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Evidence for increased ingestion of plastics by northern fulmars (*Fulmarus glacialis*) in the Canadian Arctic

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Marine plastic debris floating in the oceans is a worldwide problem. When ingested by seabirds it may cause starvation and reduced growth, as well as more subtle effects that can be difficult to detect, including reduced dietary efficiency and increased levels of PCBs and other organochlorine assimilation (van Franeker, 1985; Dickerman and Goelet, 1987; Ryan, 1988; Ryan et al., 1988). Globally, the incidence of plastics in seabirds has increased since it was first reported in 1960 (Harper and Fowler, 1987; Moser and Lee, 1992; Petry et al., 2007). By 2008, ingested plastic debris has been reported in more than 200 seabird species (Moore, 2008), and is a problem even in isolated and remote colonies (Van Franeker and Bell, 1988).

The northern fulmar, *Fulmarus glacialis*, a medium-sized petrel with a circumpolar distribution, is particularly vulnerable to

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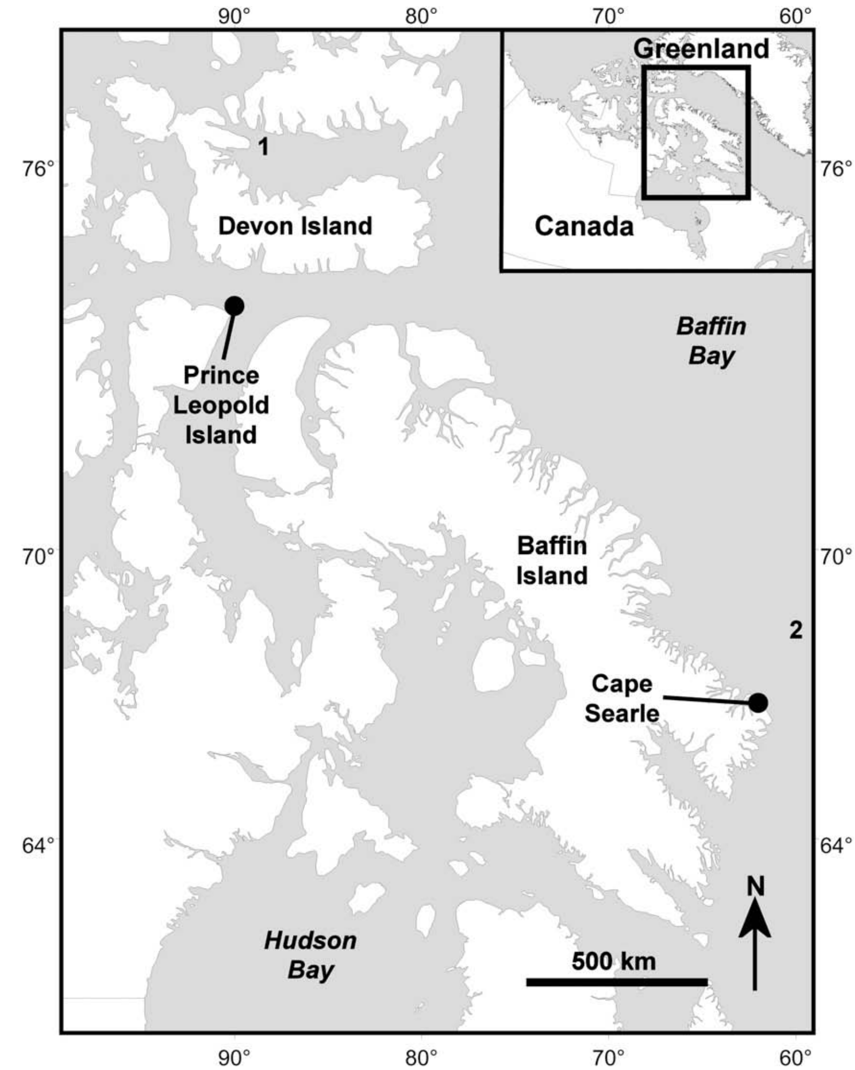

Fig. 1. Northern fulmars were collected at two colonies in the Canadian Arctic: Prince Leopold Island, and Cape Searle. Sites where previous studies have documented plastic ingestion by fulmars are noted as "1" (Cape Vera; Mallory, 2008) and "2" (Davis Strait; Mallory et al., 2006).

