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Ingested plastic in a diving seabird, the thick-billed murre (*Uria lomvia*), in the eastern Canadian Arctic

Jennifer F. Provencher[a,*], Anthony J. Gaston[b], Mark L. Mallory[c], Patrick D. O'hara[d], H. Grant Gilchrist[b]

[a] University of Victoria, Dept. of Biology, P.O. Box 3020, Station CSC, Victoria, BC, Canada V8W 3N5
[b] Science and Technology Branch, National Wildlife Research Centre, Raven Road, Carleton University, Ottawa, ON, Canada K1A 0H3
[c] Canadian Wildlife Service, P.O. Box 1714, Iqaluit, NU, Canada X0A 0H0
[d] Canadian Wildlife Service, P.O. Box 6000, 9860 W Saanich Road, Sidney, BC, Canada V8L 4B2

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ABSTRACT

Plastic debris has become ubiquitous in the marine environment and seabirds may ingest debris which can have deleterious effects on their health. In the North Atlantic Ocean, surface feeding seabirds typically ingest high levels of plastic, while the diving auks which feed in the water column typically have much lower levels. We examined 186 thick-billed murres from five colonies in the eastern Canadian Arctic for ingested plastic debris. Approximately 11% of the birds had at least one piece of plastic debris in their gastrointestinal tracts, with debris dominated by user plastics. This is the first report of ingested plastics in an auk species in Canada's Arctic, and the highest incidence of plastic ingestion to date for thick-billed murres (*Uria lomvia*).

1. Introduction

Since plastic came into common use in the 1950s floating plastic debris has been recognized as a major pollutant in the world's oceans and has been found to be ingested by almost half of the world's 300 seabird species (Vlietstra and Parga, 2002; Moore, 2008). Plastic ingestion by seabirds was first observed in 1960 in New Zealand (Harper and Fowler, 1987), and in the North Atlantic in 1962 (Rothstein, 1973). Since then, marine plastic debris has become a global problem for the world's seabirds (Spear et al., 1995; Auman et al., 2004; Van Franeker et al., 2005; Mallory, 2008; Ryan, 2008). Plastic ingestion may have a wide range of deleterious effects on seabirds, including reduced appetite, growth and dietary efficiency, as well as increased levels of POPs (Van Franeker, 1985; Dickerman and Goelet, 1987; Ryan, 1988; Ryan et al., 1988), all of which could have negative impacts on seabird populations especially when stressed by changing environmental conditions (Kitaysky and Golubova, 2000) and altered prey abundances (Mavor et al., 2008).

Seabirds have been found to ingest both user and industrial plastics (Van Franeker et al., 2009). Industrial plastics are the nurdles or pellets used by the plastics industry to transport raw plastic to factories for further processing. All other forms of plastics are considered user plastics, including hard sheet-like plastics, thread-like plastics, foamed polystyrene and polyurethane plastics, and fragmented hard plastics as used in most consumer products such as toys and drink bottles (Van Franeker et al., 2009). Despite their large populations and broad distribution (Gaston and Jones, 1998) there are few reports of plastic ingestion by auks (Alcidae) in the North Atlantic Ocean (Van Franeker, 1983; Harris and Wanless, 1994), while incidence of plastic ingestion has been reported for some auks in the North Pacific Ocean with variable results among the species studied (Day, 1980 in Robards et al., 1995; Robards et al., 1995; Blight and Burger, 1997).

Approximately five million thick-billed murres (*Uria lomvia*), about one quarter of the world's population, breed in the eastern Canadian Arctic and overwinter in the Northwest Atlantic (Gaston and Jones, 1998) where they feed on fish and invertebrates at sea in Davis Strait, Labrador Sea and around Newfoundland (Gaston and Hipfner, 2000). Thick-billed murres in the Canadian Arctic Archipelago have been monitored since the 1970s to track population size, contaminant levels, and changes in diet (Braune et al., 2001; Gaston, 2002; Woo and Elliott, 2008). In the 1970s and 1980s murres were collected from low, mid and high Arctic colonies for dietary studies (Bradstreet, 1980; Gaston and Noble, 1985; Gaston and Bradstreet, 1993). During the 2007 and 2008 breeding seasons we collected thick-billed murres from several Canadian Arctic colonies for dietary analysis, and here we report on the incidence, type and size of plastics found in murres from this region. We use the murres as sentinels of debris in the marine environment and as samplers in the absence of direct work assessing plastic debris in the Canadian Arctic and North Atlantic marine ecosystems.

* Corresponding author. Tel.: +1 2504725098; fax: +1 2507217120.
E-mail address: jennipro@uvic.ca (J.F. Provencher).

