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Plastic ingestion by fulmars and shearwaters at Sable Island, Nova Scotia, Canada

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ABSTRACT

Plastic pollution is widespread in the marine environment, and plastic ingestion by seabirds is now widely reported for dozens of species. Beached Northern Fulmars, Great Shearwaters, Sooty Shearwaters and Cory's Shearwaters are found on Sable Island, Nova Scotia, Canada regularly, and they can be used to assess plastic pollution. All species except Cory's Shearwaters contained plastic debris in their gastrointestinal tracts. Northern Fulmars, Sooty Shearwaters and Great Shearwaters all showed high prevalence of plastic ingestion (>72%), with Northern Fulmars having the highest number and mass of plastics among the species examined. There was no difference in plastic ingestion between sexes or age classes. In all species user plastics made up the majority of the pieces found, with industrial pellets representing only a small proportion in the samples. Sable Island could be an important monitoring site for plastic pollution in Atlantic Canada.

1. Introduction

Plastic pollution is ubiquitous in the world's oceans and lakes (Barnes et al., 2009; Ryan et al., 2009; Eriksen et al., 2013), and that ubiquity results in increased interactions with animals ranging from sessile invertebrates to highly migratory birds and mammals (Laist, 1997; Derraik, 2002; Goldstein and Goodwin, 2013; Baulch and Perry, 2014). There is also increasing evidence that plastic ingestion by animals, seabirds in particular, can have negative consequences for individuals and populations, including increased contaminant burden (Mato et al., 2001; Tanaka et al., 2013; Lavers et al., 2014), reduced fledging success (Hutton et al., 2008), lower body mass (Connors and Smith, 1982; Ryan, 1988) and damage to the gastrointestinal tract (Carey, 2011).

Plastic ingestion is perhaps best documented in Northern Fulmars (*Fulmarus glacialis*), which are used as an indicator of the state of the North Sea ecosystem (van Franeker et al., 2011). Outside the North Sea area, plastic ingestion by fulmars has been studied in British Columbia, Alaska, the Canadian Arctic, the western North Atlantic, Iceland, the Faroe Islands, and Jan Mayen (Table 1). An Ecological Quality Objective (EcoQO) has been established in the North Sea, with a target of no more than 10% of fulmars having >0.1 g of plastic (OSPAR, 2008), but 48–78% of fulmars exceed this goal (van Franeker et al., 2011). The EcoQO target has been applied to fulmars elsewhere, ranging from 10% on Prince Leopold Island to 78% in the English Channel (Provencher et al., 2009; van Franeker et al., 2011; Table 1).

Less is known about plastic ingestion in other procellariids (shearwaters, and petrels) in the North Atlantic Ocean. Great Shearwaters (*Puffinus gravis*), which breed on islands in the Tristan da Cunha group in the south Atlantic, have been examined intermittently from 1980 to 2006, generally with small sample sizes, but with 0–100% of birds containing plastic debris (Table 2). Beached and bycatch shearwaters from Brazil have also been examined with similarly high incidences of plastic ingestion (Table 2). In the Northern Hemisphere, plastics were noted in 39–80% of Great Shearwaters collected as early as the mid-1970s (Brown et al., 1981), in 82% of those found beached in the northeast United States from 1993 to 2011 (Haman et al., 2013), and 70% of beached birds from the eastern United States in 2005–2008 (Provencher et al., 2014a).

In the Atlantic Ocean, Sooty Shearwaters (*Puffinus griseus*) breed in the Falkland Islands and southern Chile, and like Great

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Table 1
Summary of plastic ingestion studies of Northern Fulmars. FO: Frequency of Occurrence, % EcoQO: percentage exceeding 0.1 g of plastic, % Industrial: unprocessed industrial pellets, as a percentage of the total number of pieces. Means and maximum number of pieces are per examined bird.

