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Seabirds and marine plastic debris in the northeastern Atlantic: A synthesis and recommendations for monitoring and research☆

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A B S T R A C T

Marine plastic pollution is an increasing, and global, environmental issue. Numerous marine species are affected by plastic debris through entanglement, nest incorporation, and ingestion, which can lead to lethal and sub-lethal impacts. However, in the northeastern Atlantic Ocean, an area of international importance for seabirds, there has been little effort to date to assess information from studies of wildlife and plastic 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 69 seabird species that commonly occur in the northeastern Atlantic, 25 had evidence of ingesting plastic. However, data on plastic ingestion was available for only 49% of all species, with 74% of investigated species recorded ingesting plastic. We found only three published studies on nest incorporation, for the Northern Gannet (*Morus bassanus*) and Black-legged Kittiwake (*Rissa tridactyla*). For many species, sample sizes were small or not reported, and only 39% of studies were from the 21st century, whilst information from multiple countries and years was only available for 11 species. This indicates that we actually know very little about the current prevalence of plastic ingestion and nest incorporation for many species, several of them globally threatened. Furthermore, in the majority of studies, the metrics reported were inadequate to carry out robust comparisons among locations and species or perform meta-analyses. We recommend multi-jurisdictional collaboration to obtain a more comprehensive and current understanding of how marine plastic is affecting seabirds in the northeastern Atlantic Ocean.

1. Introduction

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 the oceans annually (Andrady and Neal, 2009; Thompson et al., 2009; Jambeck et al., 2015). This includes industrial plastic, such as virgin pellets used in manufacturing, and user plastic from consumer and commercial sources (Andrady, 2011). This 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) Annex V 1978 with the latest amendment in 2012; the Convention on Biological Diversity (CBD, COP 11 Decision XI/18); and the EU Marine Strategy Framework Directive (MSFD; 2008/56/EC). 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 Clean Seas Initiative, and also requires robust quantitative data at the national and international level to measure success (Butchart

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et al., 2016). To that end, an understanding of the extent and nature of plastics' impacts on marine life is essential.

Plastic pollution is a major threat to marine biodiversity (Gray, 1997). The desirable properties of plastics (low-cost, light-weight, and durable) are those that contribute to it being problematic in the marine environment. 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; Hopewell et al., 2009). Plastic density varies depending on its polymer type and it can therefore be found throughout the water column from the seabed to the surface (Li et al., 2016), increasing the number of species that may come into contact with it (Courtene-Jones et al., 2017; Tavares et al., 2017). Furthermore, it does not biodegrade, but instead breaks up into smaller fragments that remain in the environment and threaten organisms (Day et al., 1985; Ter Halle et al., 2016). Plastic pollution affects marine species in two main ways, 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; Phillips et al., 2010; Gregory, 2013). 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 concern, where individuals either inadvertently consume plastic while foraging on other prey items, or purposefully ingest it by mistaking it for food (Day et al., 1985; Laist, 1997; Cadée, 2002). 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 (Holmes et al., 2012; Tanaka et al., 2013), which may interfere with an individual's physiology and therefore have negative consequences on reproduction and survival (Teuten et al., 2009; Herzke et al., 2016; Lavers and Bond, 2016).

Several reviews have documented species' ingestion of and entanglement with marine debris (Laist, 1987; Gall and Thompson, 2015; Kühn et al., 2015). Recent estimates indicate that over 690 marine species have been affected by marine debris, including cetaceans, pinnipeds, seabirds, turtles, fish, and crustaceans, with the majority involving plastic (Gall and 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 (for example Day et al., 1985; Moser and Lee, 1992; Spear et al., 1995; Avery-Gomm et al., 2013; Codina-García et al., 2013; Provencher et al., 2014). Seabirds are particularly at risk from marine plastic pollution, especially plastic ingestion with 99% of seabird species, and 95% of individuals, predicted to have ingested plastic by 2050 (Wilcox et al., 2015). 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 is vital to highlight further knowledge gaps, direct the focus of future monitoring, and make linkages across jurisdictions for coordinated efforts.

The northeastern Atlantic Ocean is an important region for seabirds, supporting internationally important numbers, and incorporating over 350 Important Bird and Biodiversity Area (IBAs) in marine habitats (Birdlife, 2017). The presence of plastic, particularly micro-plastic (<5 mm), is also widespread in the region with a mean of 2.46 particles m^{-3} in sub-surface waters (Lusher et al., 2014), and 0.45–1.56 items/ha on the seabed (Galgani et al., 2000). Within this region, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) 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 (OSPAR, 2010). Importantly, the OSPAR Convention 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. The Northern Fulmar (*Fulmarus glacialis*) is the EcoQO indicator species for monitoring plastic debris in the North Sea (van Franeker and Meijboom, 2002; van Franeker et al., 2011). As a result, plastic ingestion by Northern Fulmars in the northeastern Atlantic has been studied in some countries since the 1980s, with widespread sampling efforts in multiple countries in the region since 2002 via the North Sea Northern Fulmar project. This 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 spatio-temporal scale of plastic ingestion and entanglement of seabirds within the northeastern Atlantic 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 this region.

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, and to improve our understanding of how marine plastic affects seabirds in the northeastern Atlantic Ocean.

