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Seabirds & marine plastic debris in Scotland
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Seabirds and marine plastic debris in Scotland:

A synthesis and recommendations for monitoring

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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, in Scotland, an area of international importance 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 literature to obtain information on all known documented cases of plastic ingestion and nest incorporation by this group. We found that of 69 seabird species that commonly occur in Scotland, 14 (20%) had evidence of ingesting plastic. However, information from multiple countries and years was only available for three species (4%). No published information was found on nest incorporation. In terms of ingestion, for many species, sample sizes were small or not reported, and only 37% of studies were from the 21st century indicating that we actually know very little about the current prevalence of plastic ingestion and nest incorporation for most species. This synthesis highlights important gaps in our current knowledge, and we recommend co-ordinated collaboration to obtain a more comprehensive and current understanding of how marine plastic affects seabirds in Scotland.

- Plastic ingestion was recorded in 20% of seabird species that occur in Scottish waters.
- For 75% of species we do not know the extent of plastic ingestion or nest incorporation in Scotland, as they have not been examined in this region.
- Only 37% of studies included within this report referred to data collected in the 21st Century.
- We therefore know very little about current levels of plastic ingestion and nest incorporation of seabirds in Scotland for the majority of species.

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.

In Scotland, the value of the marine economy is hugely important with this sector contributing £4.2 billion to Scotland's Economy in 2014, 3.4% of the country's total Gross Value Added (Marine Scotland 2016). It is estimated that marine plastic costs the Scottish fishing industry over £10 million per year, whilst clearing Scottish beaches of marine litter costs over £600,000 per year (Mouat *et al*. 2010). Therefore, marine plastic has the potential to have considerable impact on Scotland's economy.

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In Scotland, the Scottish Government has responsibility for the protection of the marine environment under the Marine (Scotland) Act 2010. In order to comply with the MSFD, which states that all EU marine waters should be in Good Ecological Status by 2020, the Scottish Government has created a Marine Litter Strategy for Scotland. This strategy aims to "to develop current and future measures to ensure that the amount of litter entering the marine and coastal environment is minimised to bring ecological, economic and social benefits" and includes a strategy direction of improving monitoring of marine litter (Marine Scotland 2014). To that end, an understanding of the extent and nature of plastics' impacts on marine life is essential.

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, with the first reported case of plastic ingestion in seabirds in Scotland recorded in the early 1970s (Bourne 1976). 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 Scotland, is vital to highlight local knowledge gaps, direct the focus of future monitoring, and make linkages for coordinated efforts.

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Marine plastic debris and seabirds

Scotland is an important region for seabirds, incorporating 60 Important Bird and Biodiversity Area (IBAs) in marine habitats and supporting internationally important numbers of 24 species (Figure 1; Birdlife 2017). These include breeding populations of Leach's Storm-petrel (*Hydrobates leucorhous*) and Atlantic Puffin (*Fratercula arctica*), as well as wintering numbers of Long-tailed Duck (*Clangula hyemalis*) and Velvet Scoter (*Melanitta fusca*), all of which are red-listed, and 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). There are no baseline data for levels of marine plastic in Scottish seas. However, there is limited coastal information obtained from beached litter surveys. These surveys have found that plastic debris associated with fishing activity particularly occurred on beaches along Scottish coastlines (Unger & Harrison 2015). Across the UK, beached litter along the Scottish Continental Shelf contained the highest proportion of plastic (83%), with the Minches and West Scotland containing the lowest proportion (52%) (Nelms *et al*. 2016). Furthermore, micro-plastic has been found in the Norway Lobster (*Nethrops norvegicus*) in the Clyde Sea (Murray & Cowie 2011).

"Scotland is an important region for seabirds, incorporating 60 Important Bird and Biodiversity Area (IBAs) in marine habitats and supporting internationally important numbers of 24 species."