Study	Years	Status	Location	*n*	FO	Mean pieces	Max pieces	Mean mass (g)	% EcoQO	% Industrial
Mallory (2008)	2003–2004	Breeding	Cape Vera, NU, Canada	102	0.320	7.4				0.02
Mallory et al. (2006)	2002	Breeding	Davis Strait, NU, Canada	42	0.360	3.6				
Day et al. (1985)	1978–1979	Breeding	Canadian Arctic	214	0.400					
Day (1980)	1969–1977	Breeding	Alaska, USA	38	0.579					
Donnelley-Greenan (2012)	2003	Non-breeding	Monteray Bay, California, USA	178	0.750	9.2				
van Franeker and Camphuysen (1984)	1983	Breeding	Jan Mayen	29	0.760	4.0				
Kühn and van Franeker (2012)	2011	Breeding	Iceland	58	0.790	6.0		0.13	0.28	0.19
van Franeker (1983)	1981–1982	Non-breeding	Netherlands	88	0.800	5.0				
Provencher et al. (2009)	2008	Breeding	Prince Leopold Island, NU, Canada	10	0.800			0.05	0.10	0.20
Robards et al. (1995)	1988–1990	Breeding	Alaska, USA	19	0.842		26			0.63
Moser and Lee (1992)	1975–1989	Non-breeding	Western North Atlantic	44	0.864	17.0		2.12		
Provencher et al. (2009)	2008	Breeding	Cape Searle, NU, Canada	15	0.870			0.124	0.40	0.33
Avery-Gomm et al. (2012)	2009–2010	Non-breeding	Washington & Oregon, USA	31	0.871	18.1		0.326	0.45	0.08
van Franeker and The SNS Fulmar Study Group (2013)	2007–2011	Breeding	Faroe Islands	699	0.910	11.3		0.15	0.40	
van Franeker et al. (2011)	2003–2007	Non-breeding	Scotland	95	0.920	18.9		0.2	0.48	
Avery-Gomm et al. (2012)	2009–2010	Non-breeding	Eastern North Pacific	67	0.925	36.8		0.385	0.54	0.04
van Franeker et al. (2011)	2003–2007	Non-breeding	Netherlands	309	0.930	26.5		0.28	0.61	
This study	2001–2012	Non-breeding	Sable Island, NS, Canada	176	0.932	26.4	205	1.09	0.66	0.06
van Franeker et al. (2011)	2003–2007	Non-breeding	Southeastern North Sea	842	0.940	30.4		0.3	0.58	
van Franeker et al. (2011)	2003–2007	Non-breeding	Eastern England	60	0.950	35.0		0.23	0.60	
van Franeker et al. (2011)	2003–2007	Non-breeding	Skagerrak, Norway	191	0.950	47.7		0.36	0.50	
Avery-Gomm et al. (2012)	2009–2010	Non-breeding	British Columbia, Canada	36	0.972	52.9		0.354	0.61	0.03
Donnelley-Greenan (2012)	2007	Non-breeding	Monterey Bay, California, USA	185	0.980	24.1				
van Franeker et al. (2011)	2003–2007	Non-breeding	English Channel	107	1.000	56.7		0.44	0.78	
Blight and Burger (1997)	1987	Breeding	Eastern North Pacific	3	1.000	5.2	18			0.48
Baltz and Morejohn (1976)	1974–1975	Non-breeding	Monterey Bay, California, USA	3	1.000	11.3				0.68

Shearwaters, migrate north during the austral winter (Hedd et al., 2012). Sooty Shearwaters tend to have a lower incidence of plastic ingestion than Great Shearwaters, ranging from 0% to 64% in the south Atlantic, and 16% to 40% on the wintering grounds of the north Atlantic (Table 3).

Situated 160 km east of Halifax, Nova Scotia, Sable Island is a 45-km long crescent-shaped sandy island where beached seabirds have been collected regularly (Lucas et al., 2012). While no procellariids breed on Sable Island, many pass by the island during migration (Brown, 1986; Lock et al., 1994; Huettmann and Diamond, 2000), and monitoring birds beached on the island could fill an important gap in our understanding of the spatial and temporal patterns of plastic ingestion, particularly in fulmars, as there is little information from the northwest Atlantic (Provencher et al., 2014a), and also in Sooty Shearwaters, as there has been no assessment of ingestion in this species in the Northern Hemisphere since 1989 (Moser and Lee, 1992). Sable Island is near the centre of a local oceanic gyre on the Scotian Shelf that concentrates and deposits marine debris, much of it plastic, on the island's beaches (Lucas, 1992; Hannah et al., 2001).

Our objectives were to use beached birds to assess rates of plastic ingestion by Northern Fulmars, Great shearwaters, Sooty Shearwaters, and Cory's Shearwaters (*Calonectris diomedea*) found at Sable Island, Nova Scotia, Canada, and examine differences among age classes and between sexes. We also compared rates of ingestion with other published studies, and with the North Sea EcoQO for plastic ingestion in fulmars.

