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Baseline

The challenges of opportunistic sampling when comparing prevalence of plastics in diving seabirds: A multi-species example from Norway

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ABSTRACT

There is a need for baseline information about how much plastics are ingested by wildlife and potential negative consequences thereof. We analysed the frequency of occurrence (FO) of plastics >1 mm in the stomachs of five pursuit-diving seabird species collected opportunistically.

Atlantic puffins (*Fratercula arctica*) found emaciated on beaches in SW Norway had the highest FO of plastics (58.8 %), followed by emaciated common guillemots (*Uria aalge*; 9.1 %) also found beached in either SW or SE Norway. No plastics were detected in razorbills (*Alca torda*), great cormorants (*Phalacrocorax carbo*), and European shags (*Gulosus aristotelis*) taken as bycatch in northern Norway. This is the first study to report on plastic ingestion of these five species in northern Europe, and it highlights both the usefulness and limitations of opportunistic sampling. Small sample sizes, as well as an unbalanced sample design, complicated the interpretation of the results.

Plastic pollution is an increasing environmental challenge, and the amount of plastics afloat in oceans worldwide has been increasing dramatically in recent decades (Eriksen et al., 2023; Law, 2017). The most recent estimate for the year 2019 is summing up to 170 trillion plastic particles or 2.3 million tons floating in the world's oceans (Eriksen et al., 2023). Numerous studies have shown that plastics, including microplastics (i.e., particles between 0.001 mm and 5 mm in size) are ingested by wildlife (Cole et al., 2013; Lusher et al., 2013; Wieczorek et al., 2018) and/or transferred through the food web to higher trophic levels through secondary ingestion (Egbeocha et al., 2018; Ryan, 2019; Santana et al., 2017). In addition, some species have a higher risk of ingesting plastics due to their foraging habits. Specifically, surface-feeding and omnivorous seabirds can mistake floating plastics for food. Procellariiform species, and in particular petrels and shearwaters, are known to be very prone to ingesting plastics due to their omnivorous, surface-feeding behaviour (Kühn and van Franeker, 2020; Provencher et al., 2014; van Franeker et al., 2021), which has led to a research bias in favour of this species group (e.g. Clark et al., 2023). Much less information about plastic exposure, and impacts is available for other seabird species (Baak et al., 2020; O'Hanlon et al., 2017).

Seabirds are one of the most threatened groups of birds worldwide, undergoing severe population declines (BirdLife International, 2022; Croxall et al., 2012; Paleczny et al., 2015). While pollution (including plastic pollution) does not currently rank among the top five threats for seabirds worldwide (Dias et al., 2019), plastic pollution is an increasing threat and it is expected that 99 % of seabird species will be exposed to plastic ingestion by 2050 (Wilcox et al., 2015). In order to understand the implications of plastic ingestion on the health and survival of individuals, and consequently on population trends, it is important to get a better understanding of the amounts of ingested plastics in more seabird

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species (see research and monitoring recommendations in O'Hanlon et al., 2017), but also to monitor spatial and temporal variation in plastic ingestion.

The aim of this study was to provide qualitative and quantitative information on plastic ingestion in five pursuit-diving seabird species sampled opportunistically in Norway. The focal species were three alcids: the Atlantic puffin (*Fratercula arctica*), common guillemot (*Uria aalge*), and razorbill (*Alca torda*); and two cormorant species: great cormorant (*Phalacrocorax carbo carbo*) and European shag (*Gulosus aristotelis*). All five species being pursuit-divers, we expected a lower FO compared to surface feeders (O'Hanlon et al., 2017; Poon et al., 2017). Our study aimed to fill important knowledge gaps (O'Hanlon et al., 2017), with only a few studies providing data on plastics in these species within Europe (see Table 1).

