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Baseline

Plastic pollution in the Labrador Sea: An assessment using the seabird northern fulmar *Fulmarus glacialis* as a biological monitoring species

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ABSTRACT

Plastic is now one among one of the most pervasive pollutants on the planet, and ocean circulation models predict that the Arctic will become another accumulation zone. As solutions to address marine plastic emerge, is essential that baselines are available to monitor progress towards targets. The northern fulmar (*Fulmarus glacialis*), a widely-distributed seabird species, has been used as a biological monitor for plastic pollution in the North Sea, and could be a useful monitoring species elsewhere. We quantified plastic ingested by northern fulmars from the southeastern Canadian waters of the Labrador Sea with the objective of establishing a standardized baseline for future comparisons. Over two years we sampled 70 fulmars and found that 79% had ingested plastic, with an average of 11.6 pieces or 0.151 g per bird. Overall, 34% of all fulmars exceeded the Ecological Quality Objective for marine litter, having ingested > 0.1 g of plastic.

Plastic is now one of the most pervasive pollutants on the planet and represents a significant ecological and economic concern (Derraik, 2002; UNEP, 2014; van Sebille et al., 2015). To address this growing threat, numerous strategies and policies are emerging to reduce the creation of new plastics, divert plastic from entering the ocean via land and ships, and to clean up plastic that has already entered the marine environment (Braungart, 2013; Rochman et al., 2013; Rochman, 2016; Song et al., 2009). To gauge the effectiveness of these measures it is essential to monitor the amount of plastic in the ocean (Borrelle et al., 2017). Existing methods for monitoring plastic pollution include beach surveys, at-sea sampling, and the use of biological monitoring species (see Ryan et al., 2009 for review). To evaluate trends in the amount and composition of marine plastic pollution in the future, it is essential to establish a baseline.

Among available options, a relatively inexpensive strategy for monitoring plastic pollution involves examining the stomach contents of seabirds. Specifically, the northern fulmar (*Fulmarus glacialis*), a procellarid seabird with a circumpolar distribution (van Franeker and Meijboom, 2002) has been utilized since 2003 as part of an international program to monitor plastic pollution trends in the North Sea. Primarily because northern fulmars commonly ingest plastic at the ocean surface and tend not to regurgitate this plastic, the stomach content of a single bird integrates information about plastic pollution across the area in which they foraged over a period of time during which plastic is mechanically ground by the muscular stomach into particles small enough to pass the pyloric sphincter into the small intestines (Ryan, 2015; van Franeker et al., 2011).

Information about plastic ingested by northern fulmar in the North Sea is used to track progress towards the Ecological Quality Objective (EcoQO) for marine litter, which defines acceptable ecological quality as the situation where no more than 10% of fulmars exceed a level of 0.1 g of plastic in the stomach (OSPAR, 2008; Provencher et al., 2017; van Franeker et al., 2011). The program has successfully detected a shift in the type of plastic pollution, as well as regional differences in marine plastic pollution, which are corroborated by beach and at-sea surveys. This demonstrates the utility of northern fulmars as a biological monitoring species (van Franeker et al., 2011; van Franeker and Law, 2015). Although there are currently no formal programs using northern fulmar to monitor plastic pollution outside the North Sea, this species has also been used to evaluate and compare levels of plastic pollution in regions such as the eastern North Pacific, the Canadian Arctic, Atlantic Canada, Svalbard and Iceland (Avery-Gomm et al., 2012; Bond et al., 2014;

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Donnelly-Greenan et al., 2014; Kühn and van Franeker, 2012; Mallory, 2006, 2008; Poon et al., 2017; Provencher et al., 2009, 2015; Terepocki et al., 2017; Trevail et al., 2015).