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2. Methods

In June, July and August, 2007 and 2008, thick-billed murres were collected from five colonies in Nunavut, Canada, as follows (Fig. 1): Coats Island (62°98′N, 82°00′W), Digges Sound (62°33′N, 77°35′W) and Akpatok Island (60°58′N, 68°08′W) in the low Arctic oceanographic zone (Salomonsen, 1965), Prince Leopold Island (74°02′N, 90°00′W) in the high Arctic oceanographic zone, and the Minarets (67°00′N, 61°80′W), located at the boundary of these two zones.

At Prince Leopold Island we were able to sample when the birds had first arrived from the wintering grounds (June 2008, $n = 32$), and during chick-rearing (August 2008, $n = 18$) allowing us to compare plastic ingestion at different periods in the breeding season. At the Minarets we were able to sample during chick-rearing in 2007 (August; $n = 30$) and 2008 (August; $n = 20$) allowing for an inter-year comparison for this one site. All other sites were sampled only once.

We shot murres from small boats using 12 gauge shotguns and steel shot while the birds were feeding within 15 km of colonies. Immediately upon retrieving the carcass, 70% isopropanol was injected into the digestive tract to aid in the preservation of prey items in the stomach. Carcasses were kept in a cool place for up to 24 h, then frozen and transported to a laboratory for dissection. The entire digestive tract of each bird was removed and re-frozen for transport. All digestive tracts were later thawed, dissected and plastic items were set aside for examination. Plastics were sorted by type, dried and weighed (Van Franeker et al., 2005) using a Scaltec SCB22 analytical scale measuring to the nearest 0.00001 g (fibre pieces were below our detection range). Plastics were categorized as rigid plastics, soft plastic, fibres or as soft airgun pellets. All rigid and soft plastic pieces were measured ±0.1 mm.

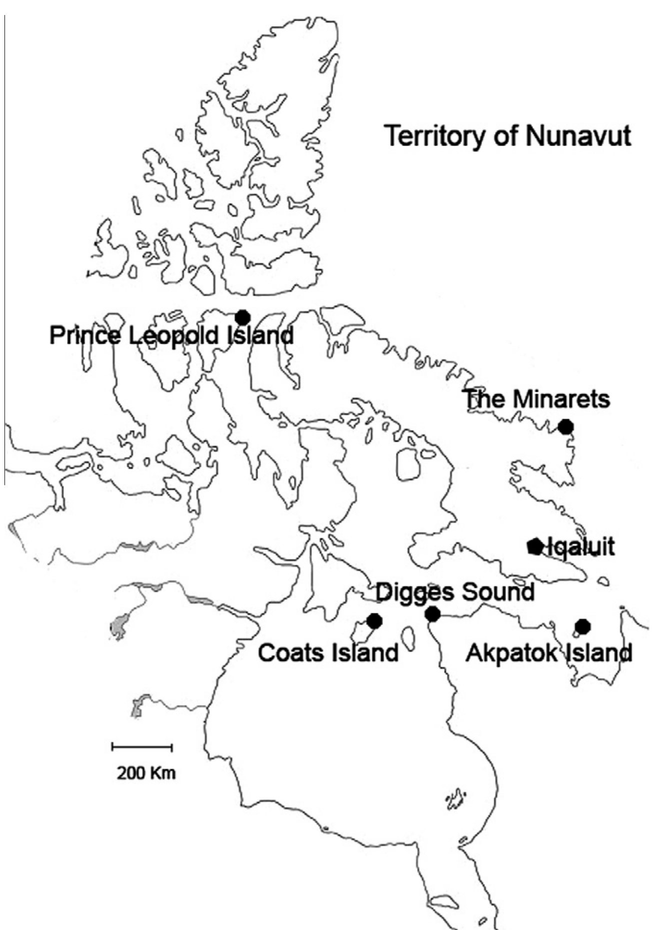

Fig. 1. Map of the thick-billed murre colonies sampled in Nunavut, Canada.

We used two-tailed Fisher Exact tests to compare the incidence of plastic debris among the samples collected at the Minarets in 2007 and 2008, and to compare the birds collected early and late in the breeding season at Prince Leopold Island. The Mann–Whitney rank sum test was used to test for variation in number and mass of plastics found at the Minarets over the two years of sampling and between the seasons sampled at Prince Leopold Island. To test for variation among colonies in numbers of pieces per bird, proportion of birds found with ingested plastic per colony and mass of ingested plastics per bird during the 2007–2008 sampling period, maximum-likelihood was used to fit generalized linear models with nonlinear link functions ("Proc Genmod"; SAS, 2008). Number of plastic pieces per colony was modeled with a loglinear model ("Proc Genmod" with a log link function). Deviation from the Poisson distribution was estimated using an index of dispersion calculated by dividing the model deviance by degrees of freedom. Data on the number of plastic pieces per stomach were underdispersed (i.e., $deviance/df = 84.8/149 = 0.57$, which is less than 1.0), and a dispersion parameter was used to correct for underdispersion ("scale = d" in "Proc Genmod"; SAS, 2008). Proportion of birds found with plastic was modeled using a logistic regression model ("Proc Genmod" with a logit link function; SAS, 2008). As well, we tested for variation in plastic mass load among colonies for birds that had consumed plastic using a General Linear Model ("Proc GLM"; SAS, 2008). Only data from birds detected with plastics were included in this analysis. Number of plastic pieces, proportions with plastic, and plastic mass loads were compared orthogonally (*a priori*) between colonies using least-squares mean statements in "Proc Genmod" and "Proc GLM" (SAS, 2008). Means are reported with standard deviation (±SD), and chi-square-values (χ) and F-values were reported with numerator and denominator degrees of freedom as subscripts. Significance was determined for all statistical tests with an alpha of 0.05.

