ARTICLE IN PRESS

MPB-08204; No of Pages 4

Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Levels of ingested debris vary across species in Canadian Arctic seabirds

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ARTICLE INFO

Article history:
Received 15 July 2016
Received in revised form 3 November 2016
Accepted 19 November 2016
Available online xxxx

Keywords:
Pollution
Marine birds
Foraging guild
Debris
Plastic

ABSTRACT

Plastic debris has become a major pollutant in the world's oceans and is found in many seabird species from low to high latitudes. Here we compare levels of plastic ingestion from two surface feeders, northern fulmars (*Fulmarus glacialis*) and black-legged kittiwakes (*Rissa tridactyla*), and two pursuit diving species, thick-billed murres (*Uria lomvia*) and black guillemots (*Cepphus grylle*) in the Canadian high Arctic. This is the first report quantifying plastic ingestion in kittiwakes in this region, and as predicted, kittiwakes and fulmars had higher frequency of plastic ingestion than guillemots and murres. Despite this, amounts of plastic ingested by birds remain lower than regions farther south.

Plastic debris has become ubiquitous in the world's oceans and is classified by the United Nations Environment Program as one of the most critical emerging threats (Barnes et al., 2009; UNEP, 2014; Wilcox et al., 2015). Marine litter is mostly comprised of plastic debris, with plastics accounting for up to 95% of debris in some areas, and plastic concentrations increasing in oceans worldwide (Moore, 2008). Plastics found in the sea can be categorized into two major types: industrial and user plastics. Industrial plastics refer to raw plastics in the form of pellets that are shipped to factories for additional processing (Azzarello and Van Vleet, 1987). User plastics refers to all other types of plastics used in commercial goods such as toys, plastic bags, ropes, bottles, etc. (Azzarello and Van Vleet, 1987). Oceanic plastic debris poses a significant threat to marine wildlife via entanglement and ingestion, with seabirds being particularly vulnerable (Azzarello and Van Vleet, 1987; Laist, 1997). Known effects of ingested plastics on seabirds include gastrointestinal blockage (Azzarello and Van Vleet, 1987), reduced storage volume of the stomach (Ryan, 1988), and uptake of hazardous chemicals (Ryan, 1988; Teuten et al., 2009). Seabirds were first reported to ingest plastic by the scientific community in the 1960s (Harper and Fowler, 1987). Plastic ingestion occurs in at least 40% of the world's seabird species, with plastic debris found in species inhabiting equatorial to polar waters (Kühn et al., 2015).

Seabirds are particularly useful organisms to understand the pervasiveness of plastic debris in the marine environment because they forage over large distances, making them likely to encounter and ingest marine plastic debris that they may mistake for prey (Derraik, 2002). In environments such as the Canadian Arctic where research is logistically challenging, seabirds offer an effective alternative to monitoring marine plastic pollution over costlier methods such as ship-based surveys (Ryan et al., 2009).

In many regions of the world, plastic ingestion varies with foraging modes in seabirds (Azzarello and Van Vleet, 1987; Ryan, 1987a; Moser and Lee, 1992). Seabirds can be classified into three main foraging types: surface feeders, plungers and pursuit divers (Ashmole, 1971). Surface feeders are more susceptible to ingesting plastic as the majority of plastics float and accumulate at the water surface (Moser and Lee, 1992; Robards et al., 1995). In particular, birds of the order Procellariiformes such as fulmars, albatrosses, shearwaters and storm-petrels have the greatest tendency to accumulate plastics (Azzarello and Van Vleet, 1987; Moser and Lee, 1992; Robards et al., 1995). Diving birds exhibit a lower incidence of plastic ingestion than surface feeders even when foraging in the same area (Robards et al., 1995; Provencher et al., 2009, 2010).

Although foraging mode influences degree of plastic accumulation in seabirds, there are few data comparing species with different foraging strategies in the Canadian Arctic. Four common species that may ingest plastic in this region include two surface feeders, the northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*), and two diving birds, the thick-billed murre (*Uria lomvia*) and the black guillemot (*Cepphus grylle*; Gaston et al., 2012). Both fulmars and murres from the Canadian Arctic are known to ingest plastic (Provencher et al., 2015), and plastic ingestion by fulmars is used as an Ecological Quality Objective (EcoQO) for marine debris in the North Sea (van Franeker

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http://dx.doi.org/10.1016/j.marpolbul.2016.11.051

et al., 2011). Plastic in kittiwakes and guillemots from the Canadian Arctic has not been quantified. To that end, we studied plastic ingestion in these four species which differ in foraging mode, and which were sampled concurrently from a single colony in the Canadian Arctic. We predicted that surface foragers (northern fulmars and black-legged kittiwakes) would exhibit a higher incidence of plastic ingestion than pursuit divers (thick-billed murres and black guillemots).

