Circular Ocean
Seabirds & marine plastic debris in Greenland
May 2017

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Seabirds and marine plastic debris in Greenland:

A synthesis and recommendations for monitoring

May 2017

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Northern Periphery and Arctic Programme 2014–2020

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In pursuit of innovative and sustainable solutions for marine plastic waste, the Circular Ocean project seeks to inspire enterprises and entrepreneurs to realise the hidden opportunities of discarded fishing nets and ropes in the Northern Periphery & Arctic (NPA) region.

As increasing levels of marine litter is particularly pertinent to the NPA region, the Circular Ocean project will act as a catalyst to motivate and empower remote communities to develop sustainable and green business opportunities that will enhance income generation and retention within local regions.

Through transnational collaboration and eco-innovation, Circular Ocean will develop, share and test new sustainable solutions to incentivise the collection and reprocessing of discarded fishing nets and assist the movement towards a more circular economy.

Circular Ocean is led by the Environmental Research Institute, www.eri.ac.uk (Scotland), and is funded under the European Regional Development Fund (ERDF) Interreg VB Northern Periphery and Arctic (NPA) Programme http://www.interreg-npa.eu. It has partners in Ireland (Macroom E www.macroom-e.com), England (The Centre for Sustainable Design www.cfsd.org.uk), Greenland (Arctic Technology Centre www.artek.byg.dtu.dk), and Norway (Norwegian University of Science and Technology www.ntnu.edu).

Summary

The presence of plastic in the marine environment is a globally recognised issue, with far-reaching economic, aesthetic, and environmental consequences. Numerous marine species interact with plastic debris through entanglement, nest incorporation, and ingestion, which can lead to negative impacts. However, across Greenland, an important region for seabirds, to date there has been little effort to assess plastic wildlife studies to better understand the spatiotemporal variation of how marine plastic affects different seabird species. To improve our understanding of seabirds and marine plastic in this region, we completed a synthesis of the published and grey literature to obtain information on all known documented cases of plastic ingestion and nest incorporation by this group. We found that of 35 seabird species that commonly occur in Greenland, two (6%) had evidence of ingesting plastic. However, information from multiple countries and years was only available for one species, the Little Auk (*Alle alle*). No published information was found on nest incorporation. This reveals that we actually know very little about the current prevalence of plastic ingestion and nest incorporation for many species. Furthermore, in all studies, the metrics reported were inadequate to carry out robust comparisons among locations and species or perform meta-analyses. This synthesis highlights important gaps in our current knowledge, and we recommend multi-jurisdictional collaboration to obtain a more comprehensive and current understanding of how marine plastic is affecting seabirds across Norway and Svalbard.

- Plastic ingestion was recorded in two seabird species that occur in Greenland waters.
- However, for 89% of species we do not know the extent of plastic ingestion or nest incorporation in Greenland, as they have not been examined in this region.
- This highlights how little we know about plastic ingestion and nest incorporation in seabirds across Greenland.

Background

Plastic pollution in the marine environment

The presence of plastic in the marine environment is a globally recognised environmental issue, with far reaching economic, aesthetic, and environmental consequences (UNEP 2016). Plastic production continues to rise with large quantities, estimated at 4.8 to 12.7 million metric tons, entering our oceans annually. This includes industrial plastic, such as virgin hard plastic pellets used in manufacturing, and user plastic from consumer and commercial sources. User plastic comes in a wide range of forms from hard plastic (polyethylene) to softer plastics such as Styrofoam (polystyrene), both of which can consist of fibres, film, foam and fragments.

The increase in marine plastic debris has led to a multitude of international and regional agreements aimed at reducing the impacts of marine plastic, including the International Convention for the Prevention of Pollution From Ships (MARPOL); the Convention on Biological Diversity (CBD); and the European Unions (EU) Marine Strategy Framework Directive (MSFD). Furthermore, the United Nations (UN) Sustainable Development Goals (SDG), a wide-ranging series of internationally-agreed ambitious goals with associated targets and indicators, includes SDG 14, which seeks to "conserve and sustainably use the oceans, seas and marine resources for sustainable development". This includes a target of significantly reducing marine pollution, including from plastics, by 2025 (UNDP 2015). SDG 14 incorporates the UN's #CleanSeas Initiative, and therefore requires robust quantitative data at the national and international level to measure success.

Impact of plastic on marine biodiversity

Plastic pollution is a major threat to marine biodiversity. The desirable properties of plastics (low-cost, light-weight, and durable) are those that contribute to it being problematic in the marine environment. For example, due to its low cost, approximately half of all plastic items are produced for single-use, resulting in plastic contributing to 10% of all waste globally (Barnes *et al*. 2009). Owing to its low density a large proportion of plastic floats, increasing the number of species that may interact with it, with potentially negative consequences. Furthermore, it does not biodegrade, but instead breaks up into smaller fragments that remain in the environment and a threat to organisms. In addition to these fragments, there is an increase in micro-plastic entering our oceans from terrestrial sources (UNEP 2016). Micro-plastic is generally defined as small particles of plastic < 5 mm in size. Micro-plastics are frequently used in the cosmetic industry and for air-blast cleaning, and include nurdles - the raw material in the manufacturing process. As micro-plastic is largely not collected during waste-water processing, along with, for example, synthetic fibres from washing clothing, large quantities end up in our oceans (Derraik 2002, Gregory 2013).