3. Results

Of the 186 thick-billed murres collected, 11% contained ingested plastics in their digestive tracts with a mean of 0.2 ± 0.8 plastic pieces found ingested per bird (Table 1). All debris found was found to be user plastic, with no industrial plastics found in the murres sampled. Plastic was found in at least one murre at all colonies sampled. Overall the average mass of the plastics found in the birds was 0.0016 g (Table 1).

Unidentifiable rigid plastic pieces (Fig. 2) were found in 5% of murres, and were the most common type of plastic debris ingested at all colonies except Coats Island. A single piece of soft plastic (incidence 0.5%) was found in a bird from Akpatok Island. A soft airgun bullet was found at Coats Island (incidence 0.5%) (Fig. 2). Fibres (incidence 5%) were also found at every colony sampled except Coats Island.

At Prince Leopold Island, 12% of the early season birds contained plastic, while none of the late season birds did so. However, this difference was not statistically significant ($P = 0.28$; Fisher's Exact). Although there was no significant difference in the birds containing plastics in the early and late season we discuss trends in plastic ingestion by the murres sampled early in the breeding season, but use only the birds collected during chick-rearing for our inter-colony comparison to control for any potential seasonal variations.

The colony at the Minarets was sampled during the 2007 and 2008 breeding season, making it the only colony we were able to

Table 1
The percentage of birds with ingested plastics, mean number of pieces per bird and mean mass of ingested plastics per bird found in thick-billed murre stomach contents collected from five Canadian Arctic sites in 2007 and 2008. SD = standard deviation.

Location	Date collected	All plastic debris	Rigid plastic	Soft plastic	Fibres	Air gun pellet	Average mass of plastics
Overall (186)							0.0016 (0.0099)
Mean number of plastic (SD)		0.20 (0.83)	0.12 (0.75)	0.005 (0.07)	0.0 (0.33)	0.005 (0.07)	
Proportion with ingested plastic		11	5	1	5	1	
Akpatok Island (31)	19-August-08						0.0025 (0.0094)
Mean number of plastic (SD)		0.29 (0.64)	0.16 (0.45)	0.03 (0.18)	0.13 (0.34)	0.00	
Proportion with ingested plastic		23	13	3	13	0	
Coats Island (25)	27-July-07						0.0032 (0.0162)
Mean number of plastic (SD)		0.04 (0.20)	0.00	0.00	0.00	0.04 (0.20)	
Proportion with ingested plastic		4	0	0	0	4	
Digges Sound (30)	11-August-08						0.0015 (0.0084)
Mean number of plastic (SD)		0.27 (0.69)	0.30 (0.18)	0.00	0.23 (0.67)	0.00	
Proportion with ingested plastic		17	3	0	13	0	
Minarets (50)	Overall						0.0003 (0.0014)
Mean number of plastic (SD)		0.06 (0.26)	0.04 (0.20)	0.00	0.02(0.14)	0.00	
Proportion with ingested plastic		6	4	0	2	0	
2007 (30)	5-August-07						0.0004 (0.0018)
Mean number of plastic (SD)		0.10 (1.40)	0.07 (0.25)	0.00	0.03 (0.18)	0.00	
Proportion with ingested plastic		10	7	0	3	0	
2008 (20)	3-August-08						0.00
Mean number of plastic (SD)		0.00	0.00	0.00	0.00	0.00	
Proportion with ingested plastic		0	0	0	0	0	
Prince Leopold Island (50)	Overall						0.0017 (0.0119)
Mean number of plastic (SD)		0.30 (1.39)	0.28 (1.38)	0.00	0.02 (0.14)	0.00	
Proportion with ingested plastic		8	6	0	2	0	
Early breeding season (32)	5-June-08						0.0026 (0.0146)
Mean number of plastic (SD)		0.47 (1.72)	0.44 (1.72)	0.00	0.03 (0.18)	0.00	
Proportion with ingested plastic		13	9	0	3	0	
Late breeding season (18)	9-August-08						0.00
Mean number of plastic (SD)		0.00	0.00	0.00	0.00	0.00	
Proportion with ingested plastic		0	0	0	0	0	