2. Methods

2.1. Sample collection and processing

Intact corpses of procellariids were collected from the entire shoreline of Sable Island throughout the year. A portion of the specimens were found during regular beached seabird surveys (Lucas et al., 2012). However, to recover additional fresh and intact specimens (not scavenged by gulls) it was necessary to collect corpses opportunistically whenever they were encountered during travel on the beach. Specimens were frozen on the island until they

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Table 2
Summary of plastic ingestion studies of Great Shearwaters. Column headings as in Table 1.

Study	Years	Status	Location	*n*	FO	Mean pieces	Max pieces	Mean mass (g)	% Industrial
Haman et al. (2013)	1993–2011	Non-breeding	SE United States	27	0.000				
Ryan (2008)	2005–2006	Breeding	Nightingale Island	53	0.113	11.8			0.14
Brown et al. (1981)	1974–1975	Non-breeding	Briar Island, NS, Canada	62	0.387				
Moser and Lee (1992)	1975–1989	Non-breeding	Western North Atlantic	55	0.636	14.2		2.52	
Ryan (2008)	1983–1985	Breeding	Gough Island	33	0.643	16.3			0.64
Provencher et al. (2014a)	2005–2008	Non-breeding	Eastern United States	11	0.706	9.5	36		0.36
Barbieri (2009)	2000–2002	Breeding	Ilha Comprida, Brazil	29	0.724				0.66
Brown et al. (1981)	1978	Non-breeding	Placentia Bay, NL, Canada	20	0.800				
Haman et al. (2013)	1993–2011	Non-breeding	NE United States	33	0.820				
Furness (1985)	1983	Breeding	Gough Island	13	0.850	12.2	53		
This study	2000–2011	Non-breeding	Sable Island, NS, Canada	84	0.881	11.8	128	0.17	0.12
Colabuono et al. (2009)	1994–2005	Breeding	Rio Grande, Brazil	18	0.890		72		0.20
Furness (1983)	1981	Breeding	Benguela Current, South Africa	10	0.900				
Randall et al. (1983)	1980	Breeding	Gough Island	2	1.000	22.0		0.692	
Bourne (1976)	1965-~1975	Non-breeding	Northern Scotland	1	1.000				

Table 3
Summary of plastic ingestion studies of Sooty Shearwaters. Column headings as in Table 1.

Study	Years	Status	Location	*n*	FO	Mean pieces	Max pieces	Mean mass (g)	% Industrial
Furness (1983)	1981	Breeding	Benguela Current, South Africa	13	0.000	5.1	14		
Brown et al. (1981)	1974–1975	Non-breeding	Briar Island, NS, Canada	30	0.167				
Brown et al. (1981)	1978	Non-breeding	Placentia Bay, NL, Canada	5	0.200				
Moser and Lee (1992)	1975–1989	Non-breeding	W. North Atlantic	5	0.400	9.0		3.22	
Day (1980)	1969–1977	Non-breeding	Alaska, USA	76	0.434				
Baltz and Morejohn (1976)	1974–1975	Non-breeding	Monterey Bay, California, USA	21	0.43–0.67	6.9			0.73
Day et al. (1985)	1978–1979	Non-breeding	California, USA	154	0.490				
Day et al. (1985)	1977	Non-breeding	California, USA	37	0.510				
Barbieri (2009)	2000–2002	Breeding	Ilha Comprida, Brazil	11	0.636				0.71
This study	2000–2011	Non-breeding	Sable Island, NS, Canada	50	0.720	2.5	12	0.07	0.07
Blight and Burger (1997)	1987	Non-breeding	Eastern North Pacific	20	0.750	1.3	23		0.35
Avery-Gomm et al. (2013)	2011	Non-breeding	Barkley Sound, BC, Canada	1	1.000	43.0		1.62	
Bourne (1976)	1965–1975	Non-breeding	Northern Scotland	1	1.000				

could be shipped to the Department of Pathology and Microbiology, Atlantic Veterinary College, in Charlottetown, Prince Edward Island.

Carcases were dissected at the Atlantic Veterinary College, University of Prince Edward Island (Charlottetown, PEI, Canada), where the upper gastrointestinal was removed, and any anthropogenic material (i.e., plastics) removed. Plastic samples were cleaned with tap water, dried, and stored. Plastics were weighed to the nearest 0.001 g using an electronic balance (total mass for plastics from each individual), counted, and sorted following van Franeker et al. (2005) into broad categories (industrial pellets, fragments, thread-like, sheet-like, foam, other user plastics) and by colour (clear, white, black, red, orange, yellow, green, blue, purple).