There are two main ways that plastic pollution affects marine species, through entanglement and ingestion (Laist 1987). Entanglement is generally passive, with individuals becoming entangled in discarded or lost fishing nets, as well as with user plastic such as plastic bags (Derraik 2002). Seabirds can also actively collect plastic as nesting material and incorporate it into their nests where it can cause entanglement of chicks and adults, resulting in direct injury or death (Votier *et al*. 2011). Ingestion of marine plastic is also of particular concern, where individuals either mistakenly consume plastic while foraging on other prey items, or purposefully ingest it by mistaking it for food (Laist 1997). Ingested plastic can have lethal and sub-lethal impacts on a wide range of marine organisms (Browne *et al*. 2015; Rochman *et al*. 2016). Furthermore, plastic fragments can absorb and/or adsorb contaminants, both organic compounds like polychlorinated biphenyls and polybrominated compounds, and inorganic metals, which may interfere with an individual's physiology and therefore have negative consequences on reproduction and survival (Holmes *et al*. 2012; Tanaka *et al*. 2013).

The first documentation of encounters between marine species and plastic was in the 1960s. Since then the issue has escalated and several reviews have documented species' ingestion of and entanglement with marine debris (Laist 1987; Gall & Thompson 2015; Kühn *et al*. 2015). Recent estimates indicate that over 690 marine species globally have been affected by marine debris, includes cetaceans, pinnipeds, seabirds, turtles, fish, and crustaceans, with the majority involving plastic (Gall & Thompson 2015). However, these reviews do not provide quantitative information that can be used to identify spatial and temporal patterns.

Many of the studies within these reviews focus on seabirds. However, despite knowing that many seabird species ingest or become entangled with marine plastic, generally we understand very little about the extent of these interactions at most locations and how this changes over time. There is an understanding of marine plastic debris and seabirds in Canadian waters due to a recent comprehensive review in the region (Provencher *et al*. 2015), which highlighted knowledge gaps and how these should be addressed. This level of understanding in other regions, such as Norway and Svalbard, is vital to highlight local knowledge gaps, direct the focus of future monitoring, and make linkages for coordinated efforts.

"Despite knowing that many seabird species ingest or become entangled with marine plastic, generally we understand very little about the extent of these interactions at most locations and how this changes over time."

Atlantic Puffin © Chris Cachia Zammit

Marine plastic debris and seabirds

Greenland is an important region for seabirds, incorporating 37 Important Bird and Biodiversity Area (IBAs) in marine habitats (Figure 1; Birdlife 2017). They also support important breeding populations of Long-tailed Duck (*Clangula hyemalis*), and Atlantic Puffin, both of which classified as vulnerable by the International Union for Conservation of Nature (IUCN 2016).

The presence of plastic, particularly micro-plastic, has been found to be widespread in the northeastern Atlantic with a mean of 2.46 particles m^{-3} (Lusher *et al*. 2014). In the East Greenland sea, micro-plastic recorded at densities of 0.99±0.62 / m^2 in 2005, increasing to 2.38±1.11 in 2014 (Amélineau *et al.* 2016). In sea ice samples collected from the north of Greenland, in the Arctic Sea, densities of micro-plastic, predominantly fibers, ranged from 38 to 234 particles / cm^3 (Obbard *et al.* 2014). To the east of Greenland, off southwest Svalbard, micro-plastic has been found at average densities of 0.34 particles / m^3 in surface waters and 2.68 particles / m^3 in the sub-surface, up to a depth of 6m (Lusher *et al*. 2015). Whilst, in the deep sea, again off Svalbard, marine debris has increased from a density of 3635 to 7710 items / km^2 between 2002 and 2011, with 59% of this debris being plastic (Bergmann & Klages 2012).

"Greenland is an important region for seabirds, incorporating 37 Important Bird and Biodiversity Area."

