitta perspicillata*), northern fulmars, Atlantic puffins (*Fratercula arctica*), thick-billed murres (*Uria lomvia*), common murres (*U. aalge*), dovekies (*Alle alle*) and Arctic terns (*Sterna paradisaea*) were collected by hunters as part of larger studies led by Environment Canada, U.S. Fish and Wildlife Service, and/or the Sea Duck Joint Venture in Canada, the Greenland Institute of Natural Resources in Greenland and the Natural Museum in the Faroe Islands (Falk and Durinck, 1993; Falk et al., 1992; Haman et al., 2013; Jamieson et al., 2006, 2001; Merkel et al., 2007; Muzaffar, 2000; Provencher et al., 2014; Provencher et al., 2013). Razorbills were confiscated by wildlife enforcement officers in Newfoundland from hunters that had obtained them illegally.

All birds were dissected by skilled workers using standard necropsy techniques, although this included many workers across the study group. Carcasses were opened along the sternum and the GIT removed. All dissections involved removing the GIT from esophagus to cloaca for examination of ingested items, both prey and foreign items. After the whole body dissections were complete, the GITs were then opened along their entire length, and all contents sorted and enumerated.

When debris material was found it was separated from the GIT contents, and when possible sorted according to protocols described by van Franeker et al. (2011). The GIT contents were examined as a whole, and not by GIT section. Plastic debris and other foreign objects were visually identified and separated from other dietary items such as otoliths, zooplankton, squid beaks and annelid jaws using dissecting microscopes. Only macro-plastics are reported (pieces large enough that can be seen with a dissecting scope, approximately 0.5 mm by 0.5 mm), because all pieces were identified while sorting through GIT items. Plastics were identified as either user (post consumer plastics) or industrial (manufactured pellets or nurdles) types, and weighed to the nearest 0.0001 g using an analytical scale where possible (van Franeker et al., 2011).

Samples from Leach's storm-petrels (*Oceanodroma leucorhoa*) were collected from live birds at breeding colonies. Birds were caught in mist-nets and regurgitated plastic debris was collected along with dietary items (Hedd et al., 2009). All plastics were enumerated and are reported on a per regurgitate basis. Although this method potentially re-samples individuals more than once, it is a useful, non-lethal way to sample plastic ingestion in birds (Bond and Lavers, 2013; Carey, 2011). Change in prevalence of regurgitate plastics was tested with a generalized linear model (GzLM) with a binomial error distribution, while the number of regurgitated plastics over time was tested using a GzLM with a Poisson error distribution in R 3.0.2 (R Development Core Team, 2013).

Sample sizes varied among species, as birds were collected or found in different regions with diverse study objectives. Results are reported as total number of carcasses examined, with prevalence indicating the percentage of birds that contained at least one plastic piece in their GIT. When the data were available, the mean and median abundance of plastic pieces with standard deviations (SD) are given. Where the mass of plastics was available the mean with SD and median mass of plastics per bird for the entire sample is presented. In addition, the percentage of plastics from industrial and user sources are given when available (van Franeker et al., 2005).

Marine debris ingestion data were acquired for 2580 individual birds representing 13 species (Table 1). Long-tailed ducks, king eiders, surf scoters, razorbills, common murres, dovekies and Arctic terns did not contain any marine debris. Five other species contained ingested marine debris. Plastic ingestion frequency and intensity in common eiders was low (1%), moderate in Leach's storm-petrels, thick-billed murres and Atlantic puffins (<12%), and relatively high in great shearwaters and northern fulmars (>50%; Table 1).

Great shearwaters had the highest prevalence of ingested debris of the species examined, with 71% of individuals containing at least one piece of plastic ($n = 17$), and a median abundance of 2 pieces found per bird (range 0–36; Table 1). Detailed plastics data were available for detailed examination from 11 great shearwaters (range 0–36; Table 2), and the number of pieces in their GITs was relatively high (two individuals had 36 plastic pieces in their GITs). No polystyrene pieces were found, but both industrial and user plastics were observed with user plastics almost twice as frequent as industrial pellets (Fig. 1; Table 2). The user plastics consisted of both hard inflexible fragments and threadlike pieces. On average the total mass of plastics in great shearwaters was 0.11 ± 0.16 g.

Northern fulmars had the second highest prevalence of ingested debris, with plastics occurring in 51% of stomachs ($n = 35$; Table 1). Individuals contained 0–7 pieces of plastic.