In the western North Atlantic, standardized information on plastic ingestion is available for northern fulmars from the Arctic (e.g., Poon et al., 2017) and the Sable Island area (Bond et al., 2014), but there are no data for the Labrador Sea in between these two locations. The only published plastic studies in the Labrador Sea, which is located between the northwestern coast of Greenland and the northeastern coast of Canada, have been whale entanglement reports from the 1970s (Perkins and Beamish, 1979). The Labrador Sea provides important habitat for many marine species including seabirds (Fifield et al., 2017; Frederiksen et al., 2012; Huettmann and Diamond, 2000; Jessopp et al., 2013) and supports commercial fisheries for northern shrimp (*Pandalus borealis)* and snow crab (*Chionoecetes opilio*; Marine Resources Service (United Nations), 2005). A recent Ecosystem Services Valuation in the Labrador Sea estimated the value of the ecosystem to the local economy at $1.3 billion CAD per year (Levins, 2017), demonstrating how the critical the health of this marine environment is to the region.

Due to a small human footprint in the surrounding coastal areas and marine environment (Halpern et al., 2008; Venter et al., 2016), we hypothesize that the Labrador Sea has low levels of plastic pollution. However, the rapid loss of sea ice due to climate change and an increase in commercial activities make the area vulnerable to increasing plastic pollution (Eguíluz et al., 2016; Smith and Stephenson, 2013). The increasing vulnerability of the region, together with emerging research indicating a significant deposition of plastic pollution to the Greenland and Barents Sea from southern latitudes via the North Atlantic branch of the Thermohaline Circulation (Cózar et al., 2017), underscores the need to establish a point of comparison for future studies of plastic pollution in the Labrador Sea.

The objective of this paper is to evaluate how plastic ingestion in northern fulmar from the Labrador Sea compares with other regions, according to internationally standardized methods. This study describes patterns of plastic accumulation in northern fulmars between sampling year, age, sex, condition and breeding status and most importantly, provides baseline information that can be used to understand trends in plastic pollution in the western North Atlantic.

Most of the western Atlantic northern fulmar population breeds at large colonies in the Canadian Arctic and Greenland (Mallory et al., 2012). A total of 70 northern fulmars were collected at sea by Nunatsiavut hunters onboard a vessel within 100 km from the eastern shore of Labrador in mid-July in 2014 and 2015 (Fig. 1). Birds were stored frozen until they could be processed in the laboratory. A standardized dissection protocol was followed to assess sex, age, and body condition (see van Franeker et al., 2011). Plumage color phase and breeding status were recorded because it may be indicative of the origin of the birds (see van Franeker, 2004).

In the laboratory, the stomachs (proventriculus and gizzard) of each bird were removed, opened, and washed over a 1 mm sieve. Plastics were separated from organic and non-organic matter under both dissecting and compound microscopes (Hidalgo-Ruz et al., 2012) and left to air dry for several days, in a filter to reduce contamination. Type was categorized as industrial plastics (small virgin plastic pellets which are the raw granular stock used to manufacture plastic products), 'user' plastics which include fragments, sheets, threads and foam or 'other' (i.e., wax, rubber, metal) following standardized protocols for northern fulmar (i.e., van Franeker et al., 2011; Provencher et al., 2017). Quantifying microbeads and microfibers was beyond the scope of this methodology. The mass of each piece of plastic was recorded using electronic Sartorius weighing scales to an accuracy of ± 0.0001 g. Length and width were measured using digital calipers (accurate to 0.01 mm) so that pieces could be classified as macro- (> 20–100 mm), meso- (> 5–20 mm) or micro-plastics (1–5 mm; Barnes et al., 2009). The dominant color of each plastic piece was recorded using a Munsell color chart for reference. For each bird, the total number of ingested plastic pieces and the total mass of ingested plastics were recorded (items classified as 'other' were excluded). Across all samples, the frequency of occurrence of plastic ingestion was calculated as the proportion of fulmar that ingested plastic and values are presented with upper and lower confidence intervals (Provencher et al., 2017). Confidence intervals were calculated using the Jeffreys method which is appropriate for proportions with small sample sizes (Brown et al., 2001). To evaluate whether plastic pollution in the Labrador Sea meets or exceeds the North Sea Ecological Quality Objective (EcoQO), the proportion of fulmars to have ingested > 0.1 g of plastic was calculated (van Franeker et al., 2011).