Great cormorants ($n = 8$), European shags ($n = 9$) and razorbills ($n = 10$) were obtained as bycatch from the commercial lumpsucker fishery in the vicinity of North Cape (71.17 N, 25.79 E; Fig. 1), the northernmost point in Norway, during May–June 2012 (Table 2). Atlantic puffins ($n = 17$), and common guillemots ($n = 4$) were collected through beached bird surveys at Jæren (58.73 N, 5.50 E), Rogaland County in the SW of Norway in February/March in 2016 and 2019, respectively. The Atlantic puffins were part of a seabird wreck in SW Norway during a winter storm, and the birds had presumably starved to death (Anker-Nilssen et al., 2017). In addition, 31 common guillemots that beached in the Oslofjord (59.80 N, 10.58 E) during November 2020 because of another mass mortality event following strong winds during autumn storms, were included in the dataset. All birds were measured and dissected following the standardized protocol described in van Franeker (2004). Stomachs were removed and either stored frozen until further analyses (birds from North Cape and Jæren) or directly analysed (birds from Oslofjord).

Stomachs of the birds from North Cape and the birds from Jæren were analysed following the protocol for plastics in stomachs developed for the OSPAR monitoring of northern fulmars (*Fulmarus glacialis*), following van Franeker and Meijboom (2002), with a lower size limit of 1 mm. Stomachs were thawed prior to opening them with a pair of scissors. The content of both proventriculus and gizzard were combined and transferred into a sieve. The stomach tissue was thoroughly rinsed over the sieve to not miss any particles. We used a setup of two sieves, one with a 1 mm mesh set on top of a finer one with 0.5 mm mesh size. This allows retrieving particles that have washed through the first sieve. Plastics and everything that looked like or could be plastics were collected from the sieves. A Leica M60 stereomicroscope (magnification range 6.3–40×) was used to examine the surface characteristics of all the pieces that were not obvious biological material to ensure that no plastics were overlooked.

Stomachs of the common guillemots from Oslofjord were visually inspected for food remains and plastics, using a M38 Wild Heerbrugg microscope (range 6.4–40×). However, in contrast to the other samples, stomach contents of these birds were not washed through a sieve. There is thus a chance that small plastics were overlooked in the sample from Oslofjord, and the estimates of the frequency of occurrence of plastics (FO) should thus be regarded as minimum estimates.

All plastics were dried and weighed individually using an analytic scale to an accuracy of ±0.001 g (birds from Oslofjord) and ± 0.0001 g (all other birds), respectively. The maximum length was measured to the nearest 0.01 mm using digital callipers. The plastics were visually sorted as either industrial plastics (raw plastic nurdles used in plastic production) or user plastics from consumer and commercial sources (sheet, thread, foam, fragment, and other), according to van Franeker et al. (2011). They were thereafter grouped into eight broad colour groups based on assumed original colour, according to the guidelines by Provencher et al. (2017); off/white-clear, grey-silver, black, blue-purple, green, orange-brown, red-pink, yellow.

With a minimum size limit of 1 mm, samples are not prone to contamination from the air or tap water. For precaution, and following lab regulations, a white cotton laboratory coat was used to prevent contamination from clothing and all equipment was made of glass or metal.

To validate the material we found as plastics, and to identify its polymer identity, we analysed all pieces found in the stomachs of the birds from SW and N Norway. A Cary 630 FTIR spectrometer with diamond attenuated total reflectance (ATR) accessory (Agilent, CA, USA) was used to collect spectra from 650 cm^{-1} to 4000 cm^{-1} (resolution 8 cm^{-1}). The absorption bands of the plastics were recorded and compared to the reference spectra in the demo library. The polymer identity was accepted if the score in the Hit Quality Index was ≥ 0.7, where 1 is a perfect match.

All data were collected and presented as recommended in Provencher et al. (2017, 2019), using abundance values (i.e., all individuals); the FO with 95 % confidence interval, the arithmetic mean with standard deviation (SD) and standard error (SE). We further present the raw data for each plastic item, including the mass and size (max length), category (industrial/user; sheet, thread, foam, fragment, and other), colour and polymer type.

Plastics were only found in Atlantic puffins (FO 58.82 %) and common guillemots from Oslofjord (FO 9.68 %; Table 1). No plastics were found in the small number of beached common guillemots from Jæren in SW Norway and in stomachs of razorbills, great cormorants and European shags that died as bycatch in N Norway.