Atlantic Puffin © Chris Cachia Zammit

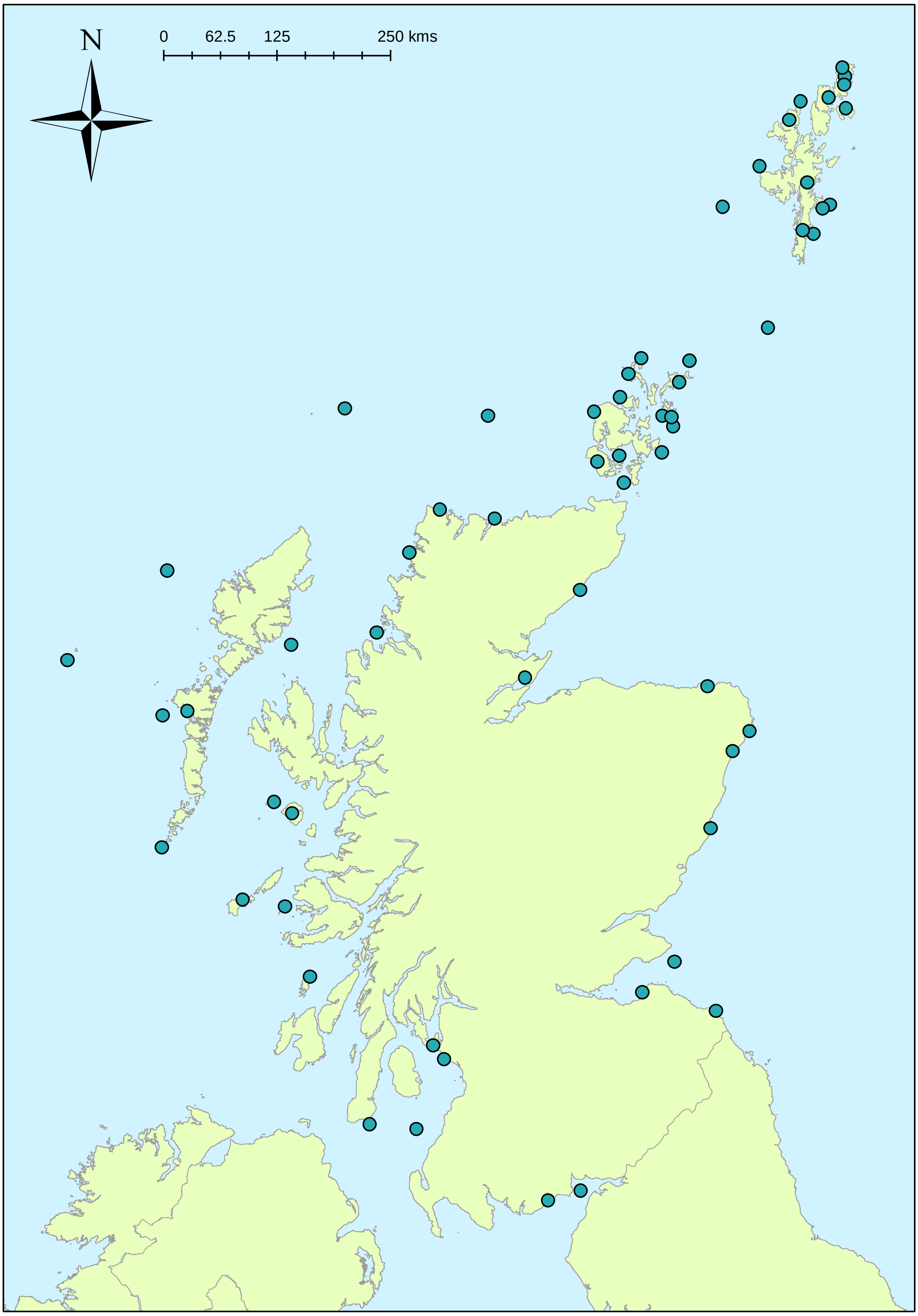


Figure 1: Location of the 60 marine Important Bird Areas (IBAs) across Scotland obtained from Birdlife 2017.

Incorporating the seas around Scotland, 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 northeastern Scotland, since 2002 via the North Sea Northern Fulmar project. In Scotland, between 2003-2007, 92% of 95 beached fulmars collected from Orkney and Shetland were found to contain ingested plastic, with 48% of these breaching the 0.1g EcoQo level (van Franeker *et al*. 2011).

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 Scottish seabirds 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 Scotland.