2. Methods

We focused on birds sampled within the northeastern Atlantic Ocean, and included the following non-continental European countries and autonomous territories: Denmark, England, the Faroe Islands, Finland, Greenland, Iceland, Republic of Ireland, Northern Ireland, Norway (including Bjørnøya), Russia, Scotland, Svalbard, Sweden, and Wales. We excluded eastern Russia to limit the synthesis to North Atlantic seabird species, including only studies from the western coast up to and including Novaya Zemlya and Franz Josef Land (Fig. 1), and also excluded the UK's Crown Dependencies (and the Balliwicks of Jersey and Guernsey). We also excluded Canada for which a similar analysis already exists (Provencher et al., 2015).

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 the listed northeastern Atlantic countries, 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

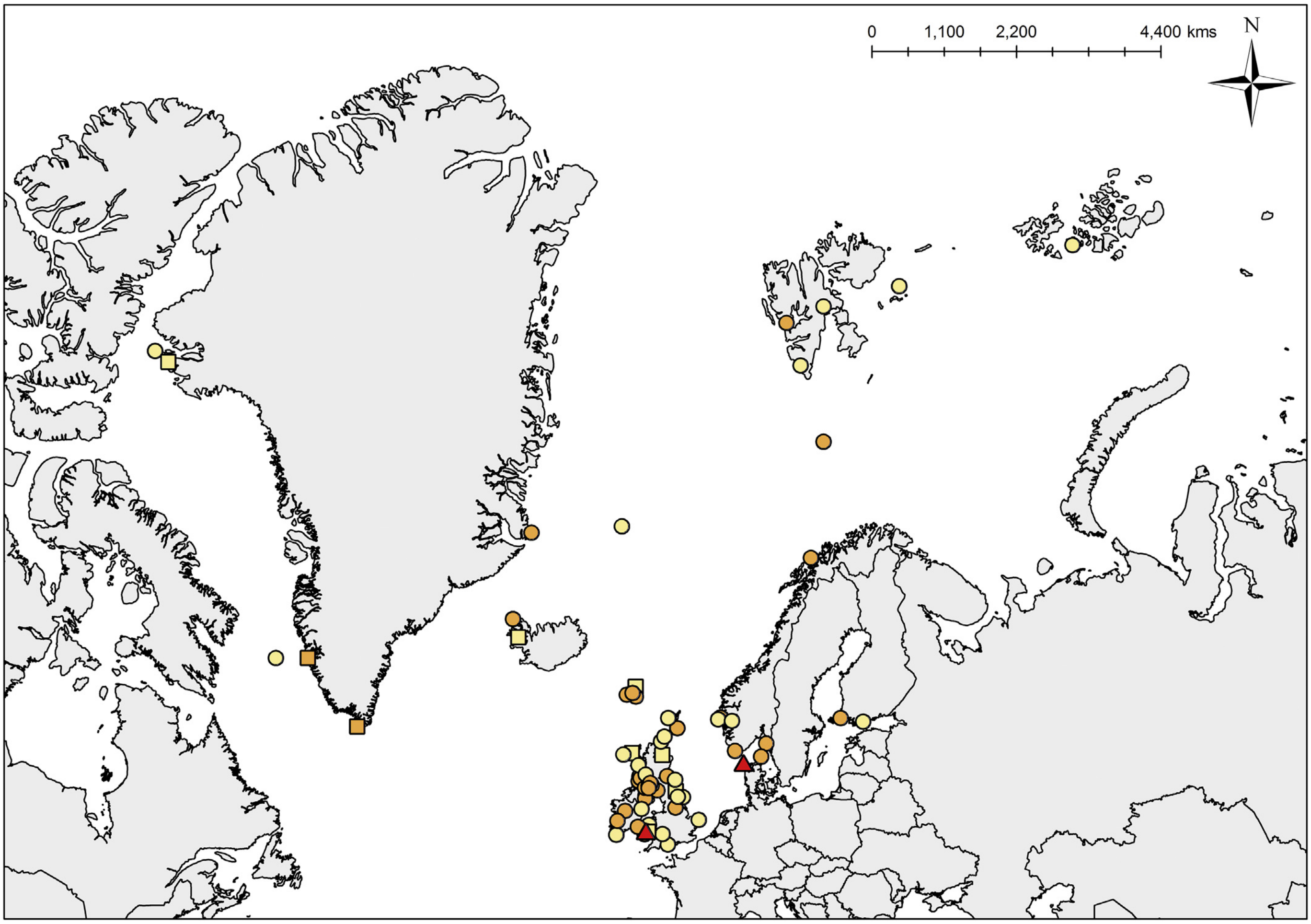

Fig. 1. Spatial distribution of documented seabird interactions with marine plastic in the northeastern Atlantic. The red triangles show nest incorporation. Squares show negative results for plastic ingestion and circles show the positive incidence of plastic ingestion. For plastic ingestion, dark orange shapes refer to studies that collected samples since 2000 and light orange prior to 2000. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(del Hoyo and Collar, 2014). The conservation status of included seabird species was obtained from the IUCN Red List (IUCN, 2016).

To obtain information on plastic ingestion and nest incorporation of plastic by seabirds within the northeastern Atlantic we carried out an extensive review of the peer-reviewed and grey 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 and Thompson, 2015; Kühn et al., 2015) and the references of relevant papers were also examined. We also contacted all country representatives of the Conservation of Arctic Flora and Fauna Circumpolar Seabird Expert Group (CAFF CBird) to identify potential grey literature and additional contacts for researchers working on plastic in seabirds in the defined northeastern Atlantic region. We 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 and Meijboom (2002), presented as the number of birds (or pellets/regurgitates) within a sample that contained evidence of plastic, including those that were examined but were not found to contain plastic (van Franeker and Meijboom, 2002). For nest incorporation, in the seabird species that construct surface nests, we recorded the frequency of occurrence as the number of nests within a sample that contained plastic. We also recorded whether studies reported 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.