Statistical analysis was done in R 3.3.2 (R Development Core Team, 2016). Following recommendations for standardized analysis (Provencher et al., 2017), we included all individuals in each analysis (i.e., including birds without ingested plastic) and present summary data as the arithmetic mean ± standard deviation. We analyzed the frequency of plastic ingestion among fulmars using Generalized Linear Models (GzLM) with age (adult or immature), sex, condition index, breeding status and year as predictors (binomial distribution with logit link; McCullagh and Nelder, 1989). These same predictors were used to examine the total number of plastics ingested by each bird using a GzLM with a negative binomial distribution with log link, to account for high occurrence of zero counts (O'Hara and Kotze, 2010). Post-hoc comparisons of fixed effects within these models were computed using Wald's Chi-squared test and are presented with χ^2-values, degrees of freedom, and *p*-values (Ver Hoef and Boveng, 2007). We verified that our models were not overdispersed by ensuring that the ratio of the residual deviance over residual degrees of freedom was ~1 (Venables and Ripley, 2013). A General Linear Model (GLM) was used to test for an effect of these predictors on the mass of plastic ingested. All effects were considered significant when $p < 0.05$. The purpose of this study is to provide a benchmark for plastic ingestion in the Labrador Sea; therefore we report plastic metrics for the pooled sample (n = 70) and provide raw data in the Supplementary materials. The arithmetic means (± SD) and geometric means for number of ingested plastic pieces and mass are reported for the full sample size (n = 70).

A total of 39 fulmars were collected in 2014, and 31 fulmars were collected in 2015. Necropsy revealed that in 2014, our sample included 32 adults and 7 immatures. In 2015, 29 fulmars were adults and the remainder were immature. The sex ratio for 2014 and 2015 was 29 males:10 females and 18 males:13 females, respectively. The color morph of fulmars in both years was 97% double light (LL) and 3% dark (D). Examination of the condition of the pectoral muscle, subcutaneous, and intestinal fat stores revealed that 96% of fulmars were in moderate or good body condition. Birds were collected in mid-July, which corresponds to the egg hatching phase (Mallory et al., 2012). Based on the development of the brood patch and gonads we assessed that 21% of fulmars in 2014 and 68% of fulmars in 2015 were non-breeders. Those classified as breeders may have been actively breeding, or recently failed breeders (46% in 2014, 32% in 2015). Birds which could not be assigned to either group were classified as unknown.

Across both years, plastic was found in the stomachs of 79% of northern fulmars (Table 1). The average number of ingested plastic pieces was 11.61 ± 21.63 SD pieces per bird (range 0–135 pieces), and the average mass was 0.151 ± 0.257 g SD (range 0–1.50 g). The geometric mean was 0.37 pieces of and 0.010 g of ingested plastic. Overall, 34% of all fulmars exceeded the EcoQO performance target, having ingested > 0.1 g of plastic. We investigated whether age, sex, overall condition, breeding status or year predicted the likelihood that fulmars ingested plastic or the amount of plastic they would ingest (total number, total mass). The frequency of occurrence of plastic ingestion was significantly higher in the fulmars collected in 2015 than it was in birds collected in 2014 ($\chi^2_1 = 4.46$, $p = 0.035$, n = 70), as was the number of pieces of plastic ingested ($\chi^2_1 = 6.08$, $p = 0.014$, n = 70). However, there was no significant difference in the mass of ingested plastic ingested by fulmar across years ($\chi^2_1 = 0.74$, $p = 0.81$,