Approach

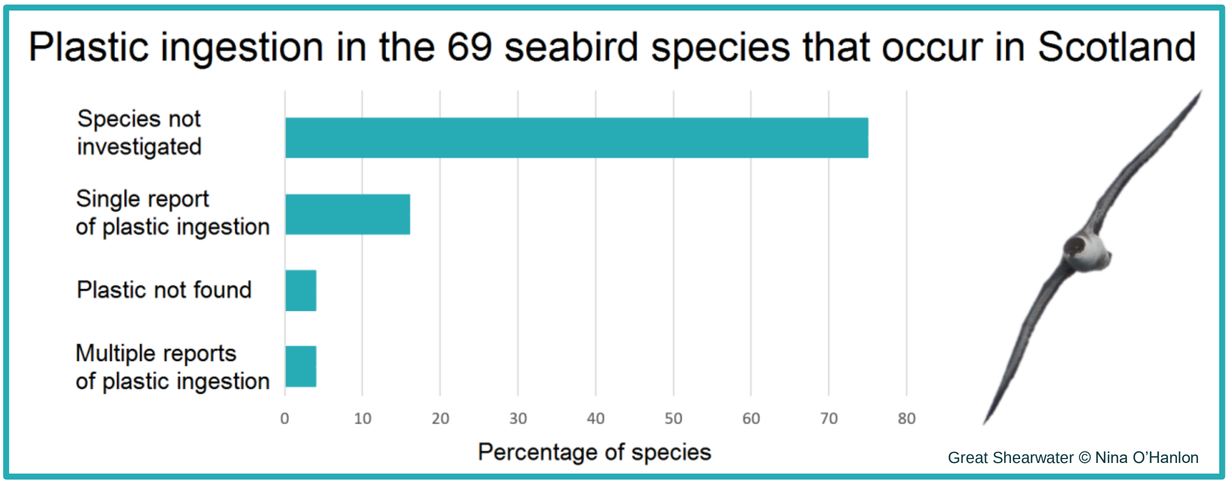
We focused on birds sampled within Scotland (Figure 1). We included species categorised as seabirds following Gaston (2004), namely the tubenoses (Procellariidae, Hydrobatidae), cormorants (Phalacrocoracidae), gannets (Sulidae), phalaropes (Charadriidae: *Phalaropus* spp.), skuas, gulls, and, terns (Laridae), 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 Scotland, 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 Scotland 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 69 seabird species that commonly occur as breeding species or migrants within Scotland (Table 1), with a total of 19 studies reporting on plastic ingestion by these species. Of these species identified, 17 (25%) had been examined for plastic ingestion (Table 2). For three species (4%), there was no evidence of plastic ingestion. Therefore, of the 69 seabird species reviewed, plastic ingestion was recorded in 14 species (20%), however only three of these species had data from multiple years and locations. This means that 52 species (75%), which can occur within Scottish waters, have not been examined for plastic ingestion, although it has been documented in 25 of these species (48%) outside of Scotland. Furthermore, in all three of the species within this synthesis where no evidence of plastic ingestion was documented, plastic ingestion has been recorded elsewhere. For the seabird species that build visible, surface nests (n = 50), data on nest incorporation of plastic was not documented.



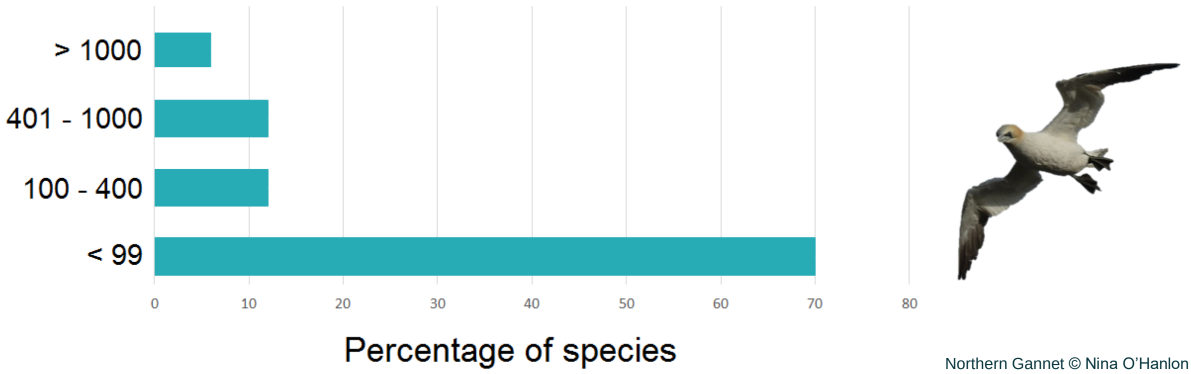
Great Shearwater © Nina O'Hanlon

For this synthesis, we obtained data from 16 published studies and three unpublished datasets. Of the published studies, only six directly investigated plastic ingestion, with eight investigating diet and two focusing on seabird mortality events. Of the standardised metric recommendations outlined by Provencher *et al*. (2017), none of the studies met them all (Table

4). All studies recorded location, year and sampling method, with the majority also including the sample size (94%) and frequency of occurrence (69%). In addition to frequency of occurrence, the mass of ingested plastic fragments is the most biologically important metric (van Franeker & Meijboom 2002). However, the mean mass of ingested plastic was recorded in only one study (van Franeker & the SNS Fulmar Study Group 2013).

The information summarised in Table 3 highlights the temporal coverage of published studies that have documented plastic ingestion in seabirds across Scotland, with the spatial distribution displayed in Figure 2. Temporally, the studies sampled seabirds over multiple years between 1969 and 2016. From the 19 studies included in this synthesis, the majority of samples (63%) were collected prior to the 21st century, implying that the collective knowledge of current ingestion levels in most species is poor. The spatial representation across Scotland within this synthesis is relatively widespread, when all species and years are considered. However, at the species level, few have been sampled from multiple locations (Table 2).

Sample sizes for the 17 seabird species in Scotland that have been investigated for plastic ingestion.