Long-tailed Duck © Nina O'Hanlon

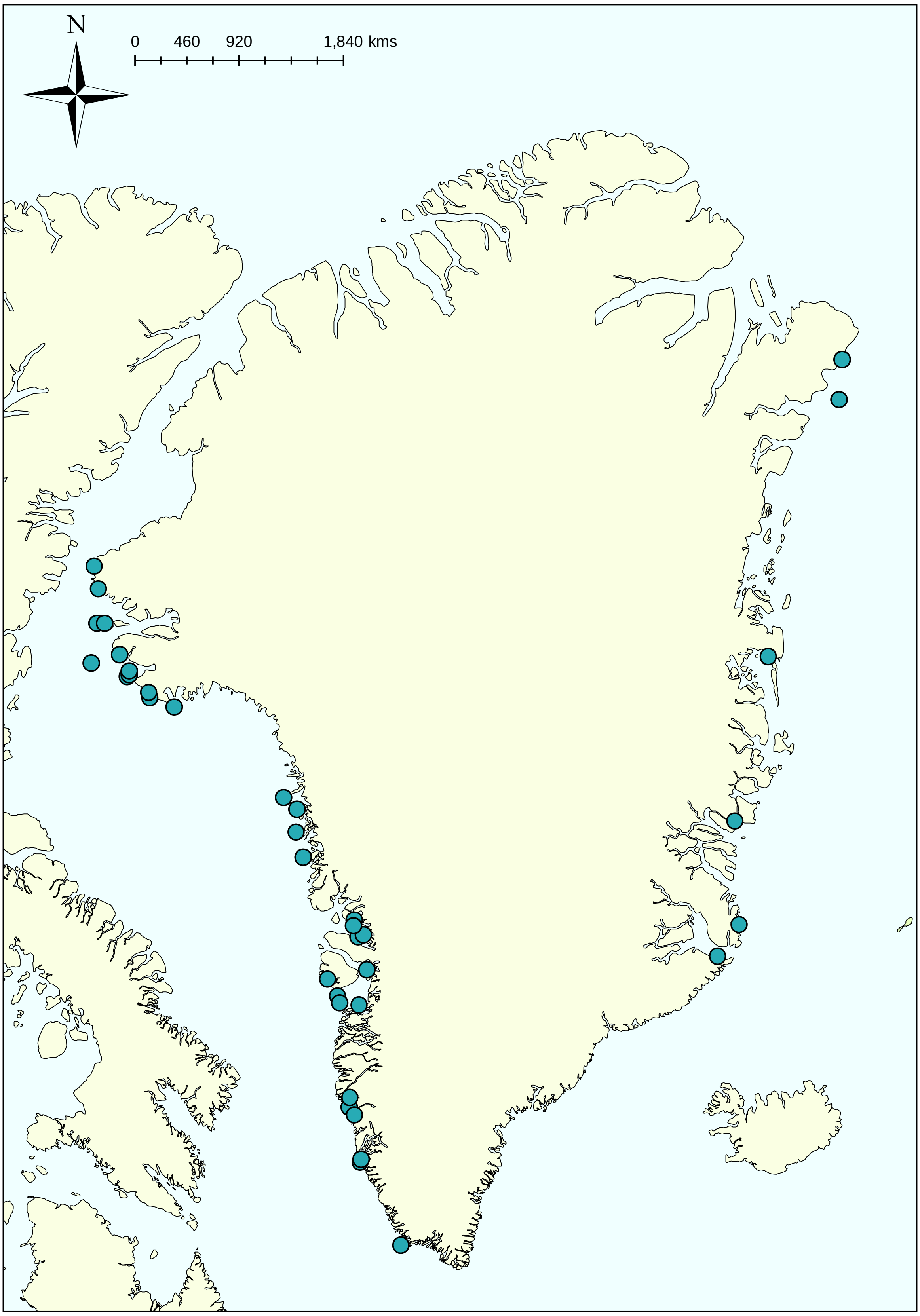

Figure 1: Location of the 37 marine Important Bird Areas (IBAs) across Greenland obtained from Birdlife 2017.

Incorporating the seas around Norway and Svalbard, the Oslo/Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) contains targets to prevent and eliminate pollution including plastic, from land-based sources and by dumping, and mandates regular assessments of the quality of the marine environment. Importantly, OSPAR has developed a system of Ecological Quality Objectives (EcoQOs) with fixed monitoring approaches and associated targets for acceptable ecological quality, including those for marine plastics (OSPAR 2008). This includes the Northern Fulmar (*Fulmarus glacialis*) as an EcoQO indicator species for monitoring plastic debris in the North Sea (van Franeker & Meijboom 2002). The EcoQO indicator states that for acceptable ecological quality no more than 10% of Northern Fulmars should exceed a critical level of 0.1 g of ingested plastic within their stomach. Plastic ingestion by Northern Fulmars has been investigated in the Netherlands since the 1980s, with widespread sampling efforts in multiple countries, including Norway, since 2002 via the North Sea Northern Fulmar project. In Norway, 52% of Northern Fulmars sampled between 2005 and 2009 breached the 0.1g EcoQo level (van Franeker *et al*. 2011), whilst in 2013 22.5% of Northern Fulmars sampled from Svalbard breached this level (Trevail *et al.* 2015).

The Northern Fulmar project has allowed spatial and temporal patterns to be examined in relation to how effective policies are, how methodologies may influence results, and how marine plastic pollution is changing in the region over time. However, we know very little about the prevalence and spatiotemporal scale of plastic ingestion, or nest incorporation, of seabirds in Norway and Svalbard outside this indicator (van Franeker *et al*. 2011). Although a number of studies have identified the prevalence of plastic ingestion in a variety of seabird species, the majority of information currently collected is ad hoc and opportunistic, with the North Sea Northern Fulmar project the only example of a coordinated effort to monitor marine plastic in seabirds in the region.

Northern Fulmar © Nina O'Hanlon

In this synthesis, we aim to determine the current level of knowledge of how seabirds actively interact with marine plastic, focusing on nest incorporation and ingestion. We then identify knowledge gaps and make recommendations for future monitoring to address them, to improve our understanding of how marine plastic affects seabirds in Greenland.

Approach

We focused on birds sampled within Greenland. We included species categorised as seabirds following Gaston (2004), namely the tubenoses (Procellariidae, Hydrobatidae), cormorants (Phalacrocoracidae), gannets (Sulidae), phalaropes (Charadriidae: *Phalaropus* spp.), skuas, gulls, and, terns (Laridae), and auks (Alcidae). We also included loons (Gaviidae), sea ducks and mergansers (Anatidae: Mergini), as these species spend the majority of the year at sea (Gaston 2004). All seabird species known to breed within Greenland, as well as regular non-breeding migrants, were included (del Hoyo *et al.* 2016). We did not include vagrants, as they do not provide useful information on systematic monitoring in our study area. Throughout, we followed the taxonomic treatment of The Handbook of the Birds of the World (HBW) and BirdLife International (del Hoyo & Collar 2014).