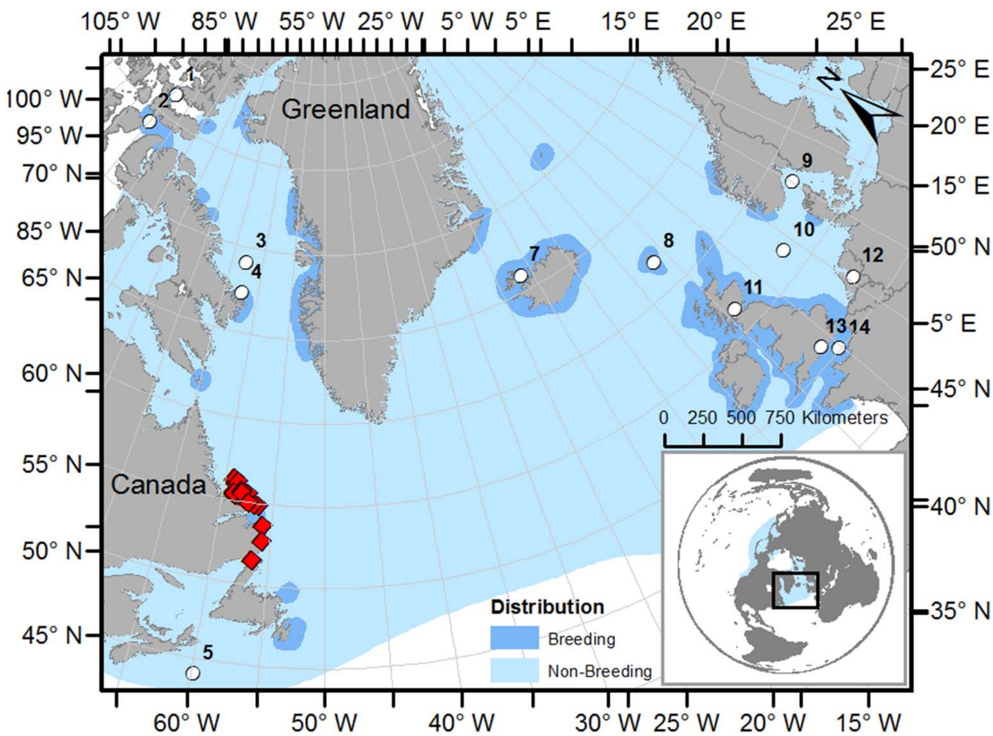

Fig. 1. Locations where northern fulmars were collected in the southern Labrador Sea for the current study (◆) and locations of previous plastic ingestion studies (○). Numbers correspond to locations and references in Fig. 2.

n = 68). We detected no effect of age, sex, body condition index or breeding status on the frequency of occurrence of plastic ingestion, the number of pieces ingested or the mass of plastic ($p > 0.5$, n = 70). These results were robust to the removal of an outlier.

Of the 921 pieces of plastic ingested by fulmars in our sample, 7% were industrial plastics. The remaining 93% were fragments (52%), threads (18%), sheets (9%) foam (2%) or other (10%) which includes non-plastic anthropogenic items (e.g., rubber, wax; Table 2). Ingested plastics were predominantly microplastics (1–5 mm, 52%) and meso-plastics (5–20 mm; 47%) with only 10 ingested macroplastics (> 20 mm). The ingested plastics were yellow (29%), white (26%), green (9%), brown (9%), black (6%), tan (5%), clear (5%) and other colors including gray, pink, orange, blue, red and purple. In 2014, most ingested plastics (n = 263) were found in the gizzard (87%). This was not evaluated in 2015. For the purposes of future comparisons raw and summary data are provided as Supplementary materials.

Increasing plastic pollution is expected in the Arctic and Labrador Sea due to rapid loss of sea ice due to climate change, and an increase in commercial activities (Eguíluz et al., 2016; Smith and Stephenson, 2013). This paper evaluates how plastic ingestion in northern fulmar from the Labrador Sea compares with other regions, and provides information that can be used to understand trends in plastic pollution in the western North Atlantic. We found that 79% of northern fulmars had ingested plastics. Ingested items were primarily broken down pieces of consumer, commercial or industrial goods 1–20 mm in size. Although the composition of plastic pollution has not been sampled in the surface waters of the Labrador Sea, this is consistent with the composition of plastics recently described from at-sea sampling of plastics in the Arctic (Cózar et al., 2017). A low proportion of industrial plastics supports earlier findings which suggest a global shift in the composition of marine plastics (Ryan, 2008; van Franeker and Law, 2015; Vlietstra and Parga, 2002).