In 1987–1988, 5% of regurgitates from Leach's storm-petrels in eastern Newfoundland contained plastics. At the same colony regurgitates were collected in 2002–2006, and 6% contained debris. Regurgitates contained plastics of varying colors, with white

Table 1
Prevalence of ingested plastics in North Atlantic seabird species.

Species	Location	Year(s)	Sample type	Sample size (*n*)	Prevalence (%)	Average, median (range)	Female/ Male/ Unknown	Adult/Sub-adult/ Unknown	Associated publications (where available)
Long-tailed duck *Clangula hyemalis*	Belcher Is, Nunavut	1998–1999	Necropsy	27	0	NA	11/16/0	3/24/0	Jamieson et al. (2001)
King eider *Somateria spectabilis*	Nuuk, Greenland	2000–2002	Necropsy	41	0	NA	26/15/0	17/24/0	Jamieson unpub data
King eider *S. spectabilis*	Cape Dorset, Nunavut	2001	Necropsy	3	0	NA	3/0/0	3/0/0	Jamieson unpub data
King eider *S. spectabilis*	Cape Dorset, Nunavut	2011	Necropsy	10	0	NA	3/7/0	10/0/0	Provencher et al. (2013)
Common eider *Somateria mollissima sedentaria*	Belcher Is, Nunavut	1998–2003	Necropsy	388	0	NA	187/203/0	110/254/24	Jamieson unpub data
Common eider *S. mollissima borealis*	Nuuk, Greenland	1999–2002	Necropsy	241	0	NA	133/108/0	135/106/0	Jamieson et al. (2006)
Common eider *S. mollissima borealis*	Cape Dorset, Nunavut	2000–2002	Necropsy	108	0	NA	89/19/0	108/0/0	Jamieson unpub data
Common eider *S. mollissima borealis*	Nuuk, Greenland	2012	Necropsy	135	0	NA	77/58/0	53/82/0	Merkel unpub data
Common eider *S. mollissima borealis*	Cape Dorset, Nunavut	2011	Necropsy	100	1	0.01, 0 (0–1)	50/50/0	99/1/0	Provencher et al. (2013)
Surf scoter *Melanitta perspicillata*	Nain, Newfoundland	2006	Necropsy	38	0	NA	38/0/0	38/0/0	Muzaffar unpub data
Leach's storm-petrel *Oceanodroma leucorhoa*	Eastern Newfoundland	1987–1988	Regurgitation	749	5	0.10, 0 (0–5)	Unknown	Unknown	Hedd et al. (2009)
Leach's storm-petrel *O. leucorhoa*	Eastern Newfoundland	2002–2006	Regurgitation	224	6	0.09, 0 (0–7)	Unknown	Unknown	Hedd and Montevecchi (2006)
Great shearwater *Puffinus gravis*	Massachusetts, Georgia, South Carolina	2005–2008	Necropsy	17	71	7.4, 3 (0–36)	6/8/3	1/15/1	Haman et al. (2013)
Northern Fulmar *Fulmarus glacialis*	Faroe Islands	1997	Necropsy	35	51	1.7, 0 (0–7)	11/21/3	Unknown	Durinck unpub data
Atlantic puffin *Fratercula arctica*	Faroe Islands/ Norwegian Sea	1987–1988	Necropsy	36	0	NA	Unknown	25/11/0	Falk et al. (1992)
Atlantic puffin *F. arctica*	Gull I., Witless Bay, Newfoundland	1999	Necropsy	2	0	NA	0/0/2	2/0/0	Muzaffar unpub data
Atlantic puffin *F. arctica*	Bay of Exploits, Newfoundland	2004	Necropsy	14	7	0.07, 0 (0–1)	0/0/14	0/14/0	Muzaffar unpub data
Razorbill *Alca torda*	Bay of Exploits, Newfoundland	2004	Necropsy	2	0	NA	0/0/2	2/0/0	Muzaffar unpub data
Razorbill *A. torda*	Notre Dame Bay, Newfoundland	2011–2012	Necropsy	8	0	NA	0/2/6	1/7/0	Bond unpub data
Thick-billed murre *Uria lomvia*	Southwest Greenland	1988–1989	Necropsy	202	6	0.09, 0 (0–3)	80/122/0	86/96/20	Falk and Durinck (1993)
Thick-billed murre *U. lomvia*	Hakluyt Island, NW Greenland	1997	Necropsy	40	0	NA	26/14	39/1/0	Falk unpub data
Thick-billed murre *U. lomvia*	Harbour Breton, Newfoundland	2005	Necropsy	7	0	NA	4/2/1	7/0/0	Muzaffar unpub data