2.2. Statistical analysis

We did not test for differences among months of collection, as this likely has little effect on the presence of plastics in these birds, which were collected away from any breeding location, and therefore unlikely to offload plastic to chicks (van Franeker and Meijboom, 2002; Hutton et al., 2008; Bond and Lavers, 2013). We also did not include collection year in any formal statistical analysis, as not all species, age classes, or sexes were collected in every year, and many sample sizes in individual years were small (Table 4).

We included all samples in descriptive analyses of the frequency of plastic ingestion, and mass of plastic ingested

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Table 4
Sample sizes of beached procellariids collected on Sable Island from 2000 to 2012.

Year	Cory's Shearwater	Great Shearwater	Northern Fulmar	Sooty Shearwater	Total
2000	0	1	0	1	2
2001	0	0	1	1	2
2002	0	0	1	0	1
2003	1	0	1	0	2
2004	1	2	13	1	17
2005	1	3	37	6	47
2006	0	25	12	10	47
2007	0	12	32	1	45
2008	0	6	15	8	29
2009	0	1	21	3	25
2010	0	11	7	5	23
2011	0	22	32	14	68
2012	0	0	4	0	4
Not recorded	0	1	0	0	1
Total	3	84	176	50	313

($n = 313$), and a subset ($n = 246$) in describing the number of pieces ingested, and their characteristics. Because of their low sample size ($n = 3$), and absence of any ingested plastic (see Results), we excluded Cory's Shearwaters from further analysis. For formal statistical analyses, we included only samples from birds that had complete data (i.e., included sex and age class; $n = 263$; $n = 220$ for analyses of the number of pieces).

In R 3.0.2 (R Development Core Team, 2013), we analysed the mass of plastic ingested using a general linear model (GLM) with species, age class (adult or immature), and sex as predictors, and Tukey's Honest Significant Differences post hoc test for multiple comparisons. We used the same predictors to examine differences in the number of pieces ingested (quasipoisson generalized linear model (GzLM), as the count data were overdispersed; null deviance/$df = 32.97$), and the frequency of plastic ingestion among groups (binomial GzLM). All effects were considered significant when $p < 0.05$. In each analysis, we included all individuals (i.e., including birds without ingested plastic), and unless stated otherwise, present summary data as the mean ± S.D.

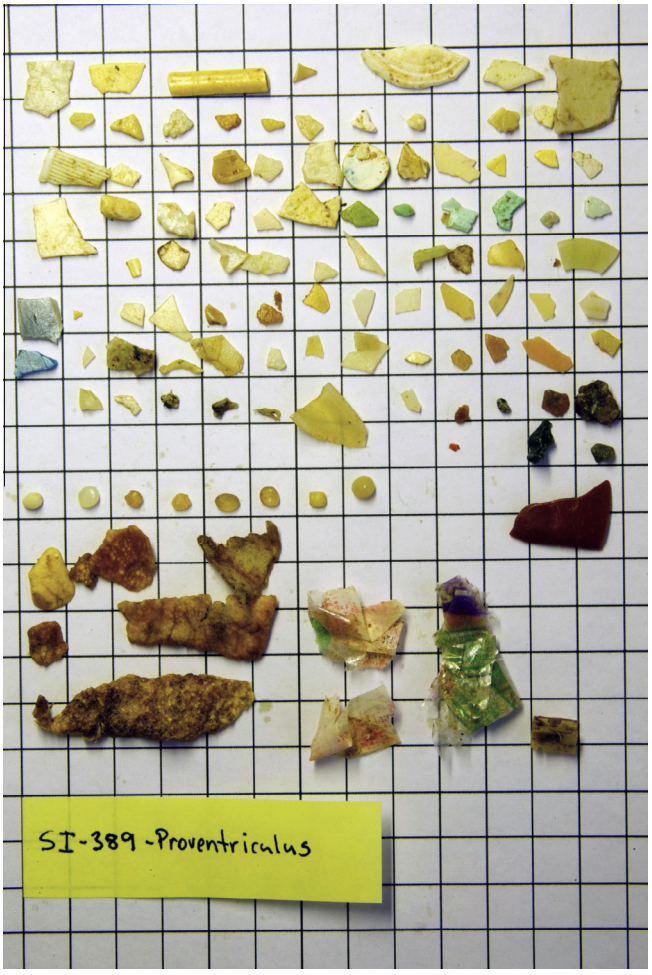

Fig. 1. A sample of the plastic ingested by a Northern Fulmar on Sable Island. Plastic was sorted into user fragments (top), industrial pellets (middle), foam-like (bottom left), and sheet-like (bottom right). Grid lines are 1 cm × 1 cm. Photo by A.L. Bond.