We detected no effect of age, sex, condition or breeding status on plastic ingestion which is consistent with the findings of others who have examined fulmar in the western Atlantic (Bond et al., 2014; Poon et al., 2017). Interestingly, we found that fulmars collected in 2015 were significantly more likely to ingest plastic than birds in 2014 (Table 1) and that they ingested more pieces of plastic - though this trend did not hold for the mass of ingested plastics. Inter-annual variation in plastic ingestion may reflect fluctuations in the abundance of plastic pollution or the foraging habits of fulmars (e.g., changing prey availability or foraging distribution). Although we can speculate on what biotic and abiotic factors may have contributed to this, best practices for using northern fulmars as biological monitors recommend pooling samples across 5 years to generate a baseline, and that trends be evaluated based on a running 5-year average (van Franeker et al., 2011). This is especially important when plastic ingestion data from fulmars will be used to inform long-term policy decisions.

By comparing our results to other regions where plastic ingestion in northern fulmars has been evaluated in a standardized way, we show that northern fulmars in the Labrador Sea ingest more plastic than those in the Canadian Arctic, ~2600 km to the north (Mallory, 2006, 2008;

Table 1
The frequency of plastic ingestion (± 95% CI), EcoQO, mass (g), and number of plastic particles in the stomachs of northern fulmars (*Fulmarus glacialis*) collected in the Labrador Sea in 2014 and 2015 are reported as arithmetic and geometric means, following standardized recommendations (van Franeker et al., 2011; Provencher et al., 2017). Annual results are pooled for baseline purposes.

Year	Frequency of plastic ingestion				Mass (g)			Over 0.1 g EcoQO	Number of ingested plastics		
	N	%	Lower 95% CI	Upper 95% CI	Mean ± SD	Geometric mean	Range		Mean ± SD	Geometric mean	Range
2014	39	64	48	78	0.114 ± 0.202	0.002	0–0.879	28	5.9 ± 10.8	0	0–48
2015	31	97	86	100	0.198 ± 0.311	0.063	0–1.496	42	18.7 ± 28.9	5.6	0–135
Pooled	70	79	68	87	0.151 ± 0.257	0.010	0–1.496	34	11.6 ± 21.6	0.4	0–135

Table 2
The mass (g) and dimensions (mm) of ingested plastics are reported with min, max, median and mean ± standard deviation for each type of plastic and all plastics pooled.

Type	N	Mass (g)				Length (mm)				Width (mm)			
		Min	Max	Median	Mean ± SD	Min	Max	Median	Mean ± SD	Min	Max	Median	Mean ± SD
Foam	27	> 0.0001	0.065	0.004	0.009 ± 0.015	1.40	15.90	3.40	4.31 ± 3.13	0.90	6.50	1.90	2.42 ± 1.55
Fragment	469	> 0.0001	0.355	0.007	0.015 ± 0.028	0.40	36.50	5.20	5.68 ± 3.57	0.01	18.20	2.00	2.51 ± 2.29
Industrial	67	0.0002	0.062	0.025	0.025 ± 0.012	2.20	6.50	4.20	4.25 ± 0.77	1.80	5.30	3.20	3.24 ± 0.72
Other	93	> 0.0001	0.169	0.004	0.008 ± 0.020	0.90	18.70	4.00	4.30 ± 2.51	0.40	5.00	2.20	2.33 ± 1.04
Sheet	86	> 0.0001	0.014	0.004	0.004 ± 0.002	1.40	19.00	4.85	5.56 ± 3.31	0.10	7.50	2.60	2.76 ± 1.50
Thread	164	> 0.0001	0.691	0.003	0.009 ± 0.054	1.60	42.40	8.00	8.93 ± 4.99	0.10	19.50	0.40	1.26 ± 2.41
Pooled	906	> 0.0001	0.691	0.005	0.013 ± 0.032	0.40	42.40	5.10	5.98 ± 3.92	0.01	19.50	2.00	2.33 ± 2.12