ingesting marine plastic debris and was one of the first species in which a high incidence of plastic ingestion was reported among North Atlantic seabirds (Baltz and Morejohn, 1976; Bourne, 1976; Furness, 1985). Because they ingest and retain a wide variety of plastic debris (van Franeker and Meijboom, 2006), fulmars are useful indicators of trends in marine debris in offshore areas. The incidence of plastics in their stomachs has been used as an indicator of marine debris in the North Sea since the 1980s (van Franeker et al., 2005). Unlike Europe's North Sea, the Canadian Arctic is remote from industrial centres and major shipping lanes. In the 1970s, Bradstreet (1976) collected Arctic fulmars for dietary analysis and reported no ingested plastic, despite the contemporary occurrence of debris in seabirds elsewhere (Baltz and Morejohn, 1976; Harper and Fowler, 1987; Moser and Lee, 1992). The first evidence of ingested plastic in breeding fulmars in the Canadian Arctic was recorded in 2003 by Mallory (2008) who sampled northern fulmars from Cape Vera, a breeding colony in the High Arctic.

In this study, we collected fulmars for dietary analysis and contaminant studies at two different colonies in the Canadian Arctic (Fig. 1). Our collections were made at colonies >250 km south of Cape Vera, where Mallory (2008) first reported ingested plastics in breeding fulmars, and thus our collections were closer to shipping traffic and with a longer open water season. Previous studies have shown that incidence of plastic pieces in fulmars is lower at higher latitudes (van Franeker, 1985; Mallory, 2008), however, the sites we sampled were still in Arctic environments constrained by sea ice, and thereby with limited sea traffic and with no industrial activity nearby.

In August 2008, 15 fulmars were shot at sea with a shotgun within 5 km of the fulmar colony at Cape Searle, Nunavut (67°15′N, 62°35′W). Farther north, 10 breeding adults with eggs or chicks were captured on their nest sites with a noose pole on the cliffs at Prince Leopold Island, Nunavut (PLI) (74°N, 90°W), and were immediately euthanized. Each carcass was kept cool until it could be placed in a freezer (within 24 h) and shipped to the laboratory. In November 2008, the carcasses were thawed, measured (standard metrics including body mass), and dissected. The gastrointestinal tracts were removed intact, refrozen, and sent to the University of Victoria for processing and sorting, while the remains of the birds were processed and entered into the National Tissue Bank at the National Wildlife Research Centre in Ottawa for other analyses. Each gastrointestinal tract was later thawed, slit along their entire length, flushed with ethanol to remove all items present,

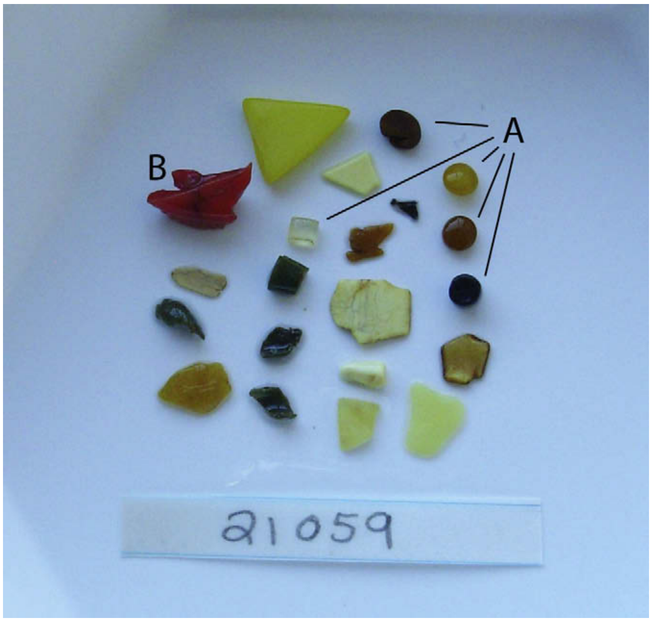

Fig. 2. Plastic pieces found in a northern fulmar collected at Cape Searle in the 2008. (A) Industrial nurdles, (B) bottle cap lid, remaining pieces are from unidentified sources.

and the contents were sorted into different prey types and plastics. All plastic debris was categorized as "user plastic" or "industrial plastic" (van Franeker et al., 2005). Total plastic debris from each stomach was dried and weighed using a Scaltec SCB22 analytical scale (±0.00001 g).