3. Results

We examined 176 Northern Fulmars, 84 Great Shearwaters, 50 Sooty Shearwaters, and 3 Cory's Shearwaters for plastic ingestion (Table 4). None of the Cory's Shearwaters contained plastic debris, while 72% (36/50) of the Sooty Shearwaters, 88% (74/84) of the Great Shearwaters, and 93% (164/176) of the Northern Fulmars contained debris (Tables 1–3 and 5). Northern Fulmars and Great Shearwaters did not differ in the proportion with ingested plastic ($z = 1.79$, $p = 0.07$), but both had a higher frequency of occurrence than Sooty Shearwaters ($z = 2.08$, $p = 0.037$). There was no effect of age class ($z = 0.48$, $p = 0.63$), or sex ($z = 0.05$, $p = 0.96$).

We identified 4375 pieces of plastic, the majority of which (76%) were plastic fragments, 7% were industrial pellets, 7% were sheet-like, 6% were foam, and 2% were thread-like (Fig. 1, Table 6). Almost half of the pieces were white (49%), with smaller numbers of clear (18%), black (10%), red (9%), green (5%), yellow (4%), orange (3%), blue (3%), or purple (<1%; Table 6).

Sooty Shearwaters had 2.48 ± 2.71 pieces (median: 3 pieces, range: 0–12), Great Shearwaters 11.81 ± 16.86 pieces (median: 7 pieces, range: 0–128), and Northern Fulmars 26.35 ± 37.49 pieces (median: 12 pieces, range: 0–205). There were significantly more pieces in Northern Fulmars than in Great Shearwaters ($t = 3.39$, $p < 0.001$), which in turn had more pieces than Sooty Shearwaters ($t = 2.46$, $p = 0.015$).

The mass of plastic ingested did vary among species ($F_{2,255} = 14.14$, $p < 0.001$), with Northern Fulmars ingesting a significantly greater mass of plastic (1.09 ± 1.93 g) than Great Shearwaters (0.17 ± 0.33 g; Tukey's HSD, $p < 0.001$) or Sooty Shearwaters (0.07 ± 0.17 g; Tukey's HSD, $p < 0.001$). There was no difference among age classes ($F_{1,255} = 0.02$, $p = 0.88$), or sexes ($F_{1,255} = 1.20$, $p = 0.28$).

Table 5
Summary of plastic ingestion studies of Cory's Shearwaters. Column headings as in Table 1.

Study	Years	Status	Location	*n*	FO	Mean pieces	Max pieces	Mean mass (g)	% Industrial
This study	2003–2005	Non-breeding	Sable Island, NS, Canada	3	0	0	0	0	0
Moser and Lee (1992)	1975–1989	Non-breeding	Western North Atlantic	147	0.25	5.1		0.48	
Rodríguez et al. (2012)	2009–2011	Chicks	Canary Islands	85	0.84	8.0	36	2.97	
Codina-Garcia et al. (2013)	2003–2010	Breeding	Catalan coast, Spain	49	0.96	14.6		0.02	
Colabuono et al. (2009)	1994–2005	Non-breeding	Rio Grande, Brazil	5	1.00				0.10

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Table 6
Beached procellariids on Sable Island, Canada, ingested primarily white user fragments of plastic. Categories after van Franeker et al. (2005).

Species	Plastic type	Black	Blue	Clear	Green	Orange	Purple	Red	White	Yellow	Total	Proportion
Great Shearwater	Foam	1	0	0	3	2	0	1	7	1	15	0.016
	Fragment	105	40	74	73	14	6	64	271	37	684	0.741
	Industrial pellet	49	4	21	2	0	0	18	19	2	115	0.125
	Other	3	0	0	2	0	0	23	2	0	30	0.033
	Sheet	15	8	19	3	0	0	4	13	0	62	0.067
	Thread	3	0	8	4	0	0	0	2	0	17	0.018
	Total	176	52	122	87	16	6	110	314	40	923	
	Proportion	0.191	0.056	0.132	0.094	0.017	0.007	0.119	0.340	0.043		
Northern Fulmar	Foam	10	0	0	1	15	0	6	217	1	250	0.075
	Fragment	155	70	526	91	59	5	185	1423	82	2596	0.777
	Industrial pellet	23	6	70	6	14	0	22	24	21	186	0.056
	Other	2	1	1	1	9	1	9	12	5	41	0.012
	Sheet	43	8	49	4	0	0	18	81	4	207	0.06
	Thread	6	5	6	14	3	0	7	19	3	63	0.019
	Total	239	90	652	117	100	6	247	1776	116	3343	
	Proportion	0.071	0.027	0.195	0.035	0.030	0.002	0.074	0.531	0.035		
Sooty Shearwater	Foam	0	0	0	0	0	0	0	5	0	5	0.046
	Fragment	12	1	3	5	0	0	5	32	0	58	0.532
	Industrial pellet	4	1	2	0	0	0	0	1	0	8	0.073
	Other	0	0	0	0	0	0	3	0	0	3	0.028
	Sheet	14	2	2	0	0	0	1	8	0	27	0.248
	Thread	7	0	0	1	0	0	0	0	0	8	0.073
	Total	37	4	7	6	0	0	9	46	0	109	
	Proportion	0.339	0.037	0.064	0.055	0.000	0.000	0.826	0.422	0.000		