In August 2013, black-legged kittiwakes, northern fulmars, thick-billed murres and black guillemots were collected from Prince Leopold Island, Nunavut, Canada (74°N, 90°W). All birds were captured alive from the colony using a noose pole and immediately and humanely euthanized as per animal care protocols. The carcasses were kept cool until they could be placed in a freezer, frozen, and later shipped to the laboratory of the Nunavut Arctic College in Iqaluit, Nunavut. Carcasses were thawed, measured and dissected in collaboration with students from the Environmental Technology Program (Provencher et al., 2013). The entire gastrointestinal tract of each bird was removed intact, refrozen and shipped to the National Wildlife Research Centre in Ottawa for examination of ingested plastics. Each gastrointestinal tract was later thawed and dissected over a 1 mm sieve, and only contents remaining in the sieve were examined while the rest was discarded. Stomach contents were examined under a binocular microscope and identified plastics were categorized as user or industrial plastics following the protocol outlined by van Franeker et al. (2005). After sorting, all items in each bird were dried and weighed using a Denver Instrument SI-234 analytical scale (±0.0001 g). Each debris piece was also measured along its length and width using digital calipers. The color of each debris piece was determined as the predominant color visible (pooling categories of white and yellow).

A Kruskal-Wallis rank sum test, followed by Dunn's Multiple comparison post hoc test for pairwise comparisons, was used to investigate the relationship between the mass of accumulated debris and species, and the relationship between the number of debris pieces and species (excluding black guillemots as there were only three samples). We used a Fisher Exact test to examine the prevalence of accumulated debris in fulmars and murres from Prince Leopold Island for the years 2008 (data from Provencher et al., 2009, 2010) and Provencher et al., 2013. To investigate the variation in the mass and number of accumulated debris found in fulmars and murres collected in August 2008 and August 2013, a Wilcoxon rank-sum test was used.

Using data from this study (2013) and data previously collected (2008) at the same site, we had sufficient data to test the relationship between sex, body condition and debris ingestion in fulmars using a general linear model (data were normally distributed; Kruskal-Wallis tests, all $p > 0.05$). Note that data were insufficient to conduct a similar test for the other species due to only one individual amongst the other species containing any debris. We determined body condition of each fulmar by dividing body mass by tarsus length (see Blackmer et al., 2005). Statistical analyses were conducted using Statistica (Stat Soft Inc., 2013), and all differences were considered significant when $p < 0.05$. Mean values were reported ± SD.

We examined nine northern fulmars, 11 black-legged kittiwakes, 10 thick-billed murres and three black guillemots for plastic ingestion. The incidence of plastic ingestion was 0% for murres and guillemots, while 9% (1/11) of kittiwakes and 89% (8/9) of fulmars contained debris in their stomachs (Table 1). Across all species, 33 pieces of litter were identified which were principally user plastics (89%), with the remainder industrial plastics (9%) and paraffin (1%). User plastics found in fulmars were mostly fragments (58%; Fig. 1), with the remainder being sheet-like, thread-like and foamed plastics (Supplementary data, Table 2). Ingested plastics came in a variety of colors: yellow/white (70%), black (9%), brown (9%), grey (6%), red (3%) and orange (3%). The majority (78%) of all ingested plastics were small (≤5 mm, hence microplastics; Arthur et al., 2009) with a mean length and width of 4.4 ± 2.6 mm and 2.8 ± 1.4 mm, respectively. The largest plastic piece, which was found in a fulmar, measured 12.1 mm × 6.8 mm.

Mass of accumulated debris (Kruskal-Wallis; $H_{30} = 19.4$, $p < 0.001$) and the number of debris pieces ingested ($H_{30} = 20.2$, $p < 0.001$) varied amongst species. Northern fulmars had a greater mass and number of accumulated debris pieces than kittiwakes (Dunn's tests; both $p < 0.001$) and murres (both $p < 0.001$). Amongst the individuals containing debris, debris represented 0.000038 ± 0.000031% of fulmar body mass. Overall, fulmars contained on average 0.025 ± 0.025 g of debris and 3.4 ± 3.0 pieces of debris, with eight pieces being the maximum number of debris found in any individual. The one kittiwake containing debris had two plastic fragments collectively weighing 0.0288 g; across all 11 birds this would average 0.003 ± 0.009 g and 0.18 ± 0.60 pieces (Table 1; Fig. 2).