To obtain information on plastic ingestion and nest incorporation of plastic by seabirds within Norway and Svalbard we carried out an extensive review of the literature. Key word searches were performed on Web of Science, Google Scholar and Google including the English and scientific names of the selected seabird species or groups. Key words relating to plastic interactions included: plastic (as well as elastic, polythene and cellophane), diet, plastic ingestion, nest, nest incorporation, nest material and marine debris. The reference lists of previous marine plastic review papers (Laist 1997; Gall & Thompson 2015; Kühn *et al*. 2015) and the references of relevant papers were also examined. We also contacted known researchers working on plastic ingestion and/or diet in seabirds, to obtain relevant unpublished data. In all cases, we restricted our data collection to articles or reports published, or data collected, up to 28 February 2017.

For each study, we recorded the species examined, the location and year of sampling, the sampling method, and the frequency of occurrence (%) of plastic ingestion or nest incorporation. The frequency of occurrence of plastic ingestion was recorded following van Franeker & Meijboom (2002), presented as the number of birds within a sample that contained evidence of plastic, including samples that were examined but were not found to contain plastic (van Franeker & Meijboom 2002). For nest incorporation, we recorded the frequency of occurrence as the number of nests within a sample that contained plastic. Where provided, we also recorded all metrics referring to the number, mass, size, type, and colour of plastics identified. For plastic ingestion, we then determined how many studies achieved the standardised metric recommendations outlined by Provencher *et al*. (2017), and which of these recommendations were most widely documented.

Results

We identified 35 seabird species that commonly occur as breeding species or migrants within Norway and Svalbard (Table 1) and a total of 7 studies reporting on plastic interactions by these species. Of these, four species (11.4%) had been examined for plastic ingestion (Table 1). For two species (5.7%), Common Eider (*Somateria mollissima*) and King Eider (*S. spectabilis*), there was no evidence of plastic ingestion. Therefore, of the 35 seabird species reviewed, plastic ingestion was recorded in two species (5.7%), Thick-billed Murre (*Uria lomvia*) and Little Auk (*Alle alle*). Therefore, 31 species (89%) within Greenland have not been examined for plastic ingestion, although it has been documented outside of this region in 21 of these species (68%). Furthermore, in the two species within this synthesis where no evidence of plastic ingestion was documented, it has been recorded in a single Common Eider in Canada (Provencher *et al.* 2013). Reports of plastic ingestion from multiple countries and years existed for just one species, the Little Auk. Of the nest building, surface-nesting seabirds (n = 25), data on nest incorporation of plastic was not documented.

Of the species with recorded incidences of plastic ingestion, the species with the highest mean frequency of occurrence was the Little Auk (27.16%, Table 2). The frequency of occurrence was low at 2.0% in the Thick-billed Murre.

Of the seven published studies, one directly investigated plastic ingestion, four investigated diet, and one parasites (Table 2). In addition, data from three studies were also published in a plastic review paper (Provencher *et al.* 2014). Of the standardised metric recommendations outlined by Provencher *et al.* (2017), none of the studies met them all, or provided any information on the mass of plastic ingested. All studies did however record location, year and sampling method (with the exception of those published in Provencher *et al.* (2014)), sample size and frequency of occurrence.

The information in Table 2 highlights the temporal coverage of published studies that have documented plastic ingestion in seabirds across Greenland, with the spatial distribution displayed in Figure 2. Temporally, studies sampled seabirds over multiple years between 1988 and 2014. However, all studies lasted three years or less, with four only collecting data from single years. The spatial representation across Greenland within this synthesis is also very localised, biased to the south of the country, with the eiders sampled from single locations. Therefore, the collective knowledge of current ingestion levels in most species is poor.