Comparing our sample of Northern Fulmars against the North Sea EcoQO of no more than 10% of birds having >0.1 g of plastic, 66% of our birds exceeded this prescribed level (Fig. 2).

4. Discussion

We found that the vast majority of beached procellariiform seabirds from Sable Island contained plastic debris, but that the proportion of affected individuals, and amount of ingested plastic (both the number of pieces and total mass) differed among species. Despite being very similar morphologically, Great and Sooty Shearwaters tend to differ in their diets in the North Atlantic, with Great Shearwaters consuming more squid and forage fish, while Sooty Shearwaters generally eat more euphausiids (Brown et al., 1981; Ronconi et al., 2010). Northern Fulmars also tend to have a high proportion of squid in their diet (Mallory et al., 2010), though European birds are generally more piscivorous (Phillips et al., 1999). Diet and feeding behaviour are likely the main drivers of the degree to which species or individuals ingest plastic (Moser and Lee, 1992; Robards et al., 1995; Laist, 1997), and that seems to be the case at Sable Island as well.

There were no differences between sexes in any metric of plastic ingestion measured. Few studies have examined sex-related differences, and for the species considered here, we argue this is justified. However, foraging differences (and consequently differences in plastic ingestion) between males and females may be more prevalent in species with sexual size dimorphism, particularly at higher latitudes (Mancini et al., 2013), including Cory's Shearwaters (Navarro et al., 2009). Conversely, although Northern Fulmar males are much larger than females, and there are intersexual foraging differences on the breeding grounds (Mancini et al., 2013), no sex-related differences in plastic ingestion were observed in Northern Fulmars from the Dutch coast (van Franeker and The SNS Fulmar Study Group, 2013), or Sable Island. Most of the cases where researchers investigated sex differences in plastic ingestion concerned tropical seabirds (Fry et al., 1987; Spear et al., 1995), and found no effect of sex. For example, there was no difference in plastic ingestion among male and female adult Short-tailed Shearwaters (*Puffinus tenuirostris*) in eastern Australia