Atlantic puffins contained between 0 and 3 pieces of plastic with a mean number (± SD) of 0.88 ± 0.96 (Table 1). In total, 15 particles were found in 10 individuals, and these items had a mean mass of 11.34 ± 10.63 mg per bird, ranging in size between 4 and 29 mm (Table 3). On average, Atlantic puffins (including those seven birds that contained no plastics) had just over 10 mg of plastics in their stomachs (Table 1). The type of plastics in the Atlantic puffin stomachs consisted of 12 user plastics (six sheets, two threads, and four fragments) and three industrial nurdles. The colours of the plastics were white (10), black (4), and green (1). The FTIR spectroscopy measurements revealed six pieces made of polypropylene (PP), and eight of polyethylene (PE). The polymer type of one plastic item could not be determined (Table 3).

Common guillemots from Oslofjord contained between 0 and 1 piece of plastic, with a mean number of 0.09 ± 0.28, and a mean mass of 51 ± 236 mg per bird (Table 1). The size ranged between 15 and 158 mm (Table 3). The three detected pieces were all user plastics (one foam, one rubber band, and one fragment) in the colours black (1), blue (1) and beige-brown (1; Table 3). The FTIR spectroscopy revealed one item made of PP, one of PE and one of polyurethane (PU).

All birds obtained as bycatch, i.e., razorbills, great cormorants, and European shags were in good body condition and had internal fat stores. In contrast, the Atlantic puffins and common guillemots that died in a wreck were emaciated and had most likely died from starvation. The recorded masses of these birds were lighter than what is expected for the species, even though birds were wet and sandy when weighed (Table 2).

Our study is the first to provide quantitative and qualitative information on plastic prevalence in five pursuit-diving seabird species in northern Europe, and it is the first to report on plastic ingestion in Atlantic puffins and common guillemots in Norway (see Table 1), thus helping to fill existing knowledge gaps and provide reference data for further studies. We found an intermediate-high FO of plastics in the stomachs of Atlantic puffins (58.8 %) and a low FO for common guillemots (9.7 %), all beached dead in the southern part of Norway. Note that the FO for common guillemots represents a minimum estimate, since small particles may have been overlooked. The stomachs of razorbills, great cormorants, and European shags which were all obtained as bycatch in northern Norway, contained no plastics >1 mm. For the North-East Atlantic, we report among the highest FO of plastics for Atlantic puffins to date (see Table 1), while the FO for common guillemots was in the lower range compared to previous studies from west and southwest Europe (Table 1). Although alcids are known to contain less plastics than Procellariiformes, such as the northern fulmar, Atlantic

Table 1

Frequency of occurrence of plastic, number and mass of plastics from previous studies within Europe, including this current study, investigating any of the five study species. Only studies focusing on the entire stomach content (i.e., from necropsies of dead birds) were included in this overview.