For fulmars, the incidence of ingested debris was similar in samples from 2008 and 2013 (Table 1; Fisher Exact Test; $p = 1.0$), as were total mean mass of ingested debris and mean number of ingested debris pieces (Wilcoxon rank sum tests, both $p \geq 0.59$). Plastic ingestion remained unchanged at 0% for murres collected in 2008 (breeding season birds considered only) and 2013. Neither fulmar body condition ($p = 0.08$) nor sex ($p = 0.36$) were significant predictors of the mass of ingested debris (GLM; $F_{2,16} = 2.45$, $p = 0.12$). Zero northern fulmars collected in 2013 contained over 0.1 g of plastic debris, meeting the EcoQO established in the North Sea (van Franeker et al., 2011). One of 10 (10%) fulmars collected in 2008 contained over 0.1 g of plastic debris, therefore just failing the EcoQO.

In this study, we had the somewhat unique opportunity to examine the variation in levels of ingested debris in different species of Canadian Arctic seabirds which represented a range of foraging modes, but which were collected concurrently from the same colony. Although our sample sizes were small, the results supported our predictions, that is, we observed a higher incidence of ingestion, mass and number of ingested debris in surface feeders than pursuit divers. The absence of debris in both diving species was likely due to the fact the majority of plastics at sea are less dense than water and are therefore predominately found floating at the surface of the sea (Ryan et al., 2009; Barnes et al., 2009). Species that dive beneath the water surface to obtain their food are less likely to ingest floating debris, though they may still ingest plastics found deeper in the water column and may be more susceptible to entanglement with larger marine plastic debris (Provencher et al., 2010). Plastic ingestion has been previously reported in kittiwakes in this region (Day et al., 1985), but the mean mass and number of plastic pieces were not determined. Both surface feeders we examined had ingested debris, this being the first report quantifying ingestion of plastic by kittiwakes in the Canadian Arctic. However, the incidence of debris accumulation was much higher in fulmars than kittiwakes. Our results are similar to

Table 1
Values for accumulated debris in northern fulmars, black-legged kittiwakes, thick-billed murres and black guillemots collected from Prince Leopold Island in August 2008 and August 2013. SD = standard deviation.

Species	Year	Sample size	Incidence (%)	Mean mass (g) ± SD	Mean number of pieces ± SD	Mean length (mm) ± SD	Mean width (mm) ± SD
Northern fulmar	2008	10	80	0.050 ± 0.099	2.5 ± 3.5	N/A	N/A
Northern fulmar	2013	9	89	0.025 ± 0.025	3.4 ± 3.1	4.2 ± 2.5	2.8 ± 1.5
Thick-billed murre	2008	10	0	0	0	N/A	N/A
Thick-billed murre	2013	10	0	0	0	N/A	N/A
Black-legged kittiwake	2013	11	9	0.003 ± 0.009	0.18 ± 0.6	7.4 ± 0.1	3.5 ± 0.9
Black guillemot	2013	3	0	0	0	N/A	N/A

Please cite this article as: Poon, F.E., et al., Levels of ingested debris vary across species in Canadian Arctic seabirds, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.11.051

Fig. 1. Ingested debris found in the gizzard of a northern fulmar (*Fulmarus glacialis*) from Prince Leopold Island, Nunavut (74°N, 90°W) in July 2013. Grid = 1 cm × 1 cm. Image shows six plastic fragments, one plastic thread and one paraffin. Total mass of this debris load was 0.08 g.

studies from the North Pacific, that also found kittiwakes had lower incidence of debris accumulation compared to fulmars; kittiwakes averaged 6.3% compared to 71.1% in fulmars between the years 1969–1977 and 1988–1990 (Robards et al., 1995). Although the incidence of plastic ingestion was high in fulmars, there was no evidence that body condition was lower in birds with greater amounts of plastic.