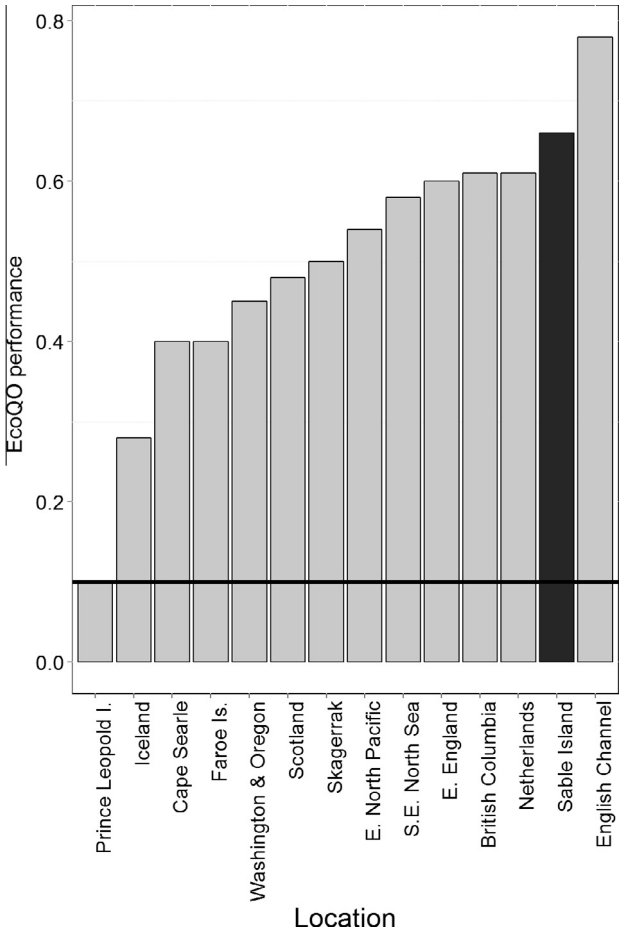

Fig. 2. EcoQO performance of Northern Fulmars in relation to the target of 10% of birds with ⩾0.1 g of plastic (horizontal black line). Studies summarized in Table 1.

(Acampora et al., 2014). However, inter-sexual foraging segregation tends to be less common in tropical species (Mancini et al., 2013). We encourage those investigating plastic ingestion in

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self-provisioning seabirds (i.e., aside from nest-bound young provisioned by parents) to investigate the effect sexual size dimorphism might play in sex-based differences or similarities in plastic ingestion.

We also found no difference between age classes (adult or immature) in plastic ingestion. Preliminary studies of Northern Fulmars in the North Sea found that younger birds tended to have more plastic than adults (van Franeker et al., 2005; Kühn and van Franeker, 2012), but this difference disappeared as the study continued (van Franeker and The SNS Fulmar Study Group, 2013). Age-related differences have not been examined in Great or Sooty Shearwaters previously. On the breeding grounds, breeding adult shearwaters tend to have little or no ingested plastic, as the majority is offloaded to chicks (Hutton et al., 2008; Carey, 2011), only to be accumulated again during the non-breeding season (Robards et al., 1995). Adult Great Shearwaters examined on the breeding ground were incubating, and so did not have the opportunity to offload plastic to their chicks (Furness, 1985; Ryan, 2008). To date there are no studies of plastic ingestion by Great or Sooty Shearwater chicks (Tables 2 and 3). Adult Northern Fulmars in the Canadian Arctic did not show any seasonal differences in plastic ingestion (Mallory, 2008), suggesting that there is minimal or incomplete offloading in this species.

We found the lowest proportion of industrial pellets relative to user plastics in Great and Sooty Shearwaters (12% and 7% respectively; Tables 2 and 3), and a very low proportion of industrial pellets in Northern Fulmars (6%; Table 1). There have been widespread reductions in the proportion of industrial pellets in a variety of seabirds (Vlietstra and Parga, 2002; Ryan, 2008), and this could represent a decrease in industrial pellets at sea resulting from efforts by the plastic manufacturing industry to reduce spillage (van Franeker et al., 2005; Ryan, 2008). Overall, industrial pellets contributed only 7% by number, and a much smaller percentage by mass, as individual pellets are smaller and weigh much less than most user plastic fragments. The greatest contributor to the plastic burden in beached seabirds from Sable Island was user plastics (93% by number).

4.1. Cory's Shearwaters

Cory's Shearwaters rarely occur in Canadian waters, and those that do are likely of the *Calonectris diomedea diomedea* subspecies (Palmer, 1962; Cramp, 1977; Godfrey, 1986; Tufts, 1986). Only 14 have been recorded on beached bird surveys on Sable Island between 1993 and 2009 (Lucas et al., 2012). Only three previous studies have examined plastic ingestion by Cory's Shearwaters: two from other non-breeding areas (waters off the eastern United States, and beached/bycatch birds from Rio Grande Brazil), and one concerning chicks on the Canary Islands (Table 5). In each of those studies, plastic was recorded in 25–100% of birds examined (n = 5–147). Our sample size is too small for any formal comparison, and it is unlikely that Cory's Shearwaters could be used to monitor trends in plastic pollution in Canada.

4.2. Sooty Shearwaters

Sooty Shearwaters that occur off Sable Island during the non-breeding season are from the Falkland Islands, and southern Chile (Hedd et al., 2012), where there have been no studies of plastic ingestion (Table 3). Indeed, all studies of plastic ingestion in Sooty Shearwaters (in both the Atlantic and Pacific Oceans) concern birds during the non-breeding season, with one exception (13 birds examined from the Benguela Current, South Africa; the breeding status of these birds was unknown; Table 3). Sooty Shearwaters from Sable Island generally had low plastic mass per individual (0.07 ± 0.17 g), but a high frequency of ingested plastic (72%), especially compared to other studies with comparable or larger sample sizes (Table 3). Compared with birds collected elsewhere in eastern Canada in the 1970s, and off the eastern United States in the early 1980s, it appears that the frequency of plastic ingestion has increased (1970s: 17–20%; 1980s: 40%; 2000s: 72%; Table 3). We also found the lowest recorded contribution of industrial pellets to ingested plastic burden in Sooty Shearwaters (7%).