3. Results

We identified 69 seabird species that commonly occur as breeding species or migrants within the northeastern Atlantic (Table 1). A total of 59 studies reported on plastic interactions by these species, 56 referring to plastic ingestion and three to nest incorporation. Within these studies, 34 species (49%) had been examined for plastic ingestion (Table 1). For nine species, there was no evidence of plastic ingestion. Therefore, of these 34 seabird species for which data were available, plastic ingestion was recorded in 25 (74%), however five of these species only had single

Table 1
Species categorised by the spatial and temporal ingested plastic data that are available within the northeastern Atlantic.

Species with ingested plastic data reported from multiple countries and years	Species with ingested plastic data reported from multiple countries or years	Species with single reports of ingested plastic	Species currently with no reports of ingested plastic
Northern Fulmar (*Fulmarus glacialis*)	Manx Shearwater (*Puffinus puffinus*)	Red-throated Loon (*Gavia stellata*)	Arctic Loon (*Gavia arctica*)
Great Cormorant (*Phalacrocorax carbo*)	European Storm-petrel (*Hydrobates pelagicus*)	Common Loon (*Gavia immer*)[a]	Yellow-billed Loon (*Gavia adamsii*)
Common Eider (*Somateria mollissima*)[a]	Northern Gannet (*Morus bassanus*)	Great Shearwater (*Ardenna gravis*)[b]	Zino's Petrel (*Pterodroma madeira*)[b]
Black-headed Gull (*Larus ridibundus*)	European Shag (*Phalacrocorax aristotelis*)	Sooty Shearwater (*Ardenna grisea*)[b]	Cape Verde Petrel (*Pterodroma feae*)[b]
Lesser Black-backed Gull (*Larus fuscus*)	King Eider (*Somateria spectabilis*)[a]	Leach's Storm-petrel (*Hydrobates leucorhous*)	Cory's Shearwater (*Calonectris borealis*)[b,c]
European Herring Gull (*Larus argentatus*)	Great Skua (*Catharacta skua*)	Pomarine Jaeger (*Stercorarius pomarinus*)[a]	Balearic Shearwater (*Puffinus mauretanicus*)[b]
Black-legged Kittiwake (*Rissa tridactyla*)	Mew Gull (*Larus canus*)	Arctic Jaeger (*Stercorarius parasiticus*)	Wilson's Storm-petrel (*Oceanites oceanicus*)[b]
Thick-billed Murre (*Uria lomvia*)	Great Black-backed Gull (*Larus marinus*)	Long-tailed Jaeger (*Stercorarius longicaudus*)[a]	Steller's Eider (*Polysticta stelleri*)
Black Guillemot (*Cepphus grylle*)	Iceland Gull (*Larus glaucoides*)	Sabine's Gull (*Xema sabini*)[a]	Harlequin Duck (*Histrionicus histrionicus*)
Little Auk (*Alle alle*)	Glaucous Gull (*Larus hyperboreus*)[a]	Arctic Tern (*Sterna paradisaea*)[a]	Long-tailed Duck (*Clangula hyemalis*)
Atlantic Puffin (*Fratercula arctica*)	Ivory Gull (*Pagophila eburnea*)[a]		Common Scoter (*Melanitta nigra*)
	Common Murre (*Uria aalge*)		Surf Scoter (*Melanitta perspicillata*)[b]
	Razorbill (*Alca torda*)		Velvet Scoter (*Melanitta fusca*)
			Red-breasted Merganser (*Mergus serrator*)
			Common Goldeneye (*Bucephala clangula*)
			Red-necked Phalarope (*Phalaropus lobatus*)
			Red Phalarope (*Phalaropus fulicarius*)
			Mediterranean Gull (*Larus melanocephalus*)
			Laughing Gull (*Larus atricilla*)[b]
			Little Gull (*Hydrocoloeus minutus*)
			Ross's Gull (*Rhodostethia rosea*)
			Bonaparte's Gull (*Larus philadelphia*)[b]
			Ring-billed Gull (*Larus delawarensis*)[b]
			Yellow-legged Gull (*Larus michahellis*)[b]
			Caspian Gull (*Larus cachinnans*)[b]
			Thayer's Gull (*Larus thayeri*)[b]
			Common Gull-billed Tern (*Gelochelidon nilotica*)[b]
			Caspian Tern (*Hydroprogne caspia*)[b]
			Sandwich Tern (*Thalasseus sandvicensis*)
			Roseate Tern (*Sterna dougallii*)
			Common Tern (*Sterna hirundo*)
			Little Tern (*Sternula albifrons*)
			Whiskered Tern (*Chlidonias hybrida*)[b]
			Black Tern (*Chlidonias niger*)
			White-winged Tern (*Chlidonias leucopterus*)[b]

[a] Species where studies looked for plastic (or noted it in other species within the same study) but no evidence of plastic ingestion was observed.
[b] Indicates migrant species.
[c] Indicates species occurring in low numbers but where plastic ingestion is studied outside the northeastern Atlantic.

instances, involving small sample sizes (range: 1–19). Within the northeastern Atlantic, this means that 35 seabird species (51%) have not been examined for plastic ingestion. Outside of this region, plastic ingestion has been documented in 12 of these 35 species (34%), as well as in five of the nine species where no evidence of plastic ingestion was recorded, but which had been examined. Reports of plastic ingestion from multiple countries and years existed for just 11 of the 34 examined species (32%). Of the nest building, surface-nesting seabirds (n = 50), data on nest incorporation of plastic were documented for just two species at two locations, the Northern Gannet (*Morus bassanus*) in Wales and Black-legged Kittiwake (*Rissa tridactyla*) in Denmark. Twelve of the species commonly recorded in the region are listed as threatened or near-threatened on the IUCN Red List (IUCN, 2016), however for seven of these we have no information on plastic ingestion or nest incorporation (Table 2; see Supplementary material in Table S1 for studies on species listed as Least Concern).