A variety of plastic types were found in the proventriculus and gizzards of the fulmars including plastic pieces from bottle caps, styrofoam (extruded polystyrene foam), industrial nurdles and plastic fragments from unidentified sources. Debris came in many colors: brown, black, grey, green, white, off-white, yellow and transparent colorless (Fig. 2). No plastic pieces were found lower in the digestive tract along the intestine. Plastics were sorted into the categories hard plastics and styrofoam, both user plastics, and industrial plastics which included all pellets and nurdles.

The incidence of plastic ingestion was similar at both colonies (Table 1; Fisher Exact test, $P = 1.0$), with 21 of 25 fulmars from both colonies (84%) containing plastic debris. The types of fragments ingested by fulmars at each colony were also similar, although styrofoam was not found in any birds from Prince Leopold Island. Fulmars at Cape Searle typically contained more pieces of plastic than those at Prince Leopold Island (Table 1; Wilcoxon rank-sum test, $P = 0.016$). The mean total mass of ingested plastic was not significantly different ($P = 0.17$), though the power of analysis of the Wilcoxon rank sum tested was very low (0.133). Ingested plastic represented on average 0.000142% of fulmar body mass. At Prince Leopold Island, 10% of fulmars contained >0.1 g of total plastic (a threshold mass used in the North Sea plastic monitoring program; OSPAR, 2008), which was less than the 40% of fulmars at Cape Searle that had ingested at least this much plastic (Fisher Exact test, $P = 0.18$).

Our results showed a markedly different pattern on the incidence of ingested plastics in fulmars of the Canadian Arctic compared to recent work in this region. More than 80% of the fulmars at Cape Searle and Prince Leopold Island had ingested plastic, nearly three times the levels recently reported from Cape Vera or Davis Strait (Mallory et al., 2006; Mallory, 2008). Although we found no difference in incidence of ingested plastics between our two sites, we did find a significant difference between the two colonies in the number of pieces ingested, suggesting that individuals at the more southerly Cape Searle colony are exposed to greater amounts of plastic debris. These findings, along with those of Mallory (2008) support the pattern of decreasing incidence of plastics with increasing latitude proposed by van Franeker (1985).

Compared to Cape Searle, the waters surrounding the Prince Leopold Island colony are ice-covered for a much greater amount of the breeding season (Mallory and Fontaine, 2004), and this colony is considerably more remote from most shipping activity, major communities, and north-flowing ocean currents, all of which could bring plastic debris into the foraging range of a colony (below). Both Canadian sites were at or above the OSPAR Ecological Quality Objective (EcoQO) for marine plastic debris used in the Save the North Sea program (10% of fulmars with an average mass of ingested plastic $\geqslant 0.1$ g; OSPAR, 2008). Reanalyzing the data presented in Mallory (2008) and Mallory et al. (2006), 11% of those 144 fulmars were also above the EcoQO objective.

Although we did not find a statistically significant difference in the mass of the plastics ingested at our two sites, the low power of analysis, most likely due to our small sample size, suggests that we lack the ability to detect a difference in mass of plastics ingested between these two sites with our current data. In fact, the average fulmar at Cape Searle had three times as many pieces of plastic and carried nearly three times the mass of plastic, compared to birds at Prince Leopold Island (Table 1). We suspect that additional sampling from these sites will confirm that ingested plastic is a greater issue at the more southern colony. Despite our small sample size, the differences between our results (84% incidence) and those from the recent studies farther north in the Canadian Arctic (36% incidence, Mallory et al., 2006; 31% incidence, Mallory, 2008) are striking, and highlight the importance of colony-specific information in environmental monitoring with seabirds (e.g., Braune et al., 2002).

The fulmars breeding in Arctic Canada are likely ingesting large amounts of plastic debris on their wintering grounds in the North Atlantic as shown by Mallory (2008) comparing plastic ingestion as

Table 1
Ingested plastic values for northern fulmars collected at a mid-Arctic colony and a High Arctic colony in the eastern Canadian Arctic during the 2008 breeding season.