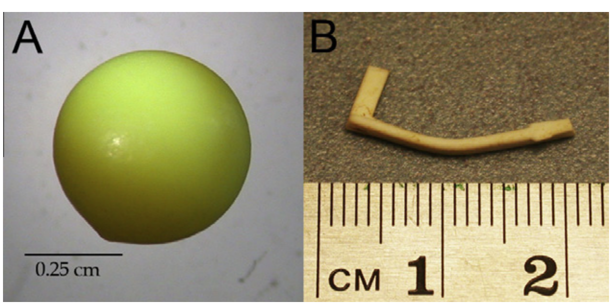

Fig. 2. (A) A soft airgun pellet found in the digestive tract of a murre from Coats Island and (B) a piece of consumer plastic found in a murre collected at Akpatok Island.

sample in multiple years. In 2007, 2/30 (7%) of the birds sampled contained ingested plastics, while none of the 20 birds collected in 2008 contained plastics ($P = 0.52$; Fisher's Exact). All birds collected at the Minarets were pooled for further analyses.

Among all the colonies sampled during the chick-rearing season both the number of ingested plastic pieces ($\chi_{4149} = 32.6$, $P < 0.0001$) and the proportion of birds containing them ($\chi_{4149} = 11.5$, $P = 0.022$) varied significantly (Fig. 3). Akpatok Island samples had the highest mean number of plastics per individual (0.3 plastic pieces per bird, $n = 31$, Table 1) and contained the highest proportion of samples with plastic (23% contained plastic, Table 1). The Prince Leopold Island sample from the chick-rearing period contained no plastics. Pairwise comparisons revealed that numbers of plastic pieces per sample varied among all colonies ($\chi_1 > 5.6$, $P < 0.018$), but not between Akpatok Island and Digges Sound ($\chi_1 = 0.28$, $P = 0.59$), Coats Island and the Minarets ($\chi_1 = 0.22$, $P = 0.64$), nor between the Minarets and Prince Leopold Island ($\chi_1 = 0$). Pairwise comparisons for proportion of birds containing plastic indicated that only Akpatok Island and the Minarets ($\chi_1 = 4.28$, $P = 0.038$), Akpatok Island and Prince Leopold Island ($\chi_1 = 1200$, $P < 0.0001$), Coats Island and Prince Leopold Island ($\chi_1 = 380$, $P < 0.0001$), and Digges Sound and Prince Leopold Island ($\chi_1 = 1020$, $P < 0.0001$) differed significantly (other pairwise comparisons $\chi_1 < 3.1$, $P > 0.079$).

For the 186 thick-billed murres sampled the average mass of plastic represented 0.0002% of body mass. This is approximately 80 times lower than amounts found in northern fulmars (*Fulmarus glacialis*) collected in the eastern Canadian Arctic during the same sampling period (0.0142%) (Mann–Whitney U test $U = 448$, $P < 0.001$ (Provencher et al., 2009). Two of the murres sampled carried plastic loads of 0.084 g (Prince Leopold Island, June 2008) and 0.081 g (Coats 2007); otherwise all murres had $\leqslant$0.05 g of plastic. When only the birds containing plastics are considered the average plastics represented 0.003% of body mass.

Plastic pieces ($n = 22$) ingested by murres were small. Mean length (4.5 ± 3.8 mm), width (3.9 ± 3.1 mm) and thickness (0.6 ± 1.1 mm) of plastic debris ingested by murres were all smaller than pieces found in northern fulmars in Nunavut (respectively 10.6 ± 10.4; 6.0 ± 4.1; 0.7 ± 0.4 mm, Mallory, 2008; Mann–Whitney U tests, all $U > 3187$, all $P \leqslant 0.03$). Several of the pieces in murres were very small and were only identified as plastic debris using a dissecting microscope. Based on visual inspection of the size of plastic and of prey items also in the gastrointestinal tracts, all of the colonies sampled had at least one murre with an ingested plastic piece that could have been potentially mistaken for a prey item by the seabird during a foraging bout.

Within birds containing plastic, the mean mass of plastic varied among the colonies (GLM $\chi_3 = 5.33$, $P = 0.014$). The murres sampled at Coats Island had the heaviest average mass of ingested plastics (Table 1), though only one bird contained plastic, and pairwise comparisons between Coats Island and all other colonies were significant (all t-values > 3.73 with $P < 0.0030$). No other pairwise comparisons were significant (all t-values < 0.53 with $P > 0.61$).