Species	Sample size	Year	Area	Source	Lower size threshold	Frequency of occurrence - % [CI]	Number of plastic particles - average ± SD [SE]	Mass of plastic in stomach - average (mg) ± SD [SE]	Study
Great cormorant	37	1985–1987	Scotland	Shot/bycatch	na	≤ 6	na	Na	Carss, 1993
	4	2016–2018	Bay of Biscay, Spain	Beached/recovery centre	1 mm	0	0	0	Franco et al., 2019
	8	2012	N Norway	Bycatch	1 mm	0	0	0	This study
European Shag	10	2012–2016	Ireland	Beached	1 mm	10	0.2 ± 0.63 [0.2]	0.1 ± [0.1]	Acampora et al., 2016
	1	2016–2018	Bay of Biscay, Spain	Recovery centre	1 mm	0	0	0	Franco et al., 2019
	9	2012	N Norway	Bycatch	1 mm	0	0	0	This study
Common guillemot	343	1983	England	Beached/mass mortality	na	0	0	0	Blake, 1984
	60	1983	Scotland	Beached/mass mortality	na	0	0	0	Blake, 1984
	220	1996	Wales	Oil spill	na	2.27	na	na	Weir et al., 1997
	25	2012–2016	Ireland	Beached	1 mm	12	0.12	0.1 + [0.1]	Acampora et al., 2016
	61	2014–2018	Bay of Biscay, France & Spain	Beached/mass mortality	1 mm	11.5	0.15 ± 0.47 [0.06]	na	Franco et al., 2019
	33	2015–2019	Lithuania	Bycatch	1 mm	3.03 [0–6.1]	0.03 ± 0.17 [0.03]	0.239 + 1.35 [0.24]	Morkūnas et al., 2021
	120	2019	The Netherlands	Beached/mass mortality	1 mm	27.5 [19.51–35.49]	0.47	3.6	Leopold et al., 2019
	1	2019	SW Norway	Bycatch	~10 mm[a]	0	0	0	Haave et al., 2021
	4	2019	SW Norway	Beached	1 mm	0	0	0	This study
	31	2020	SE Norway	Beached/mass mortality	1 mm	9.68 [0–20.09]	0.097 ± 0.296 [0.053]	50.61 ± 235.48 [42.29]	This study
Razorbill	81	1996	Wales	Oil spill	na	1.23	na	na	Weir et al., 1997
	12	2014–2018	Bay of Biscay, France & Spain	Beached/mass mortality	1 mm	0	0	0	Franco et al., 2019
	15	2012–2016	Ireland	Beached	1 mm	0	0	0	Acampora et al., 2016
	10	2012	N Norway	Bycatch	1 mm	0	0	0	This study
Atlantic puffin	6	1969–1971	East coast of Scotland England	Oil spill & storm-driven	na	66.67 [28.95–95.61]	0.67 ± 0.47 [0.19]	na	Parslow and Jefferies, 1972
	315	1969–1992	North Sea	Oil spill, beached, blown inland, killed	na	13.33 [9.58–17.09]	0.13 ± 0.34 [0.02]	na	Harris and Wanless, 1994
	43	1973–1976	Wales & West Scotland	Oil spill, beached, blown inland, killed	na	0	0	0	Harris and Wanless, 1994
	5	1996–1985	The Netherlands	Beached, partly oiled	na	20.00 [0–0.55]	0.20 ± 0.40 [0.18]	na	Camphuysen, 1986
	11	2014	Bay of Biscay, France	Beached/mass mortality	1 mm	27.3	0.27 ± 0.46 [0.14]	na	Franco et al., 2019
	3	2012–2016	Ireland	Beached	1 mm	33.3	1.33 ± 2.30 [1.33]	7.7 ± [7.7]	Acampora et al., 2016
	17	2016	SW Norway	Beached/mass mortality	1 mm	58.82 [35.43–82.22]	0.88 ± 0.96 [0.23]	10.01 ± 12.13 [2.94]	This study

[a] Lower size limit not specified, focus on “visible macro plastics”.

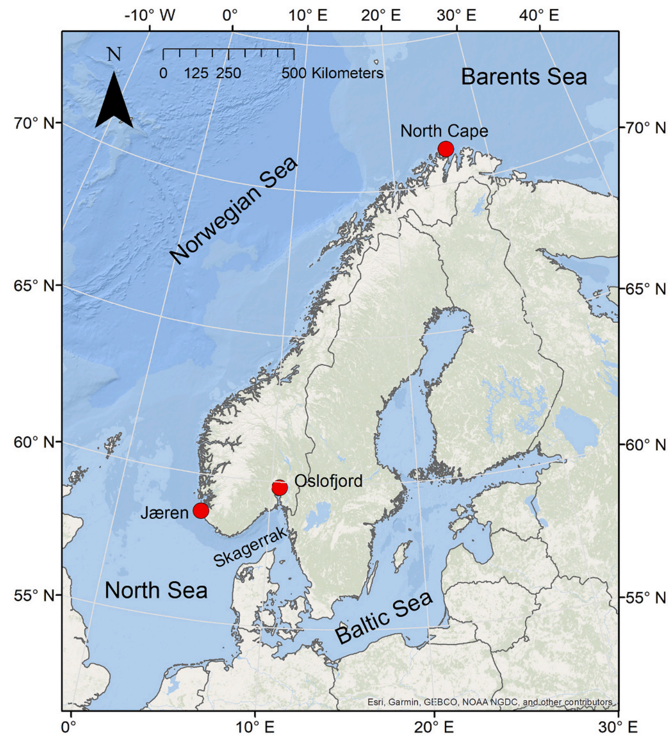

Fig. 1. Map showing the locations where birds for this study were collected. Great cormorants, European shags and razorbills were collected as unintentional bycatch in fisheries at North Cape. Atlantic puffins were collected beached at Jæren in SW Norway. Common guillemots were collected beached on both Jæren and in Oslofjord.