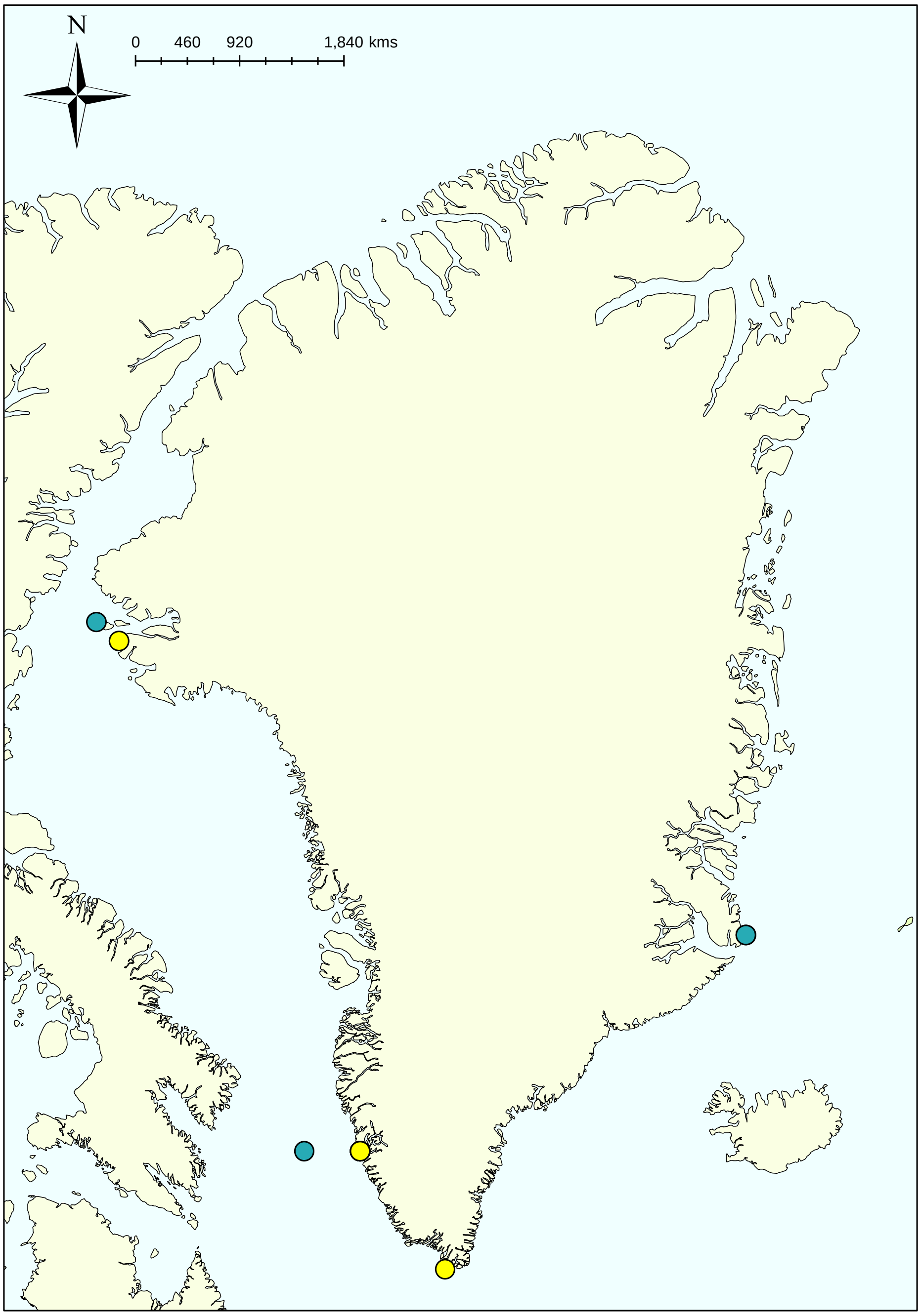

Figure 2: Spatial distribution of documented plastic ingestion by seabirds in Greenland. Yellow circles show negative results for plastic ingestion (where no plastic was found when looked for) and blue filled circles show the presence of plastic ingestion.

Table 1. Species categorised by the spatial and temporal ingested plastic data available from Greenland.

Species with ingested plastic data reported from multiple locations and years	Species with single reports of ingested plastic	Species currently with no reports of ingested plastic
Little auk (*Alle alle*)	Common eider (*Somateria mollissima*)	Red-throated loon (*Gavia stellata*)
	King eider (*Somateria spectabilis*)	Common loon (*Gavia immer*)
	Thick-billed murre (*Uria lomvia*)	Northern Fulmar (*Fulmaris glacialis*)
		Great Shearwater (*Ardenna gravis*)
		Sooty shearwater (*Ardenna grisea*)
		Manx shearwater (*Puffinus puffinus*)
		Northern gannet (*Morus bassanus*)
		Great cormorant (*Phalacrocorax carbo*)
		Harlequin Duck (*Histrionicus histrionicus*)
		Long-tailed duck (*Clangula hyemalis*)
		Common scoter (*Melanitta nigra*)
		Red-breasted merganser (*Mergus serrator*)
		Red-necked phalarope (*Phalaropus lobatus*)
		Red phalarope (*Phalaropus fulicarius*)
		Arctic jaeger (*Stercorarius parasiticus*)
		Long-tailed jaeger (*Stercorarius longicaudus*)
		Great skua (*Catharacta skua*)
		Sabine's gull (*Xema sabini*)
		Black-headed gull (*Larus ridibundus*)
		Iceland Gull (*Larus glaucoides*)
		Glaucous gull (*Larus hyperboreus*)
		Great Black-backed Gull (*Larus marinus*)
		Ross's Gull (*Rhodostethia rosea*)
		Black-legged kittiwake (*Rissa tridactyla*)
		Ivory gull (*Pagophila eburnea*)
		Thayer's Gull (*Larus thayeri*)
		Arctic tern (*Sterna paradisaea*)
		Common murre (*Uria aalge*)
		Razorbill (*Alca torda*)
		Black guillemot (*Cepphus grylle*)
		Atlantic puffin (*Fratercula arctica*)

Seabird species that breed in Greenland (in blue). Species where studies looked for plastic (or noted it in other species within the same study) but no evidence of plastic ingestion recorded (in green – these species also breed in Greenland). Migrant species to Greenland (in black).

Table 2. Publications and unpublished data on plastic interactions and seabirds in Greenland.