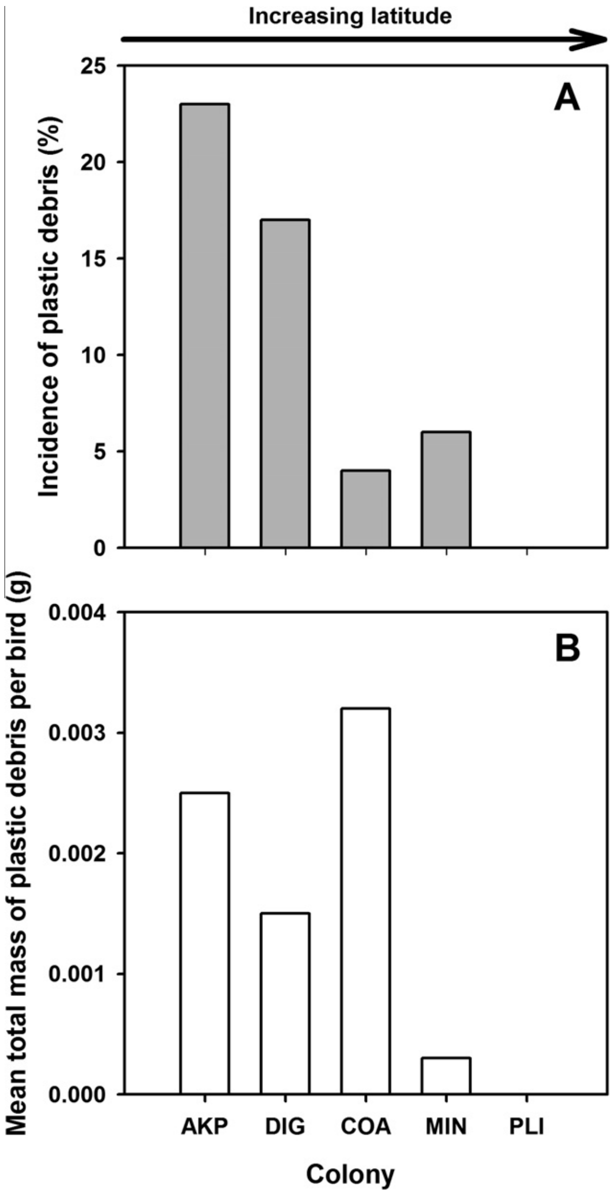

Fig. 3. The incidence (A) and mean mass of plastic per bird (B) in adult thick-billed murres during the chick-rearing period at five colonies in the Canadian Arctic (AKP – Akpatok Island; DIG – Digges Sound; COA – Coats Island; MIN – Minarets; PLI – Prince Leopold Island). A detailed breakdown of patterns are provided in Table 1.

4. Discussion

Since the 1980s seabird researchers worldwide have found the incidence of ingested plastics on the rise in many species, with plastic debris most likely mistaken for prey items and ingested during foraging bouts (Cadee, 2002). Studies have reported high levels of ingested plastics in surface feeding Procellariiformes from both hemispheres, including fulmars (Van Franeker et al., 2005; Mallory, 2008) and albatrosses (Auman et al., 1998; Petry et al., 2007). Other waterbirds may ingest high levels of plastics, including phalaropes, terns and gulls (Moser and Lee, 1992; Robards et al., 1995), but despite the large populations and wide distribution of auks in northern waters there have been few reports of ingested plastic debris for this group of birds (Day, 1980 in Robards et al., 1995; Van Franeker, 1983; Harris and Wanless, 1994; Robards et al., 1995; Blight and Burger, 1997) with very little ingested debris assessment undertaken over the last decade.

In the Canadian Arctic, Bradstreet (1980) and Gaston and Noble (1985) sampled thick-billed murres in the 1970s and 1980s, and although no plastics were reported among the stomach contents examined some birds did contain irregular, plastic-like fragments (Bradstreet pers. comm.). Plastics may have been present in thick-billed murre stomachs during the 1970s and 1980s, but here we report the first quantitative assessment of plastics in this species as a baseline for future work in this area.

Our results show thick-billed murres, which feed below the surface, also ingest marine plastics debris but at a lower incidence than most other species reported to date. The finding of ingested plastics at each of the colonies examined ranging across 11° of latitude (1300 km direct distance) suggests that this is a widespread occurrence among thick-billed murres in Canada, not just a local phenomenon. Overall, the incidence of plastic ingestion by thick-billed murres approximately follows the pattern observed in northern fulmars with the incidence of ingested plastics decreasing with increasing latitude (Van Franeker, 1985) (during chick-rearing season low Arctic: 14%, mid-Arctic: 6%, high Arctic: 0%) and plastic ingestion at all of the low Arctic sites were similar to each other, and significantly different from the high Arctic colony. This is the highest level of plastic ingestion reported to date for thick-billed murres (Day, 1980 in Robards et al., 1995).