Of the species with recorded incidences of plastic ingestion, five species had frequency of occurrence >50% (Table 3). However, with the exception of the Northern Fulmar these values refer to single studies and to sample sizes <40 (Table 3), with 100% frequency of occurrence recorded in Great Shearwater (*Ardenna gravis*), Sooty Shearwater (*Ardenna grisea*) and Arctic Jaeger (*Stercorarius parasiticus*) all referring to single individuals. Of the nine species examined for plastic ingestion with no evidence detected, only the Common Eider (*Somateria mollissima*) had large sample sizes (n > 400), across multiple locations and years, to suggest that they may be at low risk from plastic ingestion, which is similar to findings in other regions (Provencher et al., 2014). However, a recent study in the German Wadden Sea found that up to 40% of Common Eiders faeces samples contained micro-plastic fibres (P Schwemmer, pers. comm.), which highlights the challenges in comparing studies using different approaches to quantifying animals' plastic ingestion.

For this synthesis, we obtained data from 46 published studies, five unpublished datasets and five datasets that were published in Provencher et al. (2014). Of the published studies, only 18 directly investigated plastic ingestion or nest incorporation, with 27

Table 2
Publications and unpublished data on plastic and seabirds in the northeastern Atlantic for species listed as threatened or near threatened on the IUCN Red List (IUCN, 2016).

Species	Country	Sampling year	Reported frequency of occurrence % (*n*)	Interaction type	Source
Near-threatened					
Yellow-billed Loon	–	–	–	–	–
Fea's Petrel	–	–	–	–	–
Sooty Shearwater	Scotland	1972	100 (1)	Ingested	Bourne, 1976
Common Eider	Greenland	1999–2002	0 (241)	Ingested	Jamieson et al., 2006
	Greenland	2012	0 (135)	Ingested	Provencher et al., 2014
	Svalbard	1982	0 (1)	Ingested	Mehlum and Giertz, 1984
	Svalbard	1984	0 (20)	Ingested	Lydersen et al., 1989
	Russia	1991–1993	0 (5)	Ingested	Weslawski et al., 1994
Ivory Gull	Svalbard	1982	0 (6)	Ingested	Mehlum and Giertz, 1984
	Svalbard	1984	0 (4)	Ingested	Gjertz et al., 1985
Razorbill	England[a]	1983	0 (394)	Ingested	Blake, 1984
	Ireland[a]	2014–2016	0 (15)	Ingested	Acampora et al., 2016
	Scotland	1983	0 (109)	Ingested	Blake, 1984
	Wales	1996	1 (81)	Ingested	Weir et al., 1997
Vulnerable					
Steller's Eider	–	–	–	–	–
Long-tailed Duck	–	–	–	–	–
Velvet Scoter	–	–	–	–	–
Atlantic Puffin	England	1983	23 (30)	Ingested	Blake, 1984
	England/Scotland[a]	1973–2007	8 (393)	Ingested	Harris and Wanless, 2011
	Faroe Islands	1987–1988	0 (36)	Ingested	Falk et al., 1992
	Ireland[a]	2014–2016	33 (3)	Ingested	Acampora et al., 2016
	Norway	1970	22 (9)	Ingested	Berland, 1971
	Scotland[a]	1969–1971	21 (73)	Ingested	Parslow and Jefferies, 1972
Endangered					
Zino's Petrel	–	–	–	–	–
Critically Endangered					
Balearic Shearwater	–	–	–	–	–

[a] Indicates plastic interaction investigated for multiple locations within that country. – No data available. Studies relating to species listed as Least Concern can be found in the Supplemental material (Table S1).

investigating diet, three focusing on seabird mortality events and one on seabird parasites. For plastic ingestion, of the standardised metric recommendations outlined by Provencher et al. (2017), only one study met them all (Trevail et al., 2015). All published studies referring to plastic ingestion recorded location, year and sampling method, with the majority also including the sample size (98%) and frequency of occurrence (83%). Studies documented the mass of ingested plastic, including measures of variance, less frequently, even in those specifically investigating plastic ingestion (Table 4). For 18 species, we have limited data on the number and/or mass of ingested plastic (Table 5). The mass of ingested plastic fragments is the most biologically relevant metric (van Franeker and Meijboom, 2002), however, mass was recorded in multiple studies only for the Northern Fulmar, whilst just four studies reported the mean mass of ingested plastic in other species (Furness, 1995; Acampora et al., 2016, 2017a; Hammer et al., 2016). Furthermore, very few studies reported the size (13%) or colour (7%) of ingested plastic (Table 5).

For nest incorporation, all three studies reported frequency of occurrence, however only the studies of Black-legged Kittiwake recorded the number of nests sampled (Hartwig et al., 2007). The other metrics reported were the mean mass, and standard deviation, of plastic incorporated into a sample of six Northern Gannet nests (Votier et al., 2011).