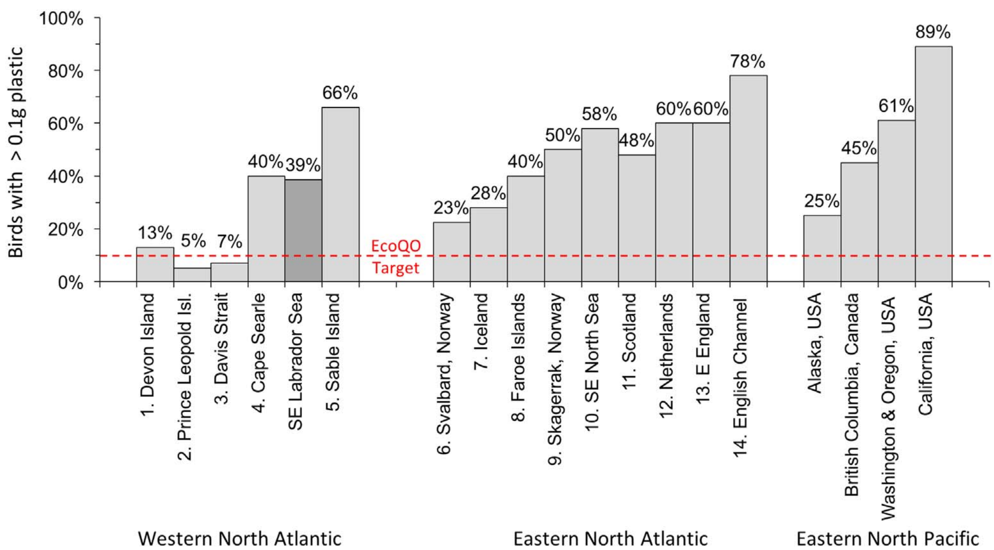

Fig. 2. Comparison of this study's EcoQO results in the southeastern Labrador Sea to Northern fulmar studies undertaken since 2000 in the western North Atlantic (1. Mallory, 2008; 2. Provencher et al., 2009, Poon et al., 2017; 3. Mallory et al., 2006; 4. Provencher et al., 2009; 5. Bond et al., 2014), the eastern North Atlantic (6. Trevail et al., 2015; 7. Kühn and van Franeker, 2012; 8, 12. van Franeker and SNS Fulmar Study Group, 2013; 9–11, 13–14. van Franeker et al., 2011), and the eastern North Pacific (Nevins et al., 2011; Avery-Gomm et al., 2012). The Ecological Quality Objective (EcoQO) for marine litter defines acceptable ecological quality as the situation where no more than 10% of fulmars exceed a critical level of 0.1 g of plastic in the stomach.

Poon et al., 2017; Provencher et al., 2009), but less than those collected at Sable Island ~2000 km to the south (Fig. 2; Bond et al., 2014). This is consistent with several earlier studies that show a negative relationship between plastic loads and latitude for northern fulmar (summarized by Provencher et al., 2017). A comparison with the broader literature indicates that plastic ingestion in the Labrador Sea is lower than many other regions in the Atlantic and Pacific (Fig. 2), suggesting that levels of plastic pollution may also be lower. However, despite the low human footprint, the Labrador Sea does not meet the EcoQO marine litter target for acceptable ecological quality (OSPAR, 2008).

There are two factors that are important to consider when ascertaining how well northern fulmar stomach contents represent the plastic pollution levels in the area where the birds were collected: how long after ingestion plastic items are retained in the animals' digestive tracts and the foraging range of fulmars during that period. For the stomach contents of the fulmars sampled in this study to represent plastic pollution in the Labrador Sea specifically, we must assume that the birds primarily foraged in this region over the period during which the ingested plastic is mechanically degraded in the muscular gizzard.