(*continued on next page*)

Table 1 (*continued*)

Species	Location	Year(s)	Sample type	Sample size (*n*)	Prevalence (%)	Average, median (range)	Female/ Male/ Unknown	Adult/Sub-adult/ Unknown	Associated publications (where available)
Thick-billed murre *U. lomvia*	St. Mary's Bay, Newfoundland	2005	Necropsy	4	0	NA	1/2/1	4/0/0	Muzaffar unpub data
Thick-billed murre *U. lomvia*	Gannet Islands, Newfoundland	2006	Necropsy	15	0	NA	3/12	15/0/0	Muzaffar (2000)
Thick-billed murre *U. lomvia*	Nuuk, Greenland	2006	Necropsy	15	0	NA	0/0/15	15/0/0	Muzaffar (2000)
Thick-billed murre *U. lomvia*	Coats Island, Nunavut	2006	Necropsy	16	0	NA	8/7/1	16/0/0	Muzaffar (2000)
Common murre *Uria aalge*	St. Mary's Bay, Newfoundland	2006	Necropsy	15	0	NA	5/5/5	15/0/0	Muzaffar unpub data
Common murre *U. aalge*	Gannet Is., Newfoundland	2006	Necropsy	15	0	NA	9/6/0	15/0/0	Muzaffar (2000)
Common murre *U. aalge*	Renews, Newfoundland	2006	Necropsy	13	0	NA	9/3/1	13/0/0	Muzaffar (2000)
Dovekie *Alle alle*	Nuuk, Greenland	1988–1989	Necropsy	19	0	NA	8/11/0	10/9/0	Falk and Durinck unpub data
Arctic tern *Sterna paradisaea*	Nasaruvaalik Island, Nunavut	2007	Necropsy	41	0	NA	21/20	41/0/0	Provencher et al. (2014)

NA indicates values that are not applicable as no debris was found in the species.

Table 2
Prevalence of ingested plastics, mean, standard deviation (SD) and range by plastic type from great shearwaters ($n = 11$) collected off the eastern coast of the US between 2005 and 2008.

	Prevalence (%)	Mean	Median	SD	Range
All plastics	70.6	9.5	2	13.6	0–36
Industrial plastics	36.4	1.5	0	2.8	0–7
User plastics	54.5	8.1	2	11.0	0–30
Hard fragments	54.5	6.6	1	10.3	0–30
Threadlike	27.3	0.5	0	0.8	0–3
Sheet like	27.3	1.0	0	2.7	0–9
Total mass of all plastics	–	0.11	0.02	0.02	0–0.6

being the most common (60%; Table 1). During both periods, regurgitates contained 0–7 pieces. The prevalence of plastic ingestion was similar through time (1980s versus 2000s; Wald $\chi^2 = 0.16$, $p = 0.87$), as was the number of pieces of plastic per regurgitate (Wald $\chi^2 = -0.46$, $p = 0.64$).

Although thick-billed murres sampled from several regions in Canada showed no evidence of ingested plastics, 11% of the birds sampled during winter off the southwest coast of Greenland in 1988–1989 contained debris. Each bird contained 1–3 hard plastic fragments in different colors and ranging in size from 1 to 16 mm (average size 6.9 mm).

Single pieces of debris were found in both common eiders and Atlantic puffins. The one common eider from Hudson Strait that contained ingested debris had a yellow fibrous material in the GIT. The one puffin from Newfoundland had ingested a piece of blue plastic.

Although samples sizes reported here were variable (2–749 individuals per sample period), and for some species, the occurrence of plastic debris was quite low, the novel ingestion data contributes to our understanding of plastic ingestion in marine birds in the North Atlantic. All but three of the species (king eider, Atlantic puffin, razorbill) had samples sizes greater than 15 per time period, making the reported occurrences comparable to other studies (Avery-Gomm et al., 2013; Blight and Burger, 1997; Moser and Lee, 1992; Robards et al., 1995). In all but two species examined, the prevalence of ingested plastic was relatively low (<12%). These levels are comparable to those found in thick-billed murres from the North Atlantic in the region of the Arctic Archipelago and Hudson Bay (Provencher et al., 2010), and off Newfoundland (Bond et al., 2013). Such low levels of plastic ingestion suggest that many of the species examined are not currently at great risk of ingesting and/or retaining large amounts of plastics.