puffins and common guillemots have been standing out with higher prevalence – along with black-legged kittiwakes (*Rissa tridactyla*) – among the non-procellariiform seabirds (Bond et al., 2013; Baak et al., 2020; O'Hanlon et al., 2017). This aligns with our results for common guillemots and Atlantic puffins. However, it contrasts with our results for razorbills that exhibited no plastics in their stomachs.

Due to the opportunistic sampling approach, we obtained different species from different areas, some emaciated and beached during winter, other caught as bycatch during spring, and for some of the collected species sample sizes were low. This makes interpretation of our results more challenging. As we discuss in the following, several non-mutually exclusive factors can contribute to explain our findings, including 1) small sample sizes, 2) inter-specific differences in foraging behaviour, 3) spatiotemporal distribution of birds and plastics, 4) plastic retention time, and 5) physiological condition prior to death.

Firstly, sample sizes for especially great cormorants, European shags and razorbills obtained as bycatch were small (≤ 10 individuals), both in comparison with most other studies (Table 1), and also in comparison with the number of common guillemots we examined. This may explain why we did not find any plastics in these three species from northern Norway and thus biased our results.

Secondly, although the three alcid species as well as European shag and great cormorant are pursuit-divers, differences in their foraging behaviour, e.g. diet, diving depth and foraging ranges (coastal versus pelagic), might lead to differences in uptake of plastics through both direct and secondary ingestion. With regards to diet, all three alcid species are to some degree opportunistic feeders, preying mostly on fish, particularly sandeel (*Ammodytes marinus*), herring (*Clupea harengus*), and capelin (*Mallotus villosus*) (e.g. Barrett, 2002; Harris and Wanless, 1986; Lilliendahl, 2009). These prey species are also common in great cormorants' and European shags' diet, although both of these species predominantly feed on cod (*Gadus morhua*) and saithe (*Pollachius virens*) in northern Norway (Barrett, 1991; Barrett et al., 1990; Dehnhard et al., 2021). Diving depths vary between locations and type of prey, with common guillemots generally diving deepest (Barrett and Furness, 1990; Burger and Simpson, 1986; max: 180 m, typical range 20–50 m; Piatt and Nettleship, 1985; Thaxter et al., 2010), followed by razorbills (max: 120 m, typically <30 m; Isaksson et al., 2019; Piatt and Nettleship, 1985; Shoji et al., 2015; Thaxter et al., 2010) and Atlantic puffins (Barrett and Furness, 1990; max: 70 m, typically <20 m; Burger and Simpson, 1986; Shoji et al., 2015). As Atlantic puffins tend to feed closest to the surface, they may be more exposed to floating plastics and more prone to ingestion, which matches our results with Atlantic puffins having the highest FO of the investigated species. On the other hand, a study from the southern Atlantic found that the probability to ingest plastics increased with diving depth (Tavares et al., 2017), and thus common guillemots should have higher levels of FO – contrasting our findings. Contrasting diving depths and associated probabilities to ingest plastics do neither provide an explanation for why razorbills would be less exposed than common guillemots. Compared to the alcids, great cormorants (dive depth max: 32 m; typically <10 m; Cosolo et al., 2010; Grémillet et al., 2005; Grémillet and Wilson, 1999) and European shags (dive depth max: 63 m, typically 7–30 m; Dehnhard et al., 2022; Wanless et al., 1991) forage in shallower water depths. Furthermore, both great cormorants and European shags tend to feed in coastal areas year-round and often perform benthic or near-benthic dives (Dehnhard et al., 2022; Grémillet et al., 2005). As such, they might also get exposed to more plastics through secondary ingestion, especially when ingesting benthic prey species and taking larger fish than the alcids (Álvarez et al., 2018). In contrast, the three alcid species forage mostly in pelagic waters, both during the breeding season and even more so during winter (Bonnet-Lebrun et al., 2021; Fayet et al., 2021; Fayet et al., 2017; Isaksson et al., 2019; Linnebjerg et al., 2018; Merkel et al., 2021). Overall, it thus seems rather unlikely that inter-specific differences in foraging behaviour can explain the lack of plastics in razorbills, European shags and great cormorants compared to common guillemots and Atlantic puffins.