The information summarised in Table 3 highlights the spatial and temporal coverage of studies that have documented plastic ingestion and nest incorporation in seabirds across the northeastern Atlantic (Fig. 1). Firstly, focusing on plastic ingestion, for 16 species (47%), our knowledge comes from samples collected from single countries. The spatial representation within this synthesis was also disproportionate with the highest coverage in Scotland (18 studies), and the lowest in Sweden and western Russia (one study each) as well as Finland, Iceland and Northern Ireland (two studies each). Temporally, the studies sampled seabirds over multiple years between 1969 and 2016. For nest incorporation, only two countries were represented, and both just for two years: in 1996 and 1997 for the Northern Gannet in Wales and in 1992 and 2005 for the Black-legged Kittiwake in Denmark. From all 56 studies included in this synthesis, the majority of data (61%) were collected prior to the 21st century, implying that the collective knowledge of current ingestion levels in certain species and locations is poor. All samples collected from Wales (four studies) and western Russia (one study) were prior to 2000, as were all data for 12 species (35%). Furthermore, for 11 species (32%) the only samples collected after 2000 were from a single study, all with sample sizes < 25 (Acampora et al., 2016).

4. Discussion

We found that active interactions with marine plastic debris were widespread across the northeastern Atlantic region. Of the 69 seabird species commonly found across the region, only 34 had been investigated for plastic ingestion (including studies where plastic was not the focus of the research). Of these 34 species, 25 had evidence of plastic ingestion, with a further nine species examined but with no evidence recorded. However, information on plastic ingestion from multiple species and locations was available for just 11 species. For 35 species, there was no empirical evidence of how, or even if, they interact with marine plastic debris in the region. Only three published studies provided quantified information about nest incorporation (Clemens and Hartwig, 1993; Hartwig et al., 2007; Votier et al., 2011). 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, especially so for nest incorporation. This synthesis reveals several key knowledge gaps, which we highlight below, along with recommendations for how to target future

Table 3
Summary information for seabird species where plastic ingestion or nest incorporation has been investigated in the northeastern Atlantic.

Species	Studies	Countries	Number of sample years			Year Range	Sample Size			Frequency of occurrence (%)			Interaction
			Total	Range[b]	Median		Total	Range	Median	Mean ± SD	Range	Median	
Red-throated Loon	1	1	1	1	–	1996	19	–	–	5.0	–	–	Ingestion
Common Loon	1	1	1	1	–	1996	3	–	–	0.0	–	–	Ingestion
Northern Fulmar	18	10	26	1–11	1	1972–2016	2247	2–699	35	65.8 ± 34.5	7–100	81	Ingestion
Great Shearwater	1	1	1	1	–	1972	1	–	–	100.0	–	–	Ingestion
Sooty Shearwater	1	1	1	1	–	1972	1	–	–	100.0	–	–	Ingestion
Manx Shearwater[a]	3	3	7	1–5	1	1983–2016	>13	3–10	7	31.5 ± 2.1	30–33	31.5	Ingestion
European Storm-petrel[a]	2	2	2	1	–	1983–1985	>21	–	–	>0.0	–	–	Ingestion
Leach's Storm-petrel	1	1	1	1	–	1983	17	–	–	59	–	–	Ingestion
Northern Gannet	2	3	6	1–5	3	1972–2016	28	13–15	14	17.5 ± 13.4	8–27	17.5	Ingestion
Northern Gannet	1	1	2	2	–	1996–1997	–	–	–	80.0	–	–	Nest incorporation
Great Cormorant[a]	3	3	7	2–3	3	1985–2015	921	37–792	92	3.0	–	–	Ingestion
European Shag	2	2	6	1–5	3	1972–2016	12	2–10	6	5.0 ± 7.1	0–10	5	Ingestion
Common Eider	5	3	10	1–4	1	1982–2012	402	1–241	20	0.0	0	0	Ingestion
King Eider	1	1	3	3	–	2000–2002	41	–	–	0.0	–	–	Ingestion
Pomarine Jaeger	1	1	1	1	–	1984	2	–	–	0.0	–	–	Ingestion
Arctic Jaeger	1	1	5	5	–	2012–2016	1	–	–	100	–	–	Ingestion
Long-tailed Jaeger	1	1	1	1	–	1982	1	–	–	0.0	–	–	Ingestion
Great Skua	2	2	3	1–2	2	2008–2013	515	165–350	258	16.0 ± 19.8	2–30	16	Ingestion
Sabine's Gull	1	1	5	5	–	2012–2016	1	–	–	0.0	–	–	Ingestion
Black-headed Gull[a]	2	3	7	2–5	4	1976–2016	43	9–34	22	22.0	–	–	Ingestion
Mew Gull	1	1	3	3	–	1980–1982	259	–	–	1.0	–	–	Ingestion
Lesser Black-backed Gull[a]	3	3	16	2–9	7	1981–2016	270	2–181	43	<100.0	–	–	Ingestion
European Herring Gull[a]	8	4	10	1–5	1	1971–2016	6107	12–3483	220	22.3 ± 16.3	5–58	19.5	Ingestion
Iceland Gull	2	2	6	1–5	3	1993–2016	14	1–13	7	4.0 ± 5.7	0–8	4	Ingestion
Glaucous Gull	3	2	5	1–3	1	1982–1993	25	2–18	5	0.0	0	0	Ingestion
Great Black-backed Gull	2	1	6	1–5	3	1986–2016	56	4–52	28	13.5 ± 16.3	2–25	13.5	Ingestion
Black-legged Kittiwake[a]	7	5	11	1–5	1	1972–2016	131	4–28	19	11.3 ± 19.6	0–50	2.5	Ingestion
Black-legged Kittiwake	2	1	2	2	–	1992–2005	777	311–466	–	48.0 ± 12.7	39–57	48	Nest incorporation
Ivory Gull	2	1	2	1	–	1982–1984	10	4–6	5	0.0	0	0	Ingestion
Arctic Tern	1	1	3	3	–	1991–1993	5	–	–	0.0	–	–	Ingestion
Common Murre	4	4	7	1–5	1	1983–2016	648	25–343	140	3.5 ± 5.7	0–12	1	Ingestion
Thick-billed Murre	7	3	9	1–3	1	1982–2006	293	1–202	15	4.3 ± 9.0	0–24	0	Ingestion
Razorbill	3	4	7	1–5	1	1983–2016	599	15–394	95	0.3 ± 0.5	0–1	0	Ingestion
Black Guillemot[a]	7	5	16	1–6	2	1975–2016	201	1–96	8	>0.0	–	0	Ingestion
Little Auk	9	4	13	1–3	1	1982–2014	506	3–184	44	20.6 ± 34.0	0–100	0	Ingestion
Atlantic Puffin	7	6	43	1–34	2	1969–2016	558	3–393	30	17.8 ± 11.8	0–33	21.5	Ingestion