4.3. Great Shearwaters

Like Sooty Shearwaters, Great Shearwaters are transequatorial migrants from breeding grounds on the islands of Tristan da Cunha to the northern Atlantic Ocean (Rowan, 1952). Studies of their plastic ingestion are roughly equal between the breeding and non-breeding grounds (Table 2). On the breeding grounds, most studies have been conducted during incubation or early chick-rearing, many with small sample sizes. Aside from a single record from Scotland (Bourne, 1976), we recorded the highest frequency of plastic ingestion on the non-breeding grounds (88%; others: 0–82%; Table 2). The number of pieces recorded per bird (11.8 ± 16.9) is identical to the number of pieces per bird reported on Nightingale Island, Tristan da Cunha in the 2005/06 breeding season (11.8 ± 18.9; Ryan, 2008), the most recent assessment of plastic ingestion on the breeding grounds. While we recorded the lowest mean mass of plastics (0.17 ± 0.33 g), we also had the largest number of pieces yet recorded for an individual of this species (128 pieces; Table 2). As one of the most frequently found beached birds on Sable Island (Lucas et al., 2012), it could be a useful indicator species for plastics in the Atlantic Ocean.

4.4. Northern Fulmars

Plastic ingestion has been best studied in the Northern Fulmar. Beached Northern Fulmars on Sable Island likely come from a variety of breeding sites, including Greenland, Iceland, and Scotland (Tufts, 1986; Gaston et al., 2008). Numerous studies throughout its range have consistently shown that a majority of birds have ingested plastic in the Atlantic and Pacific Oceans (with the exception of the Canadian Arctic; Table 1). Its ubiquity on beached bird surveys in the North Sea, and high prevalence of plastic, led to its inclusion as an indicator of the health of the marine environment through the Ecological Quality Objective (EcoQO) framework (OSPAR, 2008). Northern Fulmars from Sable Island had a high prevalence of plastic ingestion (93%) similar to birds from the Dutch coast (93%), and southeastern North Sea (94%). Sable Island Northern Fulmars also had a similar number of pieces (26.4) to Dutch birds (26.5), but a much higher mass (1.09 ± 1.93 g on Sable Island, 0.28 ± 0.35 g in the Netherlands; Table 1). Only birds from the western North Atlantic collected in the 1970s and 1980s had a greater mean mass per individual (2.12 g; Moser and Lee, 1992), and we recorded the greatest number of pieces of plastic in a single bird (205 pieces), though few studies report this metric (Table 1). Like recent studies in the Pacific Ocean, we found a very low proportion of industrial pellets in Northern Fulmars' total plastic (6%), which is considerably lower than birds from the Canadian Arctic (20–33%), and Iceland (19%; Table 1).

Using the EcoQO of the proportion of Northern Fulmars with $\geqslant$0.1 g of plastic (and a goal of no more than 10% of birds exceeding this threshold), we found the second highest proportion of birds above the EcoQO goal (66%); only birds from the English Channel, where all birds had ingested plastic (n = 107), had a higher proportion (78%; Table 1, Fig. 2). The proportion of birds above the EcoQO target has been fairly constant in birds from Dutch beaches (57–61% from 1998 to 2007; van Franeker et al., 2011).

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The data on plastic ingestion from Northern Fulmars on Sable Island fills an important gap in our understanding of spatial patterns of plastic ingestion in this indicator species, complementing studies in the Pacific, Arctic, and eastern Atlantic Oceans (Table 1) (Provencher et al., 2014b).

5. Conclusions

Sable Island is uniquely placed in Canada as the only site in Atlantic Canada where large numbers of beached birds, procellariids in particular, are encountered regularly (Wilhelm et al., 2009; Lucas et al., 2012). It could therefore form a key monitoring site for plastic marine debris in Canadian waters. Furthermore, beached shearwaters and fulmars encountered on Sable Island generally have high frequencies of plastic ingestion. The origin of Sooty and Great Shearwaters is unambiguous (there being only a single, or very few breeding sites in the Atlantic Ocean), making Sable Island an important part of monitoring plastic ingestion throughout the annual cycle for these two species. We encourage further monitoring of plastic ingestion using beached birds from Sable Island.

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