Thirdly, the amount of plastics in the marine environment is likely to vary along the latitudinal gradient over which birds were collected. Namely, razorbills, European shags and great cormorants were obtained near the North Cape of Norway, >1500 km beeline distance north of where Atlantic puffins and common guillemots were collected. Although the Arctic has been shown to not be free of plastic pollution (Bergmann et al., 2022), northern fulmars from more arctic areas contain lower amounts of plastics than those from the North Sea, as also reported for birds collected in Norwegian waters (van Franeker et al., 2021; van Franeker and Law, 2015). If, as suggested by northern fulmar studies,

Table 2

Species-specific overview of the collected material, indicating the spatio-temporal origin, sample size, age distribution (ad = adult, imm = immature, u = unknown), cause of death and body mass of birds in the different samples.

Species	Location	Collection dates	N	Age	Cause of death	Body mass (g ± SD)
Great cormorant	North Cape, N Norway	30 May–16 Jun 2012	8	8 ad	Bycatch in fishing gear	3266 ± 436, N = 8
European shag	North Cape, N Norway	14 May–10 Jun 2012	9	5 ad, 3 imm, 1 u	Bycatch in fishing gear	2032 ± 184, N = 8
Razorbill	North Cape, N Norway	17–21 May 2012	10	8 ad, 1 imm, 1 u	Bycatch in fishing gear	931 ± 50, N = 8
Atlantic puffin	Jæren, SW Norway	18 Feb–14 Mar 2016	17	14 ad, 3 imm	Starvation (beached bird)	292 ± 39, *N* = 6
Common guillemot	Jæren, SW Norway	09 Feb–06 Mar 2019	4	1 ad, 3 imm	Starvation (beached bird)	781 ± 205, N = 4
Common guillemot	Oslofjord, SE Norway	3–18 Nov 2020	31	31 imm	Starvation (beached bird)	612 ± 62, *N* = 31

Table 3
Details about plastics found in Atlantic puffins and common guillemots. Columns 1–3 refer to the species, bird ID and age of the bird for which the plastics were found. The remaining columns inform about the type of plastic, polymer, colour, size (max length) and mass of each particle. PE: polyethylene, PP: polypropylene, PU: polyurethane.

Species	Bird-ID	Age	Type	Polymer	Colour	Size (mm)	Mass (mg)
Atlantic puffin	11	imm	Fragment	PE	Green	6.2	28.2
Atlantic puffin	12	ad	Fragment	PE	Blue	4.4	3.0
Atlantic puffin	17	ad	Sheet	PP	White	9.5	2.6
Atlantic puffin	17	ad	Sheet	PP	White	4.3	2.0
Atlantic puffin	17	ad	Fragment	other	Blue	4.6	19.4
Atlantic puffin	18	ad	Sheet	PE	White	7.1	7.7
Atlantic puffin	18	ad	Sheet	PP	White	9.3	0.7
Atlantic puffin	23	ad	Thread	PP	White	23	1.4
Atlantic puffin	23	ad	Industrial nurdle	PE	Blue	3.4	11.6
Atlantic puffin	23	ad	Industrial nurdle	PP	White	4.1	13.3
Atlantic puffin	26	ad	Sheet	PE	White	6.4	2.2
Atlantic puffin	43	ad	Fragment	PE	Blue	10.2	34.9
Atlantic puffin	48	ad	Sheet	PP	White	20.4	19.2
Atlantic puffin	49	ad	Industrial nurdle	PE	White	4.3	21.5
Atlantic puffin	52	imm	Thread	PE	White	29.1	2.4
Common guillemot	105382[a]	imm	Foam	PE	Beige-brown	158.0	1326
Common guillemot	105394[a]	imm	Rubber band	PU	Black	15.0	194
Common guillemot	105397[a]	imm	Fragment	PP	Blue	17.0	49