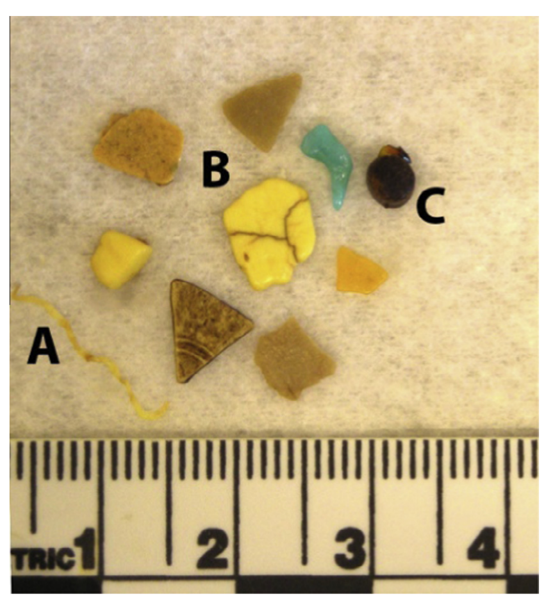

Fig. 1. Plastic debris from a great shearwater (*Puffinus gravis*) washed ashore along the coast of New England, USA. A – threadlike plastic, B – hard fragments, C – an industrial pellet.

A bird's foraging mode is assumed to play a large role in how much marine debris it ingests (Day and Shaw, 1987; Moser and Lee, 1992; Ryan, 1987). Diving birds, such as auks and seaducks, are expected to have relatively low levels of plastics because they rarely feed at the water surface where most plastics tend to float. Our data supports this prediction, with the exception of a single Atlantic puffin, a single common eider, and 11% of thick-billed murres from southwest Greenland, none of the diving species examined contained ingested plastics. In contrast, surface-feeding birds, represented by great shearwaters, northern fulmars, Arctic terns and Leach's storm-petrels, are thought to be more susceptible to ingesting plastics. Again our results primarily support this prediction; with great shearwaters and northern fulmars exhibiting the highest levels of plastic ingestion (71% and 51% occurrence, respectively). Interestingly however, Arctic terns had no ingested plastics. Braune and Gaskin (1982) also found no ingested plastics in Arctic terns from Deer Island, New Brunswick in the 1970s while common terns (*Sterna hirundo*) from the same area did, suggesting that Arctic terns may not be as susceptible to ingesting debris. This may be due to differences in foraging behaviours, foraging areas used or perhaps morphological differences in their GIT that results in low levels of plastic retention. These differences may also be caused by differences in local sources of debris, or time of sampling as a many of the species examined are migratory. Nonetheless, our findings are consistent with previous suggestions that foraging strategy may be a determining factor in ingestion of debris (Moser and Lee, 1992).

A species' physiology is also considered to play an important role in the accumulation of plastics in birds. The narrow opening between the gizzard and the proventriculus in northern fulmars is thought to prevent complete regurgitations (Azzarello and Van Vleet, 1987; Furness, 1985a). In other groups, such as the seaducks and gulls, the ability to regurgitate broken shell pieces and other foreign debris is common (Lindborg et al., 2012). Differences in the ability to regurgitate will affect how species accumulate plastics in their GIT, and the comparison of accumulation between groups thus must be done with caution.

Atlantic puffins ingest plastic chronically in the northeastern Atlantic, but at relatively low frequencies (~10–15%), and this has not changed since the 1970s (Harris and Wanless, 1994, 2011). Our data were similar, with only 7% of the Atlantic puffins from Newfoundland containing ingested plastic, although our sample size was small. Interestingly, Atlantic puffins from the Faroe Islands and the Norwegian Sea did not contain plastics suggesting perhaps regional differences. In general, however, deep-diving puffins probably ingest plastic less frequently than surface-feeding species.

Thick-billed murres from southwest Greenland had a moderate prevalence of plastics ingestion (11%), similar to rates in the Canadian Arctic (Provencher et al., 2010). Interestingly, murres sampled in Newfoundland did not show evidence of ingested plastics (Bond et al., 2013), again suggesting regional differences for this species. Regional differences illustrate the need for regular reporting to detect differences across spatial and temporal scales.

Northern fulmars from the Faroe Islands had relatively high prevalence of plastic ingestion (51%), similar to previous reports from this region (44%; van Franeker et al., 2011). The northern fulmar continues to be an important bio-indicator for marine plastics (e.g., Avery-Gomm et al., 2012; Kuhn and van Franeker, 2012; Provencher et al., 2009; van Franeker et al., 2011), and any future efforts at assessing ingested plastics should prioritize developing protocols to ensure comparability of the data between regions.