[a] One or more studies did not provide information on sample size or frequency of occurrence. See Table 2 and supplementary table 1 for details.
[b] Number or range of years studies collected samples.

Table 4
Standardised metric recommendations met by the 46 published studies reviewed in the northeastern Atlantic for plastic ingestion. "Plastic studies" were those where plastic ingestion was the focus.

Standardised metric recommendations[a]	Percentage of studies which met the recommendations[b]	
	All 46 studies	15 plastic studies
Location	100%	100%
Year	100%	100%
Sampling method	100%	100%
Sample size	98%	93%
Frequency occurrence[c]	83%	93%
Mean mass[d]	17%	47%
Mass SD/SE[e]	13%	40%
Mass range	9%	27%
Metrics by plastic type	7%	20%
Median mass	2%	7%

[a] Taken from Provencher et al. (2017).
[b] Accumulative percentage therefore includes published studies that documented the recommendation in that row as well as all the recommendations above.
[c] One study also included mass range.
[d] One study also included mass range and another study median mass.
[e] One study also included metrics by plastic type.

monitoring and research to obtain a better understanding on the impact of marine plastic and seabirds in the northeastern Atlantic Ocean.

4.1. Plastic ingestion

For species where multiple samples were available, the highest prevalence of plastic ingestion occurred in the Procellariiformes, specifically the Northern Fulmar and Leach's Storm-petrel (*Hydrobates leucorhous*). This is consistent with other studies, 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; Acampora et al., 2016). 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 (Robards et al., 1995; Spear et al., 1995; Avery-Gomm et al., 2013; Bond et al., 2014). Four procellariiform species within the region are listed as near or globally threatened on the IUCN Red List, including the Balearic shearwater (*Puffinus mauretanicus*), which is listed as Critically Endangered (IUCN, 2016). Within the northeastern Atlantic, very limited, or no, data were available for these species, which might be expected given that they are relatively uncommon migrants to the region.

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; Eriksen 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

Table 5
Summary information for species where studies reported metrics on the number, mass, size and colour of ingested plastic by northeastern Atlantic seabirds.

Species	Number of studies	Sample size	Mean number of particles ± SD	Mean mass of particles (g) ± SD	Size of particles	Colour of particles
Arctic Jaeger[a]	1	1	30.00	0.0460	–	–
Atlantic Puffin[a]	1	3	1.33	0.0077	–	–
Black Guillemot[b]	1	96	NA	NA	<1 mm up to 6 mm	–
Black-headed Gull[a]	1	9	1.33	0.0063	–	–
Black-legged Kittiwake[a]	1	4	9.00	0.0200	–	–
Thick-billed Murre[c]	1	202	0.09	NA	<10 mm	–
Common Murre[a]	1	25	0.12	0.0001	–	–
European Shag[a]	1	10	0.20	0.0001	–	–
Great Black-backed Gull[a]	1	4	2.00	0.0069	–	–
Great Cormorant[d]	1	92	0.04	0.0002	–	–
Great Skua[e]	1	165	0.90	0.0066	–	Majority white/yellow (68%)
Herring Gull[a]	1	13	1.30	0.0011	–	–
Iceland Gull[f]	1	13	1.00	NA	–	–
Leach's Petrel[g]	1	17	2.90	0.0352	–	–
Lesser Black-backed Gull[a]	1	2	1.00	0.4324	–	–
Little Auk[h]	1	44	9.49	NA	Median length 0.77	Preference for light particles
Manx Shearwater[a,g]	2	13	0.37 ± 0.05	0.0128 ± 0.0175	–	–
Northern Fulmar[i]	8	1518/1500	20.75 ± 20.86	0.3332 ± 0.3255	Mean approx. 5 mm[j]	–
Northern Gannet[a]	1	15	0.46	0.0225	One particle = 50 × 1 mm[k]	–

[a] Acampora et al., 2016.
[b] Ewins, 1990.
[c] Falk and Durinck, 1993.
[d] Acampora et al., 2017a,b.
[e] Hammer et al., 2016.
[f] Weir et al., 1995.
[g] Furness, 1995.
[h] Amélineau et al., 2016.
[i] A different combination of eight studies provided metrics on the number (n = 1518) and mass (n = 1500) of ingested plastic.
[j] Camphuysen and Van Franeker, 1997; Weslawski et al., 1994.
[k] Parslow et al., 1973.

ingestion by benthic foraging seabirds. As documented elsewhere, we found a low prevalence of plastic ingestion in loons and sea ducks (Avery-Gomm et al., 2013; Provencher et al., 2014), auks (Laist, 1987; Robards et al., 1997; Provencher et al., 2010; Acampora et al., 2016), and cormorants (Avery-Gomm et al., 2013). There are very few recorded incidences of plastic ingestion in cormorant species, with entanglement and nest incorporation of plastic thought to be a greater threat to these species (Day et al., 1985; Podolsky and Kress, 1989). Within this synthesis the sample size was very low for the European Shag (*Phalacrocorax aristotelis;* n = 12 individuals from two studies), further indicating that few studies have examined cormorant species for plastic ingestion.