Northern Gannet © Nina O'Hanlon

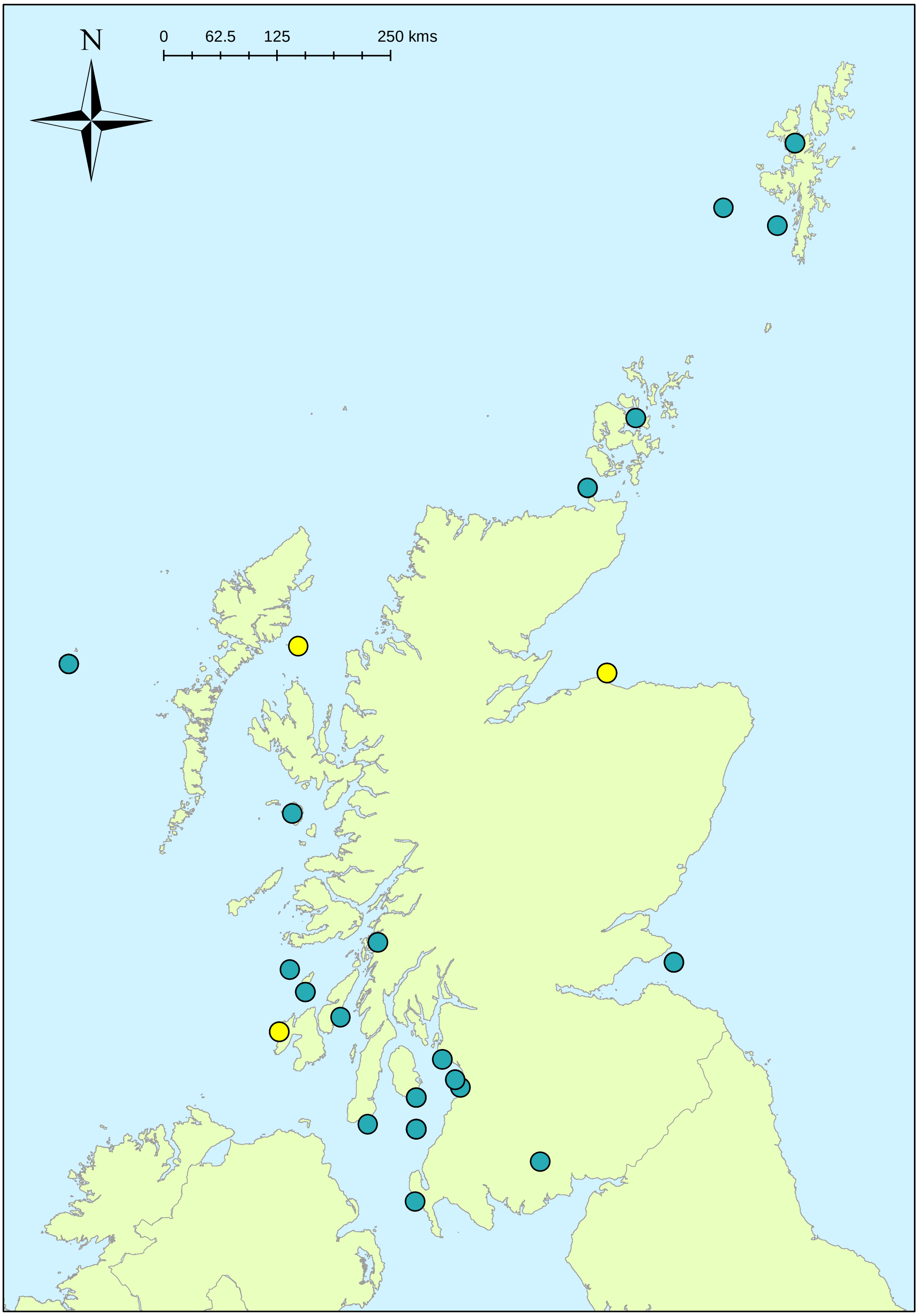


Figure 2: Spatial distribution of documented plastic ingestion by seabirds in Scotland. Yellow circles show negative results for plastic ingestion (where no plastic was found when looked for) and blue filled circles show the presence of plastic ingestion.