Great shearwaters had the highest prevalence of plastics ingestion (71%). This frequency of occurrence is similar to a larger sample of great shearwaters examined from the northeastern United States coastline, which included the birds reported here along with others (Haman et al., 2013). Furness (1985a) reported 85% of birds on Gough Island in the southern Atlantic Ocean (a breeding location for the species) had ingested plastic (up to 53 pieces), and Moser and Lee (1992) found that while in the North Atlantic between 1976 and 1984, great shearwaters had 25–100% occurrence of plastic ingestion, with an overall increasing trend. Reports from the 2000s (Haman et al., 2013; and this study) suggest great shearwaters continue to ingest relatively high levels of plastic. Even though sample sizes were small, a 71% occurrence suggests that plastic ingestion by this species is pervasive. It is also of note that user plastics are the primary type found in great shearwaters, similar to recent findings in other species (Provencher et al., 2009; Ryan, 2008). High levels of ingested user plastics suggest these should be the target of pollution prevention campaigns.

The great shearwaters are the only birds examined here that were recovered from areas that overlap with the regions where both Law et al. (2010) and Moret-Ferguson et al. (2010) have quantified marine plastic. Although the sample of great shearwaters presented here is relatively small, limiting our ability to compare between plastics found in the environment and those found in birds, larger samples of great shearwaters from this area may present an opportunity to complete more in depth studies examining marine bird selection of marine plastics at sea. Indeed, several studies have described the types of marine plastics in great detail in the North Atlantic sub-tropical gyre (Law et al., 2010; Moret-Ferguson et al., 2010), future studies on ingested plastics in the area with a focus on using similar methods could greatly increase our understanding of how marine birds may select for certain plastic types.

Quantities of plastics in great shearwaters were similar to reports for other surface-feeding seabirds, such as the northern fulmar (Provencher et al., 2009; van Franeker et al., 2011). Such quantities may make them susceptible to both direct and indirect adverse effects. The great shearwaters reported on here were collected dead on a beach. While some of those examined were in poor body condition, many were not, suggesting that even though ingestion may be high in some individuals, it was not likely the cause of death (Haman et al., 2013).

Unfortunately, the mass of plastics is not available for many of the species in this study. Mass of ingested plastics, as opposed to its frequency of occurrence, is perhaps a more important indicator of risk for marine birds, as it provides a more biologically relevant burden level (van Franeker et al., 2011). We suggest that future reports include information on the mass of ingested plastics. In this study, mass information was available only for great shearwaters. Given that the average weight of great shearwaters is 800–900 g (Brown et al., 1981), the average mass of plastics (0.11 g) represents 0.013% of body mass. The ecological quality objective established (EcoQO) for northern fulmars in the North Sea calls for <10% of the birds to have <0.1 g (van Franeker et al., 2011). Based on the EcoQO for fulmars being set to 0.1 g for a species that ranges from 450 to 1000 g, shearwaters may be approaching plastic loads that have been deemed biologically undesirable in the related northern fulmar.

While we present novel data for ingested plastics in 13 species, low levels of plastic ingestion in small sample sizes and minimal detailed information on both the birds and the plastics precluded an examination of age and sex related influences on the frequency and intensity of plastic ingestion. Van Franeker and Meijboom (2002) showed that age can be a factor in plastic ingestion metrics, with juvenile northern fulmars having higher relatively plastic loads than adults. Therefore, although the prevalence data presented here are important in assessing species at risk of ingesting plastics, future studies should include age and sex in order to better assess what factors may be influencing plastic ingestion and to address specific conservation questions.

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The details of the ingested plastics were not available for Leach's storm-petrels, but the data for this species provide a temporal assessment of potential change in plastic ingestion rates between the 1980s and the 2000s from breeding colonies in eastern Newfoundland. The prevalence and abundance of plastic between the two time periods were similar suggesting that plastic ingestion and accumulation by Leach's storm-petrels has not changed over the last few decades. While our data show that only 3–6% Leach's Storm-petrels regurgitated plastic, Bond and Lavers (2013) used an emetic and found that 43% of the birds had ingested plastic, even though no birds regurgitated plastics prior to emesis. As well, although we found a maximum of seven pieces regurgitated from a Leach's storm-petrel, this species can accumulate up to 47 pieces in its GIT (Blight and Burger, 1997; Bond and Lavers, 2013; Day and Shaw, 1987; Furness, 1985b; Robards et al., 1995), suggesting that Leach's storm-petrels can potentially have much higher loads of ingested plastics than we found. Such differing results in the prevalence or abundance of plastic ingestion between studies employing different methodologies (regurgitations versus necropsy) highlight the need for standardized methods, and the use of caution when comparing plastic ingestion data obtained in different ways.