Only user plastics were found in thick-billed murre from the Canadian Arctic indicating that local garbage sources likely represent the main source of plastic debris in the areas where the murres feed. User plastics in the marine environment come from sites such as municipal landfills, urban centres and large vessels moving through the area (Moore et al., 2005). Industrial nurdles are present in other Arctic seabirds collected in the same areas (Mallory, 2008; Provencher et al., 2009) but the lack of nurdles in the murres examined suggests that although plastics may be introduced to Arctic ecosystems far from point sources due to an absence of major shipping routes and plastics factories in Canada's North, it is likely that user plastics from local sources may have the greatest impact on this area's diving seabirds.

The retention time of plastics in murres is unknown but we can assume that smaller pieces would pass more easily than larger pieces. Small transmitters hidden inside fish fed to thick-billed murres were passed through the digestive tract in 6–24 h (Hawkins et al., 1997) but larger pieces of plastic that cannot pass from the crop, through the pyloric sphincter into the intestine, may stay in the digestive tract for much longer. As a result, we are unable to determine when and where ingested plastics were picked up by the murres which could have happened in the North Atlantic during the wintering period, or in Arctic waters during the breeding season. Further study of the passage time of plastics is essential to understanding how seabirds may be transporting plastics in the marine environment.

The bio-transport of plastics into the Arctic by seabirds is supported by our finding of more plastics in the murres sampled at PLI early in the season as compared with those collected later in the season. We found 13% of birds had ingested plastic early in the season when the birds had just arrived at the breeding colony while none of the birds sampled later in the season, after the birds had been foraging in the area for several months, had plastics in their GIT suggesting a seasonal effect on the incidence of plastic. Thick-billed murres may be ingesting plastics in the busier waters of the Northwest Atlantic during the winter months spent at sea, and bring them north during migration, however, our sample sizes were relatively small which probably contributed to the non-significant statistical results.

Digestion of the plastics through the breeding season may explain the absence of plastics in August (see also Mallory, 2008). The lack of plastic in murres from Prince Leopold Island collected during chick-rearing suggests that murres were not ingesting plastics within their foraging range in Lancaster Sound. Prince Leopold Island is the most northern site we sampled, has the most ice cover late into the season, and has east-flowing currents (i.e., towards sources of debris), which may exclude plastic debris from reaching this area. One of the impacts of less sea ice cover, which is associated with warming Arctic summers, may be an increase in plastics debris in the Arctic, leading to an increase in plastic ingestion in the marine environment (Mallory, 2008).

While the incidence of plastics found in the Prince Leopold Island sample may indicate a seasonal variation in the ingestion of plastics, it was also one of the early birds sampled at Prince Leopold Island that contained the highest number of plastics pieces (nine pieces in total). The large quantity of plastics found in a murre that had only recently arrived from the North Atlantic wintering grounds also supports the idea that most plastics are consumed in the southern regions of the range rather than in Arctic waters.

This high level of plastics from a bird sampled early in the year may indicate that we may be underestimating plastic ingestion in thick-billed murres in eastern Canadian waters by conducting most of our sampling in July and August. As many murres from the eastern Canadian Arctic breeding colonies overwinter off the coasts of Newfoundland and Greenland (Gaston and Jones, 1998), they are likely to ingest plastics in these waters that experience year-round shipping traffic, and are closer to large industrial areas. By concentrating our sampling during the chick-rearing season when birds have been in the Arctic for several months we may be missing a large portion of plastics that have passed out of the birds by this time.

Variation in debris ingestion was also observed in the birds collected at the Minarets colony collected over a two year period. This inter-annual variation demonstrates that although plastic ingestion is a widespread phenomenon in thick-billed murres in eastern Canada there is variation in the amount of plastics ingested by birds from the same colony between years. The murres at the Minarets showed plastic ingestion as high as 10% in 1 year and 0% in the next, indicating that single sampling efforts do not capture how plastic ingestion may be affecting Arctic seabird species. The difference between no plastics and some plastics in these birds is not significantly large, but do indicate very different patterns in marine debris in Arctic waters. In order to fully assess how plastics are being ingested by diving seabirds in Arctic waters a regular monitoring program must be established.