[a] Accession number in the DNA bank of the Natural History Museum in Oslo.

floating plastics are in lower amounts in the Arctic than in the North Sea, this may well explain why common guillemots and Atlantic puffins in our sample contained plastics, while the other species caught further north did not.

Fourthly, plastic retention times in the digestive system, possibly in combination with sampling dates (winter versus spring) and migratory patterns, could affect the documented amounts of ingested plastics. Cormorant species regurgitate indigestible prey items (like fish bones) in the form of pellets (Barrett et al., 2007). This could allow European shags and great cormorants to get rid of ingested plastics (Álvarez et al., 2018), and thus reduce the likelihood to retrieve plastics in stomachs of dead birds. In contrast to cormorants, alcids do not regurgitate indigestible prey items, and thus ingested plastics might be retained in their stomachs until small enough to pass through the gut (Nania and Shugart, 2021). This could explain differences in FO between the two cormorant species and the alcids, but not between razorbills compared to Atlantic puffins and common guillemots.

Lastly, the physiological condition of the birds before they died could also have affected their plastic loads. While razorbills, European shags and great cormorants were taken as unintentional bycatch in fisheries, and thus healthy until their sudden death by drowning, common guillemots and Atlantic puffins sampled in the south of Norway had died of starvation. Previous research on flesh-footed and short-tailed shearwaters (*Ardenna carneipes* and *A. tenuirostris*, respectively) has shown that physiological condition can have an impact on plastic loads, with beached birds containing more plastics than birds killed on roads or due to light-pollution (Lavers et al., 2021; Rodríguez et al., 2018). On the other hand, in the northern fulmar the data obtained from beached versus bycatch birds are considered comparable (van Franeker et al., 2021; van Franeker and Meijboom, 2002). Remarkably, seven of the plastic items found in the common guillemots and Atlantic puffins in this study were $>$ 1 cm in length, and one item was longer than 15 cm (Table 3), which suggests that the birds did not take up these plastics through secondary ingestion but mistook them for food. Possibly, starving seabirds are less picky and thus more prone to ingest plastics through primary ingestion, while healthy, well-nourished birds would rather avoid them. If this is the case, one could further expect synergistic effects, if these already weak birds get negatively impacted by the plastics in their digestive system.

To conclude, we here provide for the first time information about plastic prevalence in five pursuit-diving seabird species collected in Norway. Due to our opportunistic sampling approach, we could not tease apart if our results were driven by small sample sizes, inter-specific differences in foraging behaviour, location (northern Norway versus southern Norway), retention time and/or sampling circumstances (beached versus bycatch). This illustrates the limitations associated with opportunistic sampling in plastics research and highlights the need for further research to increase sample sizes and improve our understanding of the spatio-temporal variation of plastics in seabirds across regions, species and populations. In the meantime, we strongly recommend providing clear documentation of sampling locations and collection dates, and to report results separately for beached and bycatch individuals when reporting data on the prevalence of plastics in marine vertebrates.

CRediT authorship contribution statement

Stine Charlotte Benjaminsen: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Nina Dehnhard:** Writing – original draft, Data curation, Conceptualization. **Dorte Herzke:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Arild Johnsen:** Writing – review & editing, Formal analysis, Data curation. **Tycho Anker-Nilssen:** Writing – review & editing, Data curation. **Sophie Bourgeon:** Writing – review & editing, Supervision. **France Collard:** Writing – review & editing. **Magdalene Langset:** Writing – review & editing, Formal analysis, Data curation. **Signe Christensen-Dalsgaard:** Writing – review & editing, Data curation, Conceptualization. **Geir Wing Gabrielsen:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dorte Herzke reports financial support was provided by Research Council of Norway. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data is presented in the tables of the manuscript.

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