We recognize that having many workers involved in the dissection of the birds, and the subsequent identification of the plastics, is not ideal. Although all of the people working with the birds were skilled in handling, dissecting and treatment of bird carcasses, it is possible that different degrees of experience may have affected the detection and identification of debris. We believe that this is of minimal concern as the debris recorded and presented here are macroscopic plastics rather than microplastics which are much more difficult to detect and identify. Pieces of debris were large enough to be visually separated from other hard fragments in the bird gut, such as fish bones and squid beaks.

Small sample sizes, non-significant results and large numbers of plastic-free samples may deter researchers from dedicating the resources to publishing findings on ingested plastics debris in non-indicator species, but all plastic data add to our understanding of changes in marine debris patterns. Plastic ingestion can have a range of effects on wildlife, and it is therefore important to understand how patterns of ingestion differ among species, both spatially and temporally. In order to provide rigorous and thorough baseline data for ingested plastics in marine birds, data from all species should be included in protocols and reported regularly using widely recognized procedures (van Franeker et al., 2011). Baseline studies, such as ours, also provide data for larger syntheses of plastic ingestion data, meta-analyses, marine sampling, and biological consequences of marine pollution and management decisions.

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References

Avery-Gomm, S., O'Hara, P.D., Kleine, L., Bowes, V., Wilson, L.K., Barry, K.L., 2012. Northern fulmars as biological monitors of trends of plastic pollution in the eastern North Pacific. Mar. Pollut. Bull. 64, 1776–1781.

Avery-Gomm, S., Provencher, J.F., Bertram, D.F., Morgan, K., 2013. Plastic ingestion in marine associated birds from the Eastern North Pacific. Mar. Pollut. Bull. 72, 257–259.

Azzarello, M.Y., Van Vleet, E.S., 1987. Marine birds and plastic pollution. Mar. Ecol. Prog. Ser. 37, 295–303.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B – Biol. Sci. 364, 1985–1998.

Blight, L.K., Burger, A.E., 1997. Occurrence of plastic particles in seabirds from the eastern North Pacific. Mar. Pollut. Bull. 34, 323–325.

Boerger, C., Gwendolyn, L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Mar. Pollut. Bull. 60, 2275–2278.

Bond, A.L., Lavers, J.L., 2013. Effectiveness of emetics to study plastic ingestion by Leach's Storm-petrels (*Oceanodroma leucorhua*). Mar. Pollut. Bull. 70, 171–175.

Bond, A.L., Montevecchi, W.A., Guse, N., Regular, P.M., Garthe, S., Rail, J.F., 2012. Prevalence and composition of fishing gear debris in the nests of northern gannets (*Morus bassanus*) are related to fishing effort. Mar. Pollut. Bull. 64, 907–911.

Bond, A.L., Provencher, J.F., Elliot, R., Ryan, P.C., Rowe, S., Jones, I.L., Robertson, G., Wilhelm, S., 2013. Ingestion of plastic marine debris by common and thick-billed murres in the Northwest Atlantic from 1985 to 2012. Mar. Pollut. Bull. 77, 192–195.

Brandao, M.L., Braga, K.M., Luque, J.L., 2011. Marine debris ingestion by magellanic penguins, *spheniscus magellanicus* (aves: sphenisciformes), from the Brazilian coastal zone. Mar. Pollut. Bull. 62, 2246–2249.

Braune, B.M., Gaskin, D.E., 1982. Feeding ecology of non-breeding populations of larids off Deer Island, New Brunswick. Auk 99, 67–76.

Brown, R., Barker, S., Gaskin, D., Sandemand, M., 1981. The foods of Great and Sooty Shearwaters *Puffinus* gravis and *P. griseus* in eastern Canadian waters. Ibis 123, 19–30.

Cadee, G.C., 2002. Seabirds and floating plastic debris. Mar. Pollut. Bull. 44, 1294–1295.

Calver, M.C., King, D.R., 2000. Why publication matters in conservation biology. Pacific Conserv. Biol. 6, 2–8.

Carey, M.J., 2011. Intergenerational transfer of plastic debris by short-tailed Shearwaters (*Ardenna tenuirostris*). Emu 111, 229–234.