Ingestion of plastics by seabirds is often attributed to seabirds directly ingesting plastics in the water column (Cadee, 2002) but diving murres, who feed below the surface, are not likely to ingest plastics at the surface. The presence of a soft airgun pellet, which sinks in seawater, suggests that it is not only floating plastic debris that is affecting marine ecosystems. Murres may be picking up plastic debris directly during benthic foraging trips, or they may be consuming prey species that forage in the benthic zone and are indirectly ingesting plastics inside prey species. Similar sinking pellets have been found in northern fulmars, a seabird that does not dive deeper than a few meters below the surface and yet have been found to contain plastic debris that is known to sink (van Franeker pers. comm.). Unlike fulmars, murres do forage on a number of benthic species including several sculpins species and cumaceans (Gaston and Bradstreet, 1993; Provencher and Gaston unpubl. data) but again it is difficult to determine whether the birds directly ingested plastic items, or indirectly via prey species. Regardless of the route of the plastic debris through the ecosystem, ingested plastics can have a number of negative impacts on marine species with seabirds being top predators, and the potential end point of plastics accumulating up the food chain.

The site with the highest proportion of birds with ingested plastics was the low Arctic colony of Akpatok Island, and this site differed significantly from the Minarets (mid-Arctic) and Prince Leopold Island in the high Arctic, but was similar to the other low Arctic colonies in proportion of birds with ingested plastics. The location of wintering areas differs among the murre colonies examined (Donaldson et al., 1997; AJG and Smith, unpubl. data) and the high incidence of plastic among Akpatok murres suggests that birds from this colony may winter in areas with higher levels of plastic debris. Unfortunately the main wintering area for this colony is unknown (Donaldson et al., 1997). As the murre colony on Akpatok Island is the largest in Canada this high level of ingested plastics indicates that a large portion of thick-billed murres may be ingesting plastic debris on a regular basis.

Although the mass of plastics is small in murres and on average represents only 0.0002% of the body mass, plastic ingestion by this species demonstrates that surface feeders are not the only seabirds that are susceptible to ingesting marine debris. However, the murres sampled had a significantly lower mass of plastics to body mass ratio compared to northern fulmars sampled at the same time in the same areas (Provencher et al., 2009) indicating that although murres ingest marine debris, the plastic load carried by each bird on average is still much lower than those carried by breeding northern fulmars using the same areas. The mass of plastics did differ significantly at Coats Island when compared with the other colonies but since a single piece of plastic (a soft airgun pellet) dominated the sample it is difficult to interpret the biological significance of this plastic load.

We interpret the detection of plastic ingestion by thick-billed murres in the eastern Canadian Arctic reported here as evidence of an increase in plastics in the marine environment in general. This finding mirrors the recent results from northern fulmars (Mallory, 2008; Provencher et al., 2009), which also indicated increasing ingestion of plastic by Arctic seabirds. The plastic pieces ingested by the murres were significantly smaller than pieces found in northern fulmars in the same region, suggesting that murres may be selecting for smaller pieces of debris than fulmars.

The Canadian Arctic is considered a pristine, remote area of the world with a small population and little industrialization. Although the Arctic is remote from point sources of pollution, atmospheric and oceanographic processes, and bio-transport are bringing pollutants from the south into these northern landscapes (Braune and Scheuhammer, 2008; Mallory, 2008). As ship traffic increases in the area and the human population grows, more plastic debris is likely to enter the Arctic marine environment, and we predict that the incidence of plastic debris ingestion by Arctic seabirds will continue to increase. This study provides a necessary baseline for future comparative studies measuring potential impacts associated with these changes.

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References

Auman, H.J., Ludwig, J.P., Giesy, J.P., Colborn, T., 1998. Plastic ingestion by *Laysan albatross* chicks on Sand Island, Midway Atoll, in 1994 and 1995. In: Albatross biology and conservation, Surrey Beatty and Sons Pty Limited.

Auman, H.J., Woehler, E.J., Riddle, M.J., Burton, H., 2004. First evidence of ingestion of plastic debris by seabirds at sub-Antarctic Heard Island. Marine Ornithology 32, 105–106.

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

Bradstreet, M.S.W., 1980. Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring: diets and food availability along ice edges. Canadian Journal of Zoology – Revue Canadienne de Zoologie 58, 2120–2140.

Braune, B.M., Scheuhammer, A.M., 2008. Trace element and metallothionein concentrations in seabirds from the Canadian Arctic. Environmental Toxicology and Chemistry 27, 645–651.

Braune, B.M., Donaldson, G.M., Hobson, K.A., 2001. Contaminant residues in seabird eggs from the Canadian Arctic. Part I. Temporal trends 1975–1998. Environmental Pollution 114, 39–54.

Cadee, G.C., 2002. Seabirds and floating plastic debris. Marine Pollution Bulletin 44, 1294–1295.

Dickerman, R.W., Goelet, R.G., 1987. Northern Gannet starvation after swallowing Styrofoam. Marine Pollution Bulletin 18, 293.

Donaldson, G.M., Gaston, A.J., Chardine, J.W., Kampp, K., Nettleship, D.N., Elliott, R.D., 1997. Winter distribution of thick-billed murres from the east Canadian Arctic and western Greenland in relations to age and time of year. Occasional Paper of Canadian Wildlife Services 96, 26.