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

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
Northern fulmar (*Fulmarus glacialis*)	Great shearwater (*Ardenna gravis*)	Red-throated loon (*Gavia stellata*)
European herring gull (*Larus argentatus*)	Sooty shearwater (*Ardenna grisea*)	Common loon (*Gavia immer*)
Atlantic puffin (*Fratercula arctica*)	Manx shearwater (*Puffinus puffinus*)	Arctic loon (*Gavia arctica*)
	European storm-petrel (*Hydrobates pelagicus*)	Yellow-billed loon (*Gavia adamsii*)
	Leach's storm-petrel (*Hydrobates leucorhous*)	Zino's petrel (*Pterodroma madeira*)
	Northern gannet (*Morus bassanus*)	Cape Verde petrel (*Pterodroma feae*)
	Great cormorant (*Phalacrocorax carbo*)	Cory's shearwater (*Calonectris borealis*)
	European shag (*Phalacrocorax aristotelis*)	Balearic shearwater (*Puffinus mauretanicus*)
	Lesser black-backed gull (*Larus fuscus*)	Wilson's storm-petrel (*Oceanites oceanicus*)
	Iceland gull (*Larus glaucoides*)	Steller's eider (*Polysticta stelleri*)
	Black-legged kittiwake (*Rissa tridactyla*)	Common eider (*Somateria mollissima*)
	Common murre (*Uria aalge*)	King eider (*Somateria spectabilis*)
	Razorbill (*Alca torda*)	Harlequin duck (*Histrionicus histrionicus*)
	Black guillemot (*Cepphus grylle*) [a]	Long-tailed duck (*Clangula hyemalis*)
		Common scoter (*Melanitta nigra*)
		Surf scoter (*Melanitta perspicillata*)
		Velvet scoter (*Melanitta fusca*)
		Red-breasted merganser (*Mergus serrator*)
		Common goldeneye (*Bucephala clangula*)
		Red-necked phalarope (*Phalaropus lobatus*)
		Red phalarope (*Phalaropus fulicarius*)
		Pomarine jaeger (*Stercorarius pomarinus*)
		Arctic jaeger (*Stercorarius parasiticus*)
		Long-tailed jaeger (*Stercorarius longicaudus*)
		Great skua (*Catharacta skua*)
		Mediterranean gull (*Larus melanocephalus*)
		Laughing gull (*Larus atricilla*)
		Little gull (*Hydrocoloeus minutus*)
		Sabine's gull (*Xema sabini*)
		Ross's gull (*Rhodostethia rosea*)
		Bonaparte's gull (*Larus philadelphia*)
		Black-headed gull (*Larus ridibundus*)
		Ring-billed gull (*Larus delawarensis*)
		Mew gull (*Larus canus*)
		Yellow-legged gull (*Larus michahellis*)
		Glaucous gull (*Larus hyperboreus*)
		Great black-backed gull (*Larus marinus*)
		Caspian gull (*Larus cachinnans*)
		Thayer's gull (*Larus thayeri*)
		Ivory gull (*Pagophila eburnea*)
		Common gull-billed tern (*Gelochelidon nilotica*)
		Caspian tern (*Hydroprogne caspia*)
		Sandwich tern (*Thalasseus sandvicensis*)
		Roseate tern (*Sterna dougallii*)
		Common tern (*Sterna hirundo*)
		Arctic tern (*Sterna paradisaea*)
		Little tern (*Sternula albifrons*)
		Whiskered tern (*Chlidonias hybrida*)
		Black tern (*Chlidonias niger*)
		White-winged tern (*Chlidonias leucopterus*)
		Thick-billed murre (*Uria lomvia*)
		Little auk (*Alle alle*)


Herring Gull © Neil James

Seabird species that breed in Scotland (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 Scotland). Migrant species to Scotland (in black).