Location (n)	Female (%)	Total pieces	Industrial	User	Hard plastic	Styrofoam	Total plastic mass per fulmar (g)	% above EcoQO[a]
Overall (25)	52							
Incidence		84%	28%	84%	84%	8%		
Mean (SD)		5.6 (6.0)	0.4 (1.0)	5.1 (5.5)	5.1 (5.6)	0.1 (0.3)	0.094 (0.143)	28
PLI (10)	50							
Incidence		80%	20%	80%	80%	0%		
Mean (SD)		2.5 (3.5)	0.2 (0.4)	2.3 (3.5)	2.3 (3.5)	0.0 (0)	0.050 (0.099)	10
Cape Searle (15)	53							
Incidence		87%	33%	87%	87%	13%		
Mean (SD)		7.6 (6.6)	0.6 (1.2)	7.0 (5.9)	6.9 (6.0)	0.1 (0.4)	0.124 (0.162)	40

[a] OSPAR (2008).

the breeding season progressed. However, colony-specific differences suggest that debris is also being ingested during migration and/or the breeding season. Two mechanisms could explain the observed differences. First, fulmars at more northern colonies, such as Cape Vera, may have less plastic debris within their foraging range because sea ice excludes surface currents from bringing debris into some areas (Mallory, 2008). At more southern colonies, foraging seabirds may be exposed to larger amounts of plastics as ocean and wind currents bring floating debris north from the more populated areas of eastern North America, and from refuse blown or washed into the marine environment from Arctic communities. Second, during the three to five year interval between these studies the amount of plastics floating in the ocean in this region could have increased. A growing human population, increases in ship traffic, and changing oceanographic processes (i.e., ice cover and currents; ACIA, 2005) could all result in more refuse entering the eastern Canadian Arctic. Unfortunately, no data on debris occurrence in the sea, or temporal sampling of fulmars are available to discern between these possibilities.

Plastic ingestion has also been shown to differ with age and breeding status of northern fulmars in the North Sea. Van Franeker and Meijboom (2006) have found that younger birds consistently ingest higher levels of plastics when sample sizes are large enough for the comparison. Due to our small sample size we were unable to compare plastic ingestion across age groups but age is also likely to be a factor in Canadian birds as has been observed in the North Sea.

The incidence of plastic in our study (84% of birds) approaches that found in the much more industrialized North Sea (95–100%, 1997–2003; van Franeker et al., 2005, 2008). Although the mean mass and number of ingested plastic fragments that we found in fulmars in Arctic Canada (0.09 g, 6 pieces) was lower than levels found in European birds (0.33 g, 40 pieces, 2002–2004; van Franeker et al., 2005, 2008), the mean mass of ingested plastics exceeded the EcoQO goal set for fulmars in the North Sea in 28% of the birds in our sample. Given that Bradstreet (1976) reported no plastic debris in 181 fulmars collected in the Canadian Arctic in the 1970s, but our study (2008) combined with that of other recent investigations (2003–2005; Mallory, 2008; Mallory et al., 2006) found 40% of 169 fulmars in this same region containing ingested plastic (and 87% at the most southern colony) it seems clear that the amount of plastic debris entering Canadian Arctic waters is increasing, albeit still below levels seen in more industrial areas. This increase in incidence of plastics in Arctic seabirds, coupled with the much higher number of plastic pieces and mass of plastics found at the more southern colony indicate plastic debris is now reaching Arctic marine systems with potentially negative effects on seabirds and other marine organisms.

Northern fulmars have been identified as an appropriate species to track the incidence of marine plastic debris and are used to monitor debris in Europe (van Franeker and Meijboom, 2006), and may now be useful monitors of marine plastic debris in the eastern Canada. Van Franeker et al. (2005) proposed that the mass of plastics in seabirds stomachs be reported as this measurement is relatively easy to assess, report and compare across studies and geographic areas. Similar protocols and procedures could be modified to work along the coast of eastern Canada using seabirds (particularly fulmars), further enhancing their utility as indicators of the health of marine ecosystems (Schreiber and Burger, 2002; Frederiksen et al., 2006).

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