Species	Country	Sampling year	Reported frequency of occurrence % (*n*)	Interaction type	Source
Common eider	Nuuk	1999-2002	0 (241)	Ingested	Jamieson *et al.* 2006
(*Somateria mollissima*)	Nuuk	2012	0 (135)	Ingested	Provencher *et al.* 2014
			0 (376)		
King eider (*Somateria spectabilis*)	Nuuk	2000-2002	0 (41)	Ingested	Provencher *et al.* 2014
Thick-billed murre	Greenland*	1988-1989	6 (202)	Ingested	Falk & Durinck 1993
(*Uria lomvia*)	Hakluyt Island	1997	0 (40)	Ingested	Provencher *et al.* 2014
	Nuuk	2006	0 (15)	Ingested	Muzaffar 2000
			2 (257)		
Little auk	Nuuk	1988-1989	0 (19)	Ingested	Provencher *et al.* 2014
(*Alle alle*)	Hakluyt Island	1997	9 (104)	Ingested	Perdersen & Falk 2001
	Cape Farewell & Nuuk	2010-2011	0 (184)	Ingested	Rosing-Asvid *et al.* 2013
	Ukaleqarteq	2005 & 2014	100 (44)	Gular pouch	Amélineau *et al.* 2016
			27 (351)		

[a] Plastic interaction investigated at multiple locations (Maniitsoq and Nuuk / Paamiut and Qaqortoq), but study did not specify at which site(s) the samples with plastic ingestion were collected from. [b] Where more than one study is listed, the mean frequency of occurrence and total sample size, in parenthesis, is also provided in bold.


Common Eider © Nina O'Hanlon

Discussion

We found evidence for seabirds ingesting marine plastic from s locations across Greenland. Of the 35 seabird species commonly found across the region, two had evidence of plastic ingestion, with a further two species examined but with no evidence recorded. However, information on plastic ingestion from multiple species and locations was available for just one species, the Little Auk. For the remaining 31 species, there was no empirical evidence of how, or even if, they interact with marine plastic debris in Greenland. No studies were found that provided quantified information about nest incorporation. Therefore, although active interactions with marine plastic occurred across the region, information on the extent of these interactions for specific species and locations is limited. This synthesis reveals several key knowledge gaps, which we highlight below, along with recommendations for how to target future monitoring and research to obtain a better understanding on the impact of marine plastic and seabirds in Greenland.

"No studies were found that provided quantified information about nest incorporation."

Plastic ingestion

For species where multiple samples were available, the highest prevalence of plastic ingestion occurred in the Little Auk, with every individual sampled at Ukaleqarteq found to have ingested micro-plastic. Ingested plastic has also been recorded in Little Auks beached in the UK (Blake 1984) and those sampled off Svalbard (Lydersen *et al*. 1989), with similar prevalence. The only other species found to have ingested plastic within this synthesis was also in the auk family, the Thick-billed Murre. Given the abundance of floating marine plastic (Cozar *et al*. 2014), diving species, such as auks and cormorants are generally thought to be less susceptible to plastic ingestion (Avery-Gomm *et al*. 2013). However, they are not completely immune, to ingesting plastic, as this study demonstrates, with a recent study indicating that the frequency of occurrence in seabirds of the coast of Brazil was higher in species foraging at intermediate and deep depths rather than those foraging at the surface (Tavares *et al*. 2017). There is also the potential that where plastic does sink it is ingestion by benthic foraging seabirds. Furthermore, Little Auk s may be more susceptible to ingesting plastic, particularly micro-plastic, as this species predominantly feeds on smaller prey items, particularly copepods, and therefore are more likely to mistake micro-plastic for prey, or ingest it accidentally whilst foraging (Amélineau *et al.* 2016).

It is more difficult to establish which species might be at lowest risk of plastic ingestion, largely because of inadequate sampling. However, plastic ingestion was not recorded in the Common Eiders, despite having reasonable samples sizes in both included studies, which is similar to findings outside of Greenland (Provencher *et al.* 2014).

No other species have been examined for plastic ingestion in Greenland. In other regions, the seabirds with the highest prevalence of plastic ingestion are generally Procellariiformes, particularly the Northern Fulmar and shearwaters, highlighting that as surface-feeders, Procellariiformes are highly susceptible to plastic ingestion (Day *et al.* 1985; Ryan 1987; van Franeker *et al.* 2011; Provencher *et al.* 2014). Other surface foraging seabirds can also be susceptible to plastic ingestion. In terms of skuas, plastic has been found in Great Skua pellets in the Faroe Islands, with the highest frequency of occurrence from individuals that had eaten Northern Fulmars (Hammer *et al*. 2016). Skuas may therefore be susceptible to plastic ingestion, directly and through secondary ingestion. The amount of plastic observed in the pellets of certain gull species can also quiet high, however these tend to be species, such as Herring (*Larus argentatus*) and Lesser Black-backed Gulls (*L. fuscus*), which are known to forage on terrestrial, anthropogenic resources, such as landfill sites. Based on other studies, the frequency of occurrence of ingested plastic in terns is thought to be low, however for many species in this group we have very little information (Day *et al*. 1985; Provencher *et al*. 2015). Outside of Scotland, plastic ingestion has been recorded in the Common Tern (*S. hirundo*) and Black Tern (*Chlidonias niger*), including within regurgitated pellets, although sample sizes were small (Hays & Cormons 1974; Braune & Gaskin 1982; Moser & Lee 1992). Being diving species, plastic ingestion is generally thought to be low in these species, however it has been recorded in Red-throated Loons sampled in Wales (Weir *et al.* 1997).