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

Species	Location	Sampling year	Reported frequency of occurrence % (*n*)	Interaction type	Source
Northern fulmar (*Fulmarus glacialis*)	Northern Scotland	1972	Present (36)	Ingested	Bourne 1976
	St. Kilda	1982	8 (12)	Regurgitates	Camphuysen & Franeker 1996
	Foula & St. Kilda	1978 - 1982	7 (415)	Regurgitates	Furness & Todd 1984
	Foula & St. Kilda	1983	76 (21)	Ingested	Furness 1995
	Clyde	1985	Present (unknown)	Ingested	Zonfillo 1985
	Orkney & Shetland	2002 - 2012	92 (214)	Ingested	van Franeker *et al*. 2013
Great shearwater (*Ardenna gravis*)	Northern Scotland	1972	100 (1)	Ingested	Bourne 1976
Sooty shearwater (*Ardenna grisea*)	Northern Scotland	1972	100 (1)	Ingested	Bourne 1976
Manx shearwater (*Puffinus puffinus*)	Rhum, Inner Hebridies	1984	30 (10)	Ingested	Furness 1995
European storm petrel (*Hydrobates pelagicus*)	St. Kilda	1983	0 (21)	Ingested	Furness 1995
Leach's storm petrel (*Hydrobates leucorhous*)	St. Kilda	1983	59 (17)	Ingested	Furness 1995
Northern gannet (*Morus bassanus*)	England / Scotland	1972	8 (13)	Ingested	Parslow *et al*. 1973
Great cormorant (*Phalacrocorax carbo*)	Loch Awe	1985 - 1987	Present (37)	Ingested	Carss 1993
European shag (*Phalacrocorax aristotelis*)	Northern Scotland	1972	0 (2)	Ingested	Bourne 1976
Lesser black-backed gull (*Larus fuscus*)	Dumfries	2002 - 2003	Present (181)	Pellets	Coulson & Coulson 2008
Herring gull (*Larus argentatus*)	Ailsa Craig	1991	28 (408)	Pellets	Nogales *et al*. 1995
	Sanda, Clyde	2006	Present (220)	Pellets	Kim 2008
	Southwest Scotland [a]	2013 - 2014	9 (599)	Pellets	Nina O'Hanlon (unpublished data)
	Ailsa Craig	2015	58 (12)	Pellets	Crystal Maw (unpublished data)
	Southwest Scotland [a]	2016	26 (234)	Pellets	Alix Scullion (unpublished data)
Iceland gull (*Larus glaucoides*)	Shetland	1993	8 (13)	Ingested	Weir *et al*. 1993
Black-legged kittiwake (*Rissa tridactyla*)	Northern Scotland	1972	Present (28)	Ingested	Bourne 1976
Common murre (*Uria aalge*)	Moray Firth	1983	0 (60)	Ingested	Blake 1984
Razorbill (*Alca torda*)	Moray Firth	1983	0 (109)	Ingested	Blake 1984
Black guillemot (*Cepphus grylle*)	Shetland & Orkney	1979 - 1984	Present (96)	Ingested	Ewins 1990
Atlantic puffin (Fratercula arctica)	West Scotland	1969 - 1971	21 (73)	Ingested	Parslow & Jeffries 1972
	England / Scotland*	1973 - 2007	8 (393)	Ingested	Harris & Wanless 2011

[a] Multiple colonies samples within Southwest Scotland. [b] Sampled collected from the North Sea (so may also include Northern England) and from the west coast of Scotland.

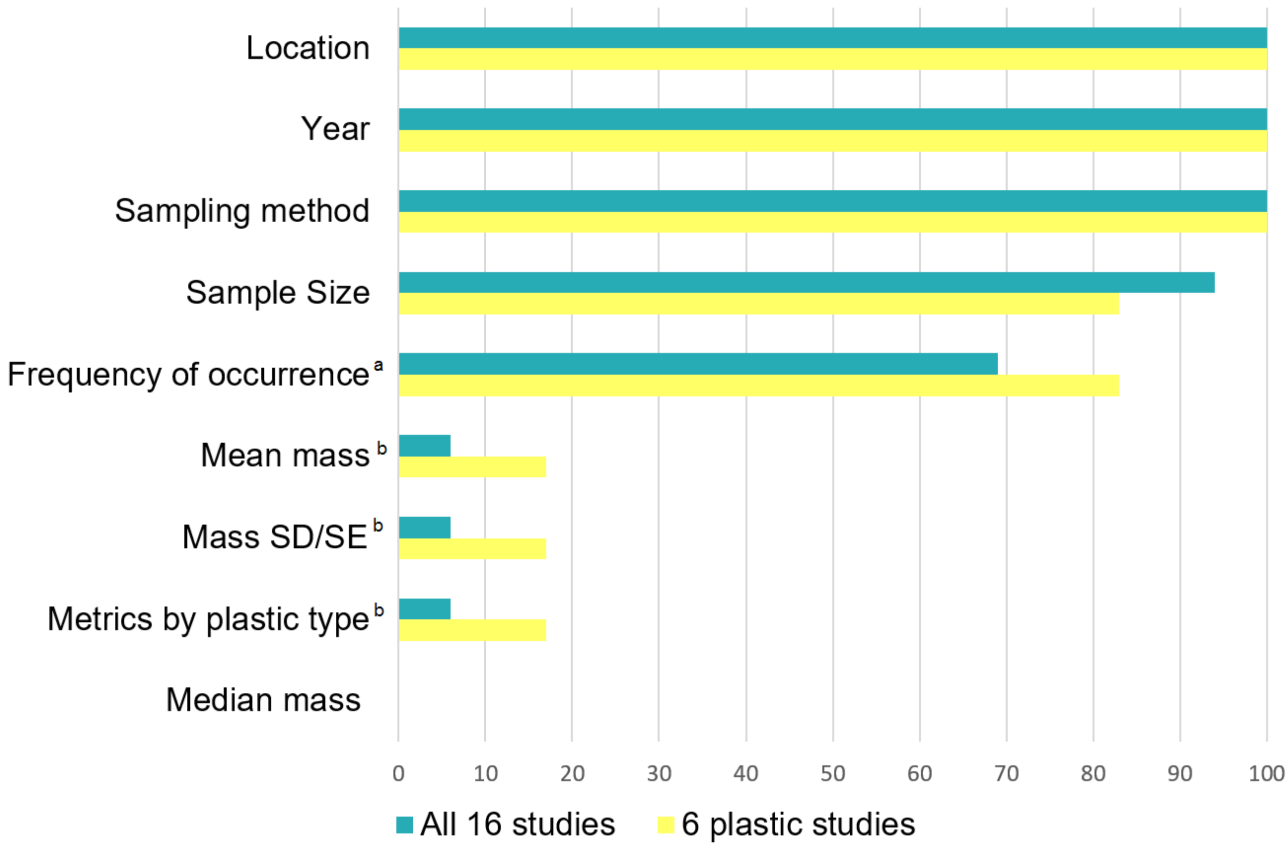
Table 3. Summary information for seabird species where plastic ingestion has been investigated in Scotland.