Gaston, A.J., 2002. Results of monitoring thick-billed murre populations in the eastern Canadian Arctic, 1976–2000. Occasional Paper of Canadian Wildlife Service 106, 13–50.

Gaston, A.J., Bradstreet, M.S.W., 1993. Intercolony differences in the summer diet of thick-billed murres in the eastern Canadian Arctic. Canadian Journal of Zoology – Revue Canadienne de Zoologie 71, 1831–1840.

Gaston, A.J., Hipfner, J.M., 2000. Thick-billed murre *Uria lomvia*. Birds of North America, 1–32.

Gaston, A.J., Jones, I.L., 1998. The Auks. Oxford University Press, Oxford.

Gaston, A.J., Noble, D., 1985. The diet of thick-billed murres (*Uria Lomvia*) in west Hudson Strait and northeast Hudson Bay. Canadian Journal of Zoology – Revue Canadienne de Zoologie 63, 1148–1160.

Harper, P.C., Fowler, J.A., 1987. Plastic Pellets in New Zealand storm-killed Prions Pachyptila-Spp. 1958–1977. Notornis 34, 65–70.

Harris, M.P., Wanless, S., 1994. Ingested elastic and other artifacts found in puffins in Britain over a 24-year period. Marine Pollution Bulletin 28, 54–55.

Hawkins, P.A.J., Butler, P.J., Woakes, A.J., Gabrielsen, G., 1997. Heat increment of feeding in Brunnich's guillemot *Uria lomvia*. The Journal of Experimental Biology 200, 1757–1763.

Kitaysky, A.S., Golubova, E.G., 2000. Climate change causes contrasting trends in reproductive performance of planktivorous and piscivorous alcids. Journal of Animal Ecology 69, 248–262.

Mallory, M.L., 2008. Marine plastic debris in northern fulmars from the Canadian high Arctic. Marine Pollution Bulletin 56, 1501–1504.

Mavor, R.A., Heubeck, M., Schmitt, S., Parsons, M., 2008. Seabird numbers and breeding success in Britain and Ireland, 2006. UK Nature Conservation 31, 1–113.

Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat, Academic Press Inc. Elsevier Science (p. 131–139).

Moore, C.J., Lattin, G.L., Zellers, A.F., 2005. Density of plastic pellets found in zooplankton trawls from coastal waters of California to the North Pacific Central gyre. In: Proceedings from the Plastic Debris Rivers to Sea Conference.

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

Petry, M.V., Fonseca, V.S.D., Scherer, A.L., 2007. Analysis of stomach contents from the black-browed albatross, *Thalassarche melanophris*, on the Coast of Rio Grande do Sul, Southern Brazil. Polar Biology 30, 321–325.

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. Marine Pollution Bulletin 58, 1092–1095.

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

Rothstein, S., 1973. Plastic particle pollution of surface of Atlantic Ocean – evidence from a seabird. Condor 75, 344–345.

Ryan, P.G., 1988. Effects of ingested plastic on seabird feeding – evidence from chickens. Marine Pollution Bulletin 19, 125–128.

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

Ryan, P.G., Connell, A.D., Gardner, B.D., 1988. Plastic ingestion and Pcbs in seabirds – is there a relationship. Marine Pollution Bulletin 19, 174–176.

Salomonsen, F., 1965. Geographical variation of fulmar (*Fulmarus Glacialis*) and zones of marine environment in North Atlantic. Auk 82, 327.

Spear, L.B., Ainley, D.G., Ribic, C.A., 1995. Incidence of plastic in seabirds from the tropical pacific, 1984–1991 – relation with distribution of species, sex, age, season, year and body-weight. Marine Environmental Research 40, 123–146.

Van Franeker, J.A., 1983. Inwendig onderzoek aan zeevogels. (dissection of seabirds). Nieuwsbrief NSO 4 (4/5), 144–167.

Van Franeker, J.A., 1985. Plastic ingestion in the North Atlantic fulmar. Marine Pollution Bulletin 16, 367–369.

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., Meijboom, A., De Jong, M., 2009. Fulmar litter EcoQO monitoring in the Netherlands 1979–2007 in relation to EU directive 200/59/EC on Port Reception Facilites. IMARES Report No. C032/09, Wageningen IMARES, Texel.

Vlietstra, L.S., Parga, J.A., 2002. Long-term changes in the type, but not amount, of ingested plastic particles in short-tailed shearwaters in the southeastern Bering Sea. Marine Pollution Bulletin 44, 945–955.

Woo, K.J., Elliott, K.H., 2008. Individual specialization in diet by a generalist marine predator reflects specialization in foraging behaviour. Journal of Animal Ecology 77 (6), 1082–1091.