Among auks, a possible exception to being at low risk to plastic ingestion is the Little Auk (*Alle alle*), where the prevalence of plastic ingestion was very variable, even within a country. Although Little Auks also forage through diving, they predominantly feed on smaller prey items, particularly copepods, and therefore may be more likely to mistake micro-plastic for prey (Amélineau et al., 2016). Although overall the median prevalence was low, in one study that specifically quantified for micro-plastic (items < 5 mm) ingested plastic was found in all individuals sampled (Amélineau et al., 2016).

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 seabirds. Therefore, when examining seabirds it is important to report the minimum size threshold of plastic detected, or at least a recognised 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 important in advancing our understanding of whether seabirds acquire plastic indirectly, through secondary ingestion of contaminated marine invertebrates (Van Cauwenberghe and Janssen, 2014) and vertebrates such as fish (Boerger et al., 2010; Foekema et al., 2013).

Excluding the Procellariiformes, the frequency of occurrence of ingested plastic in the remaining surface feeders (skuas, gulls, terns, and phalaropes) was variable, as was the spatial and temporal coverage, and sample sizes, of the studies included. Gulls that breed in the northern parts of the region, as well as those in the Baltic Sea, were particularly under-represented in this synthesis. The prevalence of plastic ingested by gulls is likely to depend on their foraging habitats. The higher frequency of occurrence of plastics recorded in the Black-headed Gull (*Larus ridibundus*), Lesser Black-backed Gull (*L. fuscus*), European Herring Gull (*L. argentatus*) and Great Black-backed Gull (*L. marinus*) may partially be attributed to these species foraging on terrestrial, anthropogenic resources, specifically landfill sites (Kubetzki and Garthe, 2003; Cook et al., 2008; Lenzi et al., 2016). The European Herring Gull had the highest frequency of ingested plastic, and was also the most studied species in terms of coverage and sample sizes, largely through sampling regurgitated pellets. Species that regurgitate the hard parts of their diet 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 and 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. As the European Herring Gull is widely distributed across the northeastern Atlantic, the non-invasive collection of pellets may be useful in monitoring trends in plastic ingestion from coastal and inland locations across this region.

Although the skua species do forage in surface waters, many individuals are partial kleptoparasites, and the Great Skua (*Catharacta skua*) also depredates other seabird species (Phillips et al., 1997). Plastic ingestion in Great Skuas is therefore likely a combination of secondary ingestion via the species they depredate and primary ingestion (Ryan and Fraser, 1988; Hammer et al., 2016). In the Faroe Islands, the highest frequency of occurrence of plastic in pellets were from Great Skuas that had depredated Northern Fulmars (Hammer et al., 2016). As only a couple of individuals of the other three skua species have been examined within the northeastern Atlantic, we know very little about their interactions with plastic. However, a single Arctic Jaeger examined in Ireland (Acampora et al., 2016) did contain ingested plastic, whilst another single Arctic Jaeger was found to contain ingested plastic in the northwestern Atlantic (from a sample size of five individuals) (Moser and Lee, 1992). This suggests that this species may be susceptible to plastic ingestion, whether directly or through secondary ingestion.

Being surface plungers, targeting individual prey or schools of fish (Uttley et al., 1989; Safina et al., 1990), the frequency of occurrence of ingested plastic in terns is also thought to be low, although for many species in this group we have very little information (Day et al., 1985; Moser and Lee, 1992; Provencher et al., 2015). Within this synthesis information was available for only one species, the Arctic Tern (*Sterna paradisaea*) from one study in western Russia (Weslawski et al., 1994). Elsewhere, plastic ingestion has been recorded in the Common Tern (*S. hirundo*) and Black Tern (*Chlidonias niger*), including within regurgitated pellets, although again sample sizes were small (Hays and Cormons, 1974; Braune and Gaskin, 1982; Moser and 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, we found no studies that had looked for plastic ingestion in the other migrant seabird species regularly occurring within the northeastern Atlantic region. For migrants, it may be more appropriate to investigate interactions with marine plastic in their breeding grounds. However, sampling 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 seabirds may be differentially vulnerable by marine plastic pollution throughout the annual cycle, and therefore have potentially different effects on different life history traits.

With the exception of the Northern Fulmar, the spatial and temporal coverage of plastic ingestion studies of seabirds in the northeastern Atlantic, and the sample sizes involved, were low. The good representation for the Northern Fulmar is largely due to the North Sea Northern Fulmar monitoring project (OSPAR, 2008; van Franeker et al., 2011; van Franeker and 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 and The SNS Fulmar Study Group, 2013), Svalbard (Trevail et al., 2015) and Iceland (Kühn and 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 increasing latitude, and separate processes occurring in the Atlantic and Pacific basins (Provencher et al., 2017).