Species	Studies	Number of sample years			Year Range	Sample Size			Frequency of occurrence (%)		
		Total	Range [b]	Median		Total	Range	Median	Mean ±SD	Range	Median
Northern fulmar [a]	6	19	1 - 11	2	1972 - 2012	698+	12 - 415	36	45.8 ± 44.7	8 - 92	42
Great shearwater	1	1	NA	NA	1972	1	NA	NA	100	NA	NA
Sooty shearwater	1	1	NA	NA	1972	1	NA	NA	100	NA	NA
Manx shearwater	1	1	NA	NA	1984	10	NA	NA	30	NA	NA
European storm-petrel	1	1	NA	NA	1983	21	NA	NA	0	NA	NA
Leach's storm-petrel	1	1	NA	NA	1983	17	NA	NA	59	NA	NA
Northern gannet	1	1	NA	NA	1972	13	NA	NA	8	NA	NA
Great cormorant [a]	1	3	NA	NA	1985 - 1987	37	NA	NA	Present	NA	NA
European shag	1	1	NA	NA	1972	2	NA	NA	0	NA	NA
Lesser black-backed gull [a]	1	2	NA	NA	2002 - 2003	181	NA	NA	Present	NA	NA
European herring gull [a]	5	6	1 - 2	1	1991 - 2016	1473	12 - 599	234	30.3 ± 20.4	0 - 58	27
Iceland gull	1	1	NA	NA	1993	13	NA	NA	8	NA	NA
Black-legged kittiwake [a]	1	1	NA	NA	1972	28	NA	NA	Present	NA	NA
Common murre	1	1	NA	NA	1983	60	NA	NA	0	NA	NA
Razorbill	1	1	NA	NA	1983	109	NA	NA	0	NA	NA
Black guillemot [a]	1	5	NA	NA	1979 - 1984	96	NA	NA	Present	NA	NA
Atlantic puffin	2	37	3 - 35	19	1969 - 2007	466	73-393	233	14.5 ± 9.2	8 - 21	14.5

[a] One or more studies did not provide information on sample size or frequency of occurrence. See Table 2 for details. [b] Number or range of years studies collected samples.

- Data on plastic ingestion was available for only 17 seabird species in Scotland.
- Eleven species only had data on plastic ingestion from single years.
- Twelve species had total sample sizes less than 100.

Figure 4: Standardised metric recommendations taken from Provencher *et al*. (2016). met by the 16 published studies reviewed in Scotland. “Plastic studies” were those where plastic ingestion was the focus.



[a] One study also included mass range, no other study recorded this metric. [b] The same one study reported these three metrics within it. Accumulative percentage therefore includes published studies that documented the recommendation in that row as well as all the recommendations above.

Razorbill © Nina O’Hanlon

Discussion

We found evidence for seabirds ingesting marine plastic from multiple locations across Scotland. Of the 69 seabird species commonly found across the region, 14 had evidence of plastic ingestion, with a further three species examined but with no evidence recorded. However, information on plastic ingestion from multiple species and locations was available for just three species. For the remaining 52 species, there was no empirical evidence of how, or even if, they interact with marine plastic debris in Scotland. 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 Scotland.

"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 Procellariiformes, specifically the Northern Fulmar, Leach's Storm-petrel and Manx Shearwater (*Puffinus puffinus*). This is consistent with other studies, highlighting that as surface-feeders, Procellariiformes are highly susceptible to plastic ingestion (Day *et al*. 1985; Provencher *et al*. 2014). Furthermore, in the Northern Fulmar, the actual frequency of occurrence of ingested plastic is likely to be higher than the mean and median provided here, as these values included regurgitates, which are known to under-estimate the occurrence of plastic present in an individual. Though only one study recorded ingested plastic in single individuals of Great Shearwater and Sooty Shearwater, these species are known to ingest a large amount of plastic throughout their ranges (Avery-Gomm *et al*. 2013; Bond *et al*. 2014). Although, no evidence of plastic ingestion was observed in the European Storm-petrel (*Hydrobates pelagicus*), this species was only sampled at one location, with a small sample size of 21 individuals.