Species that regurgitate the hard parts of their diet via pellets may be less at risk than species that cannot, as plastic does not accumulate to the same extent within their gastro-intestinal tract compared with other species (Ryan 1987). However, this will depend on the proportion of ingested plastic that is expelled via pellets. It is likely that some will remain in the birds' gastro-intestinal tract (Ryan 1987; Ryan & Fraser 1988) and therefore we need to understand the proportion of ingested plastic that is expelled in pellets. Nonetheless, monitoring plastic ingestion in these species can still be useful to look at relative spatiotemporal trends and therefore, the non-invasive collection of pellets from these species may be useful in monitoring trends in plastic ingestion from coastal, and inland, locations across this region. Finally, outside of Greenland very few studies have investigated plastic ingestion in the loons and sea-ducks, excluding the eiders.

The spatial and temporal coverage of plastic ingestion studies of seabirds across Greenland was low. This is also the case across the northeastern Atlantic as a whole, with the exception of the Northern Fulmar. The good representation for the Northern Fulmar is largely due to the North Sea Northern Fulmar monitoring project, which is incorporated into the Ecological Quality Objectives (EcoQOs) set by OSPAR for the North Sea (OSPAR 2008; van Franeker *et al.* 2011; van Franeker & the SNS Fulmar Study Group 2013). Although this monitoring project is focused on the North Sea region, Northern Fulmar samples have also been opportunistically collected, following the same standardised methodology, from the Faroe Islands (van Franeker & the SNS Fulmar Study Group 2013), Svalbard (Trevail *et al.* 2015) and Iceland (Kühn & van Franeker 2012), as well as elsewhere throughout the northern hemisphere, allowing for comparisons across their entire range (Provencher *et al*. 2017). This wide geographical coverage has increased our understanding of plastic ingestion in the Northern Fulmar revealing decreased frequency of occurrence with latitude, and separate processes occurring in the Atlantic and Pacific basins (Provencher *et al*. 2017). It would therefore be beneficial to carry out this level of monitoring across Greenland for other species.

Opportunistic studies are useful to compare current frequency of occurrence levels and provide a point of comparison to determine how plastic ingestion may change over time, for example with the Atlantic Puffin in the North Sea (Harris & Wanless 2011). However, systematically monitoring species, preferably annually, is a more robust way of detecting spatiotemporal trends (van Franeker & Meijboom 2002). In addition to frequent monitoring, adequate sample sizes are also required. For the Northern Fulmar in the North Sea, to detect a reliable change in the frequency of occurrence or quantity of plastic ingested, a sample size of at least 40 birds was required annually over a period of 4-8 years, to detect a 25% change in the mass of ingested plastic. The annual sample size required to detect a change will vary depending on the species, location, and the level of detectable change required (Provencher *et al.* 2015). With the exception of the Northern Fulmar, no species in this synthesis had annual sample sizes > 40 in > 4 years, which also limits our ability to assess the statistical power associated with proposed sampling regimes. Ideally, to detect spatial variation among taxonomic groups and age classes (Provencher *et al*. 2015), this level of monitoring would occur for all species across Greenland. However, this effort is likely impractical, therefore it is important to identify which species are of highest priority, and where they occur, to target future coordinated monitoring.

With the exception of the study by Amélineau *et al.* (2016), who was specifically looking at micro-plastic, none of the included studies specified the minimum size of the plastic recorded. Given that the focus of these studies was not specifically for ingested debris, they likely overlooked the presence of micro-plastic, and also ultrafine- and nano-plastic (items < 1 mm). While seabirds can be used to monitor relative levels of plastic debris in the marine environment, it is difficult to detect the presence of all plastics smaller than 1 mm in this group. Therefore, when examining seabirds it is important to report the minimum size threshold of plastic detected, or at least a recognized size category, so that the scale of plastic detected is known in order to improve our overall understanding on how plastic affects species (Provencher *et al.* 2017). This is particularly important in advancing our understanding of how seabirds may acquire plastic indirectly, through secondary ingestion of contaminated marine invertebrates (Van Cauwenberghe & Janssen 2014) and vertebrates such as fish (Boerger *et al.* 2010; Foekema *et al.* 2013).

"When examining seabirds it is important to report the minimum size threshold of plastic detected, or at least a recognized size category, so that the scale of plastic detected is known."

Nest incorporation

The lack of quantitative information highlights how little we know about nest incorporation of plastic by seabirds in Greenland. Of the species included within our synthesis, nest building, surface nesters include the Northern Gannet, Great Cormorant and European Shag as well as the gulls, skuas, loons and sea ducks (n = 25). Outside of this region, incorporation of plastic into nests has been reported in Northern Gannets (Votier *et al.* 2011), Black-legged Kittiwakes (*Rissa tridactyla*) (Hartwig *et al*. 2007), cormorants (Podolsky & Kress 1989) and gulls (Witteveen *et al*. 2016). In order to obtain systematic, quantified data on nest incorporation it would be valuable to establish a monitoring scheme for multiple species across the country to provide a better understanding on which species are the most affected.

Recommendations

To increase our knowledge of marine plastic pollution in Greenland, and how this affects the seabird species in this region, further monitoring is required to address current species, spatial, and temporal knowledge gaps.