Colabuono, F.I., Barquete, V., Domingues, B.S., Montone, R.C., 2009. Plastic ingestion by procellariiformes in Southern Brazil. Mar. Pollut. Bull. 58, 93–96.

Day, R.H., Shaw, D.G., 1987. Patterns in the abundance of pelagic plastic and tar in the North Pacific Ocean, 1976–1985. Mar. Pollut. Bull. 18, 311–316.

Falk, K., Durinck, J., 1993. The winter diet of thick-billed murres, *Uria lomvia*, in Western Greenland, 1988–1989. Can. J. Zool. – Rev. Can. Zool. 71, 264–272.

Falk, K., Jensen, J.K., Kammp, K., 1992. Winter diet of Atlantic puffins (*Fratercula arctica*) in the Northeast Atlantic. Colon. Waterbirds 15, 230–235.

Furness, R.W., 1985a. Ingestion of plastic particles by seabirds at Gough Island, South Atlantic Ocean. Environ. Pollut. Ser. A – Ecol. Biol. 38, 261–272.

Furness, R.W., 1985b. Plastic particle pollution – accumulation by procellariiform seabirds at scottish colonies. Mar. Pollut. Bull. 16, 103–106.

Gomercic, H., Gomercic, M.D., Gomercic, T., Lucic, H., Dalebout, M., Galov, A., Skrtic, D., Curkovic, S., Vukovic, S., Huber, D., 2006. Biological aspects of Cuvier's beaked whale (*Ziphius cavirostris*) recorded in the Croatian part of the Adriatic Sea. Eur. J. Wildlife Res. 52, 182–187.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. B – Biol. Sci. 364, 2013–2025.

Haman, K., Norton, T.M., Ronconi, R.A., Nemeth, N.M., Thomas, A.C., Courchesne, S.J., Segars, A., Keel, M.K., 2013. Great shearwater (*Puffinus gravis*) mortality events along the eastern coast of the United States. J. Wildlife Dis. 49, 235–245.

Harris, M., Wanless, S., 1994. Ingested elastic and other artifacts found in puffins in Britain over a 24 year period. Mar. Pollut. Bull. 28, 54–55.

Harris, M., Wanless, S., 2011. The Puffin. T & AD Poyser, London.

Hedd, A., Montevecchi, W.A., 2006. Diet and trophic position of Leach's storm-petrel *Oceanodroma leucorhua* during breeding and moult, inferred from stable isotope analysis of feathers. Mar. Ecol. Prog. Ser. 322, 291–301.

Hedd, A., Montevecchi, W.A., Davoren, G., Fifield, D.A., 2009. Diets and distributions of Leach's storm-petrel (*Oceanodroma leucorhua)* before and after an ecosystems shift in the Northwest Atlantic. Can. J. Zool. – Rev. Can. Zool. 87, 787–801.

Jamieson, S.E., Robertson, G.J., Gilchrist, H.G., 2001. Autumn and winter diet of long-tailed duck in the Belcher Islands, Nunavut, Canada. Waterbirds 24, 129–132.

Jamieson, S.E., Gilchrist, H.G., Merkel, F.R., Diamond, A.W., Falk, K., 2006. Endogenous reserve dynamics of northern common eiders wintering in Greenland. Polar Biol. 29, 585–594.

Kuhn, S., van Franeker, J.A., 2012. Plastic ingestion by the northern fulmar (*Fulmarus glacialis*) in Iceland. Mar. Pollut. Bull. 64, 1252–1254.

Laist, D., 1997. Impacts of marine debris: entanglement of marine like in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J., Rogers, D. (Eds.), Marine Debris: Sources, Impacts, and Solutions. Springer-Verlag, New York, NY, pp. 99–140.

Law, K.L., Moret-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science 329, 1185–1188.

Lindborg, V.A., Ledbetter, J.F., Walat, J.M., Moffett, C., 2012. Plastic consumption and diet of glaucous-winged gulls (*Larus glaucescens*). Mar. Pollut. Bull. 64, 2351–2356.

Merkel, F.R., Jamieson, S.E., Falk, K., Mosbech, A., 2007. The diet of common eiders wintering in Nuuk, Southwest Greenland. Polar Biol. 30, 227–234.

Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ. Res. 108, 131–139.

Moret-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C.M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Mar. Pollut. Bull. 60, 1873–1878.

Moser, M.L., Lee, D.S., 1992. A 14 year survey of plastic ingestion by western North-Atlantic seabirds. Colon. Waterbirds 15, 83–94.