"For species where multiple samples were available, the highest prevalence of plastic ingestion occurred in the Procellariiformes, specifically the Northern Fulmar, Leach's Storm-petrel and Manx Shearwater."

It is more difficult to establish which species might be at lowest risk of plastic ingestion, largely because of inadequate sampling. Given the abundance of floating marine plastic (Cozar *et al*. 2014), diving species are likely less susceptible, though not completely immune, to ingesting plastic (Tavares *et al*. 2017). Furthermore, where plastic does sink there is potential for ingestion by benthic foraging seabirds. As documented elsewhere, we found a low prevalence of plastic ingestion in auks (Laist 1987; Provencher *et al*. 2010) and cormorants (Avery-Gomm *et al*. 2013). However, again sample sizes for these species in Scotland were small (between 2 and 109, all from single studies), although the sample size was larger for the Atlantic Puffin (n = 466), where individuals were found to have ingested plastic from multiple locations.

Excluding the Procellariiformes, the presence of ingested plastic in the remaining surface feeders was variable and was limited to four gull species. The highest frequency of occurrence was in the Herring Gull. The prevalence of plastic ingested by gulls is likely to depend on their foraging habitats. Both Herring Gulls, and Lesser Black-backed Gulls (*L. fuscus*), are known to forage on terrestrial, anthropogenic resources, specifically landfill sites. Species that regurgitate the hard parts of their diet are less at risk than species that cannot, as plastic does not accumulate as much within their gastro-intestinal tract compared with other species (Ryan 1987). However, we need to understand the proportion of ingested plastic that is expelled in pellets, as it is likely that some will remain in the birds' gastro-intestinal tract (Ryan 1987; Ryan & Fraser 1988). Nonetheless, monitoring plastic ingestion in these species can still be useful to investigate relative spatiotemporal trends.

Within Scotland, we have no information of potential plastic ingestion in the loons or sea-ducks, skuas or terns. In the Faroe Islands, plastic has been found in Great Skua (*Stercorarius skua*) pellets, 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 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). Therefore, collecting tern pellets may also be an option for monitoring plastic ingestion in this group.

Aside from the Sooty and Great Shearwater, and the Iceland Gull (*Larus glaucoides*), we found no studies that had looked for plastic ingestion in the other migrant seabird species regularly occurring within Scottish waters. For these species, it may be more appropriate to investigate interactions with marine plastic in their breeding grounds. However, sampling all species in both their breeding and non-breeding areas may help determine where they are most likely to encounter marine plastic, if large enough sample sizes can be collected. 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.

The spatial and temporal coverage of plastic ingestion studies of seabirds in Scotland, and the sample sizes involved, were 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 Scotland for the Northern Fulmar and other species.

There was temporal and spatial bias in where samples were collected based largely on where specific studies have occurred. For example, with Northern Fulmars collected in Orkney and Shetland as part of the the North Sea Northern Fulmar monitoring project, and pellets collected across southwestern Scotland as part of a project on Herring Gull resource use. In the majority of cases, studies covered single species and study locations for short periods of one or two years (74%). Furthermore, the resolution of the location recorded in some studies was very broad, meaning that it was difficult to determine exactly where samples were collected. Therefore, there is a definite need for current information to be collected given that the majority of data within this synthesis was obtained prior to 2000, highlighting that we know very little about the current frequency of occurrence of plastic ingested by most seabirds across Scotland. Given the importance of seabirds in Scotland, and the number of researchers and organisations that do work at seabird colonies across the country, a coordinated approach, particularly around widely distributed species, would ensure the greatest value of systematic standardised sampling.

"In the majority of cases, studies covered single species and study locations for short periods of one or two years (74%)."

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 Scotland. 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.

The majority of studies within this synthesis did not specify the minimum size of the plastic recorded, and given that the focus of most studies was not specifically for ingested debris, it is likely that they 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 Scotland. 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 = 50). Outside of Scotland, incorporation of plastic into nests has also been reported in Northern Gannets, Black-legged Kittiwakes (*Rissa tridactyla*) (Hartwig *et al*. 2007), cormorants (Podolsky & Kress 1989) and gulls (Witteveen *et al*. 2016). Furthermore, in Scotland there is anecdotal evidence that Northern Gannets incorporate plastic into nests (Nelson 2002). 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 Scotland, 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 Scotland.** 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 Scotland, 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 and 3), 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, with the exception of the Northern Fulmar, 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 (Lavers *et al*. 2014) or pellets (Acampora *et al.* 2017a).** 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** (Acampora *et al*. 2017b). As the European Herring Gull and Great Cormorant are both widely distributed across Scotland, the non-invasive collection of pellets may be useful in monitoring trends in plastic ingestion from coastal and inland locations across this region.

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 Scotland. 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.

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