1. The majority of the plastic ingestion metrics reported were inadequate for comparisons among species and locations. **Future studies that report plastic metrics should follow the standardised recommendations made by Provencher *et al.* (2017).** The most important of these are mass and frequency of occurrence of ingested plastics, as the most biologically relevant. Furthermore, studies should report the minimum plastic size threshold detected so that when comparing between studies the scale of plastic recorded is known. These suggestions also pertain to studies where the focus is not ingested plastic, to ensure that the presence and quantity of plastic, and other marine debris, that might be found for example in diet studies is documented adequately to further address the knowledge gaps associated with plastic ingestion in seabirds.

2. At present, monitoring seabirds for plastic ingestion is largely opportunistic with limited, if any, co-ordination. This makes identifying spatial and temporal trends among and between species challenging. **Coordinated, collaborative effort is therefore necessary to obtain samples required to monitor the temporal and spatial variation in plastic ingestion among seabird species in Norway and Svalbard.** Where possible, advantage should be made of existing trips to seabird colonies by scientists and management agencies. Furthermore, those visiting seabird colonies should be actively approached to establish whether they can collect samples following a standardised protocol, especially if the method of obtaining samples is straightforward such as collecting pellets. Seabird wrecks should also be exploited to examine beached birds for plastic ingestion by necropsy. Taking advantage of current diet monitoring or ringing activities may seem opportunistic however, if carried out in a standardised manner, and the information reported adequately, then this information can still be extremely useful. Opportunities should be exploited across Greenland, and for all species, however particular emphasis should be on those species for which we have very little current information for (based on table 1), especially those which may be at higher risk i.e. the Procellariiformes, and in locations that are currently under represented.

3. From the data collated within this synthesis it was not possible to determine the sample sizes required to detect significant changes in ingestion trends over time. When collecting samples, the number required to provide a large enough sample to detect potential changes needs to be considered, and so that adequate samples sizes can be determined for future monitoring. **Methods that allow for frequent collection of a large number of samples from multiple species and locations may therefore be necessary, for example endoscopy, lavage or pellets.** For species that regurgitate or produce pellets, these can provide a non-invasive means of examining for ingested plastic. As stated above**, this requires coordinated effort to regularly collect large sample sizes from multiple colonies by, for example, visiting researchers and ringing groups**. The non-invasive collection of pellets may be useful in monitoring trends in plastic ingestion from coastal and inland locations across this region. This would be particularly useful if species can be sampled in both their breeding and non-breeding areas to help determine where they are most likely to encounter marine plastic. Furthermore, examining these species in breeding and non-breeding regions may allow for insights into how seabird may be differentially vulnerable by marine plastic pollution throughout the annual cycle, and therefore have potentially different effects on different life history traits.

4. **To document nest incorporation of nest building, surface nesters across Scotland, a standardised, repeatable protocol should be established.** Coordinated monitoring, as described for plastic ingestion, can then be carried out at colonies that are repeatedly visited by researchers, ringers, and tourists (through photographs where feasible) in order that spatiotemporal changes for different species can be detected.

In terms of future research priorities, the proportion of plastic that remains in the gastro-intestinal tract of different pellet producing species is unknown. This could be investigated further through comparing the quantities of plastic detected in pellets to that detected through lavage or necropsy on the same species at a similar time and location. Furthermore, we know little on how long plastic remains in the gastro-intestinal tracts of different seabird species, or how contaminants that come from the plastics, or adhere to it, impact seabirds (Ryan 2015). In terms of nest incorporation, much research is required to establish the extent of plastic incorporation in to the nests of different species and what affect this may have on both the chicks and adults of these species.

There is wide scope for the use of citizen scientists for documenting the location and extent of plastic incorporation in nests through photographs. In addition, as has been highlighted elsewhere, we still do not fully understand the impacts plastic has on seabirds (Provencher *et al.* 2015, 2017). Plastic can have a negative impact on species at the sub-organismal level, however, very little is known about the impact of plastic at the organismal and ecological level, especially that has been demonstrated rather than simply inferred (Rochman *et al.* 2016). Therefore, investigations into these aspects of marine plastic and seabirds should also be a priority for future research.

"To establish a better understanding of the growing issue of plastic marine debris in the marine environment, we require a region wide, coordinated effort to collect information on both plastic ingestion and nest incorporation, collected and reported in a standardised manner."

Here we focused on knowledge gaps associated with monitoring the interactions between plastic and seabirds in Greenland. Our synthesis highlights that our knowledge about the incorporation of plastic into the nests of those species that build them is very poor. We also know very little about the frequency of occurrence of plastic species in the majority of seabird species, at many locations across the region, especially the current state of occurrence. To establish a better understanding of the growing issue of plastic marine debris in the marine environment, we require a region wide, coordinated effort to collect information on both plastic ingestion and nest incorporation, collected and reported in a standardised manner. This is vital to meet national and international targets, and more importantly understand the impacts of marine plastic debris on seabirds and other marine organisms.

Acknowledgements

We thank many members of the RSPB's Marine Nature Recovery Group for initial discussions as well as Flemming Merkel and Aqqalu Rosing-Asvid for information. The ERDF Interreg VB Northern Periphery and Arctic (NPA) Programme funded this activity through the Circular Ocean project. Comments from J. Provencher improved this report.

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Circular Ocean is funded under the European Regional Development Fund (ERDF) Interreg VB Northern Periphery and Arctic (NPA) Programme

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