Variation in the incidence of litter accumulation between the two surface feeders may be attributed in part to species-specific regurgitation abilities and diet (Day, 1980; Ryan, 1987a, 1987b). The northern fulmar is part of the order Procellariiformes and many species of this order, including fulmars, do not typically regurgitate indigestible prey remains due to the anatomy of their stomach and thus retain plastic in their gizzard (Furness, 1985). In contrast, black-legged kittiwakes and other species from the order Charadriiformes habitually regurgitate indigestible prey remains such as fish bone, which may limit the accumulation of plastic debris in this species (Ryan, 1987b). As well, fulmars consume primarily cephalopods and crustaceans in the Canadian Arctic (Mallory et al., 2010), while the diet of the kittiwakes is dominated by fish (Hatch et al., 2009). Previous studies have found that birds consuming a diet high in crustaceans and cephalopods had a significantly higher incidence of plastic ingestion (Day, 1980; Moser and Lee, 1992). Furthermore, fulmars are generalists and opportunistic foragers (Hatch and Nettleship, 1998), which may increase their susceptibility to ingest marine debris (Ryan, 1987a). Finally, fulmars typically travel much farther to forage than kittiwakes (Thaxter et al., 2012), and plastics may be more prevalent in offshore areas where they concentrate in oceanic gyres (Lebreton et al., 2012; Eriksen et al., 2014). Fulmars may therefore be ingesting plastics far from their breeding grounds and potentially from more polluted areas than those used by kittiwakes.

Fig. 2. Ingested plastic found in the gizzard of a black-legged kittiwake (*Rissa tridactyla*) from Prince Leopold Island, Nunavut (74°N, 90°W) in July 2013. Grid = 1 cm × 1 cm. Image shows two plastic fragments. Total mass of this plastic load was 0.0288 g.

Despite documented increases in plastics entering oceans (Moore, 2008; Gregory, 2009), we found no difference in ingestion rates for murres or fulmars from this high Arctic colony over a five year period (Provencher et al., 2009, 2010). This lack of a temporal pattern is consistent with studies on the east and west coasts of North America, which found little change in the incidence of plastic in murres over 2–3 decades (Robards et al., 1997; Bond et al., 2013). For fulmars, a positive finding was that none of our birds sampled in 2013 exceeded the North Sea EcoQO guidelines of 0.1 g for total mass of accumulated debris (OSPAR, 2008), suggesting that despite the high incidence of plastic in the birds (~90%), the amount of plastic ingested is still relatively low. In fact, mean mass of plastics in fulmars from this study was 2–43 times less that previously reported in Canadian fulmar studies, all of which had some birds with ingested plastic levels that exceeded the EcoQO guidelines (Mallory, 2008; Provencher et al., 2009; Avery-Gomm et al., 2012; Bond et al., 2014). Such studies demonstrate the need for regular, standardized monitoring of plastic ingestion in the Canadian Arctic as there is in the North Sea to track changes in the quantity and type of plastics found in this region (OSPAR, 2008).

A multi-species sampling approach such as the one used in this study helps us understand which species are most susceptible to ingesting plastic, thereby allowing us to prioritize the research and conservation of these species. Our data suggest that fulmars remain a priority for monitoring the prevalence of plastic pollution in the Canadian Arctic, but that surface-feeding marine birds in general are at higher risk. We lack knowledge of the incidence of plastic ingestion for 57% of Canada's marine bird species (Provencher et al., 2015), and yet Arctic Canada is expected to experience increases in industrial activity and shipping in the coming decades (Arctic Council, 2009; Trevail et al., 2015), which inevitably suggests higher pollution risk. Thus we encourage the long-term, regular monitoring of plastic ingestion in the Canadian Arctic to assess how levels of marine plastic pollution in this region will change over time.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marpolbul.2016.11.051.

Acknowledgements

The field work component of this project was supported by Environment and Climate Change Canada, Acadia University (48-0-504807) and the Northern Contaminants Program (58-0-205554) (Indigenous and Northern Affairs Canada). We thank the students from Nunavut Arctic College for their assistance in dissecting the specimens of birds. Thanks to MR Forbes, AJ Gaston and HG Gilchrist for logistic assistance in the field, at the National Wildlife Research Center, and at Carleton University.

Please cite this article as: Poon, F.E., et al., Levels of ingested debris vary across species in Canadian Arctic seabirds, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.11.051

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Please cite this article as: Poon, F.E., et al., Levels of ingested debris vary across species in Canadian Arctic seabirds, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.11.051