There is a strong spatial bias in where studies have occurred to date, with Finland, Iceland, Sweden and western Russia being particularly under-represented (Fig. 1). These are therefore high priority areas for future monitoring to determine how seabirds interact with marine plastic, and how this compares to other locations within the region. There are also biases in the temporal coverage of studies, with the majority conducted before 2000. For a number of species, the sample sizes examined after this date are small and from a single study (Acampora et al., 2016), highlighting that we know very little about the current frequency of occurrence of plastic ingested by most seabirds in the northeastern Atlantic. Given the multi-jurisdictional nature of the region, a coordinated approach among scientists and management agencies, particularly around widely distributed species, would ensure the greatest value of systematic standardised sampling.

While some sites and species have several data points over time, most studies cover single species and study locations for short periods, with the majority only collecting samples over one or two years (79%). 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 (*Fratercula arctica*) in the North Sea (Harris and Wanless, 1994, 2011). However, systematically monitoring species, preferably annually, is a more robust way of detecting spatiotemporal trends (van Franeker and 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 within the northeastern Atlantic. 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 multi-jurisdictional monitoring.

As so few studies provided quantitative data on the type, number, size, mass or colour of ingested plastic we were unable to determine whether seabird species within this region were more susceptible to certain types, colour or size categories of plastic. Reporting these metrics is therefore vital. The type of plastic ingested may infer details on its origin, whilst its colour, especially in relation to that of plastic debris within the seabirds' foraging range, will help in understanding how seabirds select plastic (Provencher et al., 2017).

4.2. *Nest incorporation*

The lack of quantitative information highlights how little we know about nest incorporation of plastic by seabirds in the northeastern Atlantic. 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. Quantitative information was only available for the Northern Gannet and Black-legged Kittiwake (Hartwig et al., 2007; Votier et al., 2011), although nest incorporation has been anecdotally reported from other Northern Gannet colonies across the United Kingdom (Nelson, 2002). Over 80% of nests in a Northern

Gannet colony in Wales contained plastic resulting in the entanglement of 62 individuals on average each year (Votier et al., 2011). The amount of plastic within the colony was estimated at 18.46 tonnes, largely comprised of synthetic rope from fishing activities. This is the only documented case where plastic incorporated into nests has resulted in the direct mortality of seabird chicks and adults through entanglement (Votier et al., 2011). For the Black-legged Kittiwake, at a colony in Denmark, 57% of nests contained plastic in 2005, an increase of 46% from 1992 (Hartwig et al., 2007). The amount and type of plastic debris incorporated in to seabird nests is thought to be related to that available to the birds within the vicinity of the breeding colony (Hartwig et al., 2007; Bond et al., 2012). With the amount of plastic debris in the oceans increasing, so too might the proportion of nests with incorporated debris. Outside of the northeastern Atlantic, incorporation of plastic into nests has also been reported in cormorants (Podolsky and Kress, 1989), gulls (Witteveen et al., 2016) and other Suliformes (Bond et al., 2012; Verlis et al., 2014). In order to obtain systematic, quantified data on nest incorporation it would be valuable to establish a monitoring scheme for multiple species across the northeast Atlantic. This would provide a better understanding on which species are the most affected, and where.

4.3. Recommendations

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

4.3.1. Monitoring recommendations

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 are frequency of occurrence and mass of ingested plastics, as there are 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, coordination. This makes identifying spatial and temporal trends among and between species challenging. A multi-jurisdictional, coordinated, collaborative effort is therefore necessary to obtain samples required to monitor the temporal and spatial variation in plastic ingestion among seabird species in the northeastern Atlantic. 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. Although these may be starved individuals, no bias has been observed in the extent of plastic ingestion found in beached versus presumed healthy birds collected, for example after collisions or drowning (van Franeker and Meijboom, 2002). 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 (Acampora et al., 2017b). Opportunities should be exploited across the northeastern Atlantic, and for all species, however particular emphasis should be on those species for which we have very little current information for (based on Table 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), regurgitates, or pellets (Acampora et al., 2017a). Endoscopy and lavage are relatively invasive and therefore care should be taken that such sampling is not undertaken too frequently. However, these methods may be useful for sampling species that do not produce pellets or regurgitate readily. For species that do regurgitate or produce pellets, these 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. Collecting pellets for gulls and Great Cormorants would allow monitoring of both marine and freshwater habitats.
4. To document nest incorporation of nest building, surface nesters across the northeastern Atlantic, 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 and ringers in order that spatiotemporal changes for different species can be detected. This could be further expanded upon by establishing a citizen science project to obtain information on nest incorporation from photographs taken by tourists visiting seabird colonies across the region.

4.3.2. Research recommendations

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 is important in order to understand how representative monitoring plastic ingestion using pellets and regurgitates is, especially when comparing between species, and in determining how at risk different species are from plastic ingestion. 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. Increasing our understanding on how species are affected by secondary ingestion of plastic is also important, as not to underestimate the risk of plastic ingestion in species that might otherwise be thought of as at low risk, such as benthic and diving foragers. 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 adsorbed to it, impact seabirds (Ryan, 2015). 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 ingestion or nest incorporation at the organismal and ecological level, and any potential effect is often not empirically proved, but 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 better understand the scale of the threat and inform conservation priorities.

Here we focused on knowledge gaps associated with monitoring the interactions between plastic and seabirds in the northeastern Atlantic. Our synthesis highlights that our knowledge about the incorporation of plastic into the nests of those species that build them is poor. We also know very little about the frequency of occurrence of plastic 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, multi-jurisdictional 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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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2017.08.101.

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