Muzaffar, S.B., 2000. Helminths of murres (Alcidae: *Uria* spp.): markers of ecologocal change in the marine environment. J. Wildlife Dis. 45, 672–683.

OSPAR, 2008. Background Document for the EcoQO on Plastic Particles in Stomachs of Seabirds, Biodiversity Series. OSPAR Commission.

Petry, M.V., Kruger, L., da Silva Fonseca, V.S., Brummelhaus, J., da Cruz Piuco, R., 2009. Diet and ingestion of synthetics by Cory's Shearwater Calonectris diomedea off southern Brazil. J. Ornithol. 150, 601–606.

Provencher, J.F., Gaston, A.J., Mallory, M.L., 2009. Evidence for increased ingestion of plastics by northern fulmars (*Fulmarus glacialis*) in the Canadian Arctic. Mar. Pollut. Bull. 58, 1092–1095.

Provencher, J.F., Gaston, A.J., Mallory, M.L., O'Hara, P.D., Gilchrist, H.G., 2010. Ingested plastic in a diving seabird, the thick-billed murre (*Uria lomvia*), in the eastern Canadian Arctic. Mar. Pollut. Bull. 60, 1406–1411.

Provencher, J.F., McEwan, M., Mallory, M.L., Braune, B., Carpenter, J., Harms, H., Savard, G., Gilchrist, H., 2013. How wildlife research can be used to promote wider community participation in the North. Arctic 66, 237–243.

Provencher, J.F., Braune, B., Forbes, M.R., Gilchrist, G., Mallory, M.L., 2014. Trace elements and gastrointestinal parasites in Arctic terns breeding in the Canadian high Arctic. Sci. Total Environ. 476–477, 308–316.

R_Development_Core_Team, 2013. R: a Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria.

Robards, M.D., Piatt, J.F., Wohl, K.D., 1995. Increasing frequency of plastic particles ingested by seabirds in the sub-Arctic North Pacific. Mar. Pollut. Bull. 30, 151–157.

Ryan, P.G., 1987. The incidence and characteristics of plastic particles ingested by seabirds. Mar. Environ. Res. 23, 175–206.

Ryan, P.G., 2008. Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans. Mar. Pollut. Bull. 56, 1406–1409.

Scargle, J.D., 2000. Publication bias: the 'File-Drawer' problem in scientific literature. J. Sci. Explor. 14, 91–106.

Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M., Watanuki, Y., 2013. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Mar. Pollut. Bull. 69, 219–222.

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Bjorn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Pham, H.V., Tana, T.S., Prudente, M., Boonyatumanond, R., Zakaria, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philos. Trans. R. Soc. B – Biol. Sci. 364, 2027–2045.

Titmus, A.J., Hyrenbach, K.D., 2011. Habitat associations of floating debris and marine birds in the North East Pacific Ocean at coarse and meso spatial scales. Mar. Pollut. Bull. 62, 2496–2506.

Udyawer, V., Read, M.A., Hamann, M., Simpfendorfer, C.A., Heupel, M.R., 2013. First record of sea snake (*Hydrophis elegans*, Hydrophiinae) entrapped in marine debris. Mar. Pollut. Bull. 73, 336–338.

UNEP, 2011. UNEP Year Book 2011: emerging issues in our global environment. In: United Nations Environment Programme, Nairobi, Kenya.

van Franeker, J.A., Meijboom, A., 2002. Litter NSV – Marine litter Monitoring by Northern Fulmars: A Pilot Study. Alterra, Wageningen, The Netherlands, p. 72.

van Franeker, J.A., Heubeck, M., Fairclough, K., Turner, D.M., Grantham, M., Stienen, E.W.M., Guse, N., Pedersen, J., Olsen, K.O., Andersson, P.J., Olsen, B., 2005. Save the 'North Sea' Fulmar study 2002–2004: a regional pilot project for the Fulmar-Litter EcoQO in the OSPAR area. Alterra-Rapport 1162, 1–70.

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. Environ. Pollut. 159, 2609–2615.

Votier, S.C., Archibald, K., Morgan, G., Morgan, L., 2011. The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. Mar. Pollut. Bull. 62, 168–172.

Yamashita, R., Takada, H., Fukuwaka, M.A., Watanuki, Y., 2011. Physical and chemical effects of ingested plastic debris on short-tailed shearwaters, *Puffinus tenuirostris*, in the North Pacific Ocean. Mar. Pollut. Bull. 62, 2845–2849.

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