Importantly, the distance that a fulmar may cover during the summer is influenced by its breeding status. As colonial nesting seabirds, the distance breeding northern fulmars can travel is constrained because both partners participate in incubation, brooding, and feeding the chick (Mallory, 2009). The maximum range for foraging trips during the breeding season is 580 km (Thaxter et al., 2012) although at least one longer trip has been recorded (Edwards et al., 2013). The fulmars in this study were collected in mid-July, which corresponds to the egg hatching phase of the breeding cycle (Mallory et al., 2012). It was not possible to distinguish between active breeders and failed breeders based on brood patch and gonad development, but for fulmars that were actively breeding, it is likely that they originated from Greenland based on their color morphs (Gaston et al., 2006). Failed breeders or non-breeding individuals may travel much greater distances in pursuit of foraging opportunities (Edwards et al., 2013; Falk and Møller, 1995; Mallory, 2006). For example, non-breeding northern fulmar from the Northeast Atlantic (e.g., Iceland and the North Sea) have been found to travel as far west as the Labrador Sea and as far south as Sable Island, Nova Scotia, Canada (Lyngs, 2003; Mallory et al., 2012). Therefore, it is possible that the stomach contents of some proportion of fulmars sampled in the western North Atlantic reflect plastics that birds ingested in more polluted regions of the eastern North Atlantic. If so, plastic pollution in the Labrador Sea may be lower than is indicated by observed levels of plastic ingestion.

At present, the retention time of ingested plastic has not been experimentally studied for northern fulmar. We found some plastics in the proventriculus, indicating recent ingestion (within days), though most ingested plastics were in the small muscular gizzard. Available evidence for procellariiforms is conflicting with some studies suggesting that ingested plastics may be retained in the gizzard for 1 to 12 months, with an average of 4 months being likely (Provencher et al., 2017; van Franeker and Law, 2015), and others suggesting a much longer time frame (Ryan, 2015). If retention times are protracted, then the area over which fulmars potentially foraged increases – and our results are better interpreted as integrating information about plastic pollution for the western North Atlantic, rather the Labrador Sea specifically. Future studies directly measuring the retention times of plastic particles in the stomachs of northern fulmar would resolve uncertainty about the potential foraging area of sampled birds and so improve the interpretation of past and future plastic ingestion data as an indicator of environmental pollution.

Among northern fulmars collected in the Labrador Sea, we detected no effect of age, sex, condition, or breeding status on plastic ingestion. This is consistent with the findings of others who have examined fulmar in the western Atlantic (Bond et al., 2014; Poon et al., 2017). Interestingly, we did find that fulmars collected in 2015 were more likely to ingest plastic than birds in 2014 (Table 1) and ingested more pieces of plastic, though this trend did not hold for mass of ingested plastics. Inter-annual variation in plastic ingestion may reflect fluctuations in the abundance of plastic pollution or the foraging habits of fulmars (e.g., changing prey availability or foraging distribution). Although we can speculate on what biotic and abiotic factors may have contributed to this, best practices for using northern fulmars as biological monitors recommend pooling samples across 5 years to generate a baseline, and that trends be evaluated based on a running 5-year average (van Franeker et al., 2011). This is especially important when plastic ingestion data from fulmars will be used to inform long-term policy decisions.

This study, which has sampled 70 birds over two years according to standardized protocols, describes levels of plastic ingestion for northern fulmar collected in the Labrador Sea and provides new information about plastic pollution in the western North Atlantic. Our results indicate plastic pollution in the region is among the lowest in the world (Fig. 2) but is likely higher than other regions of the western North Atlantic. This should be viewed as a liberal estimate. The overall value of northern fulmar as biological monitors could be improved by measuring the retention time of ingested plastics. Multi-colony tracking studies that establish the origins and movements of breeding and non-breeding northern fulmar in the Labrador Sea could improve the interpretation of plastic ingestion data, as well as have numerous other benefits (e.g., Fort et al., 2013).

Increased plastic pollution in the western North Atlantic is predicted due to increasing commercial activity, and ocean circulation models now predict the eventual formation of a plastic accumulation zone within the Arctic Polar Circle (Cózar et al., 2017). We recommend that local sources of pollution in the region be addressed and that an optimal monitoring program for plastic pollution is established in the western North Atlantic using northern fulmar as a biological monitor (e.g., van Franeker et al., 2011; Provencher et al., 2017). Such a program would provide a means to evaluate the success of plastic pollution mitigation efforts and progress towards environmental targets, such as the EcoQO (OSPAR, 2015, 2008).

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2017.10.001.

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