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# Plastic burdens in northern fulmars from Svalbard: Looking back 25 years

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ABSTRACT

The northern fulmar *Fulmarus glacialis* ingests a larger number of (micro)plastics than many other seabirds due to its feeding habits and gut morphology. Since 2002, they are bioindicators of marine plastics in the North Sea region, and data are needed to extend the programme to other parts of their distribution areas, such as the Arctic. In this study, we provide data on ingested plastics by fulmars collected in 1997 in Kongsfjorden, Svalbard. An extraction protocol with KOH was used and for half of the birds, the gizzard and the proventricular contents were analysed separately. Ninety-one percent of the birds had ingested at least one piece of plastic with an average of 10.3 (±11.9 SD) pieces. The gizzards contained significantly more plastics than the proventriculus. Hard fragments and polyethylene were the most common characteristics. Twelve percent of the birds exceeded the EcoQO value of 0.1 g.

## 1. Introduction

Plastics pollute every region of the world, including the high Arctic, despite its remoteness (reviewed in Bergmann et al., 2022; Halsband and Herzke, 2019). This field of research is on the rise and plastic, including microplastic (<5 mm), has been found in many places (e.g. Collard et al., 2021; Huntington et al., 2020; Kanhai et al., 2020; Kim et al., 2021; Mu et al., 2019) and many organisms (e.g. Iannilli et al., 2019; Kühn et al., 2018; Moore et al., 2020; Pinzone et al., 2021). Particularly, seabirds are more studied than other large groups of animals (Collard and Ask, 2021) and vulnerable to this type of pollution (Kühn and van Franeker, 2020). More than 50 Arctic seabird species have been investigated for plastic ingestion so far and plastic pieces were found in more than half of them (Baak et al., 2020a). The northern fulmar *Fulmarus glacialis* (hereafter called fulmar) is widely studied within the Arctic (e.g. Kühn and van Franeker, 2012; Mallory, 2008; Provencher et al., 2009; Trevail et al., 2015). Indeed, the fulmar ingests a larger number of (micro)plastics than many other seabirds due to its feeding habits (e.g. van Franeker et al., 2011) and gut morphology (Furness, 1985). Their two stomachs (proventriculus and gizzard) are separated by a constriction which makes regurgitation of the gizzard content impossible. Therefore, large plastic pieces, together with other hard particles, are assumed to be stuck in the gizzard until ground into particles small enough to pass the pylorus (e.g. Day et al., 1985). These characteristics make them a suitable species for the monitoring of plastic pollution (AMAP, 2021). Since 2002, they are bioindicators of marine plastics in the North Sea region (OSPAR Commission, 2008) and data are needed to extend the programme to other parts of their distribution areas, such as the Arctic. Data were gathered in several Arctic regions but are lacking in many others. Svalbard is one example where few studies were performed (Collard and Ask, 2021). In addition, since plastic pollution is gaining the attention of scientists these past years, data from before that raise of awareness are lacking. Consequently, it is impossible to calculate trends in ingested plastics and evaluate the quality of the environment regarding plastic pollution, except perhaps in the North Sea thanks to the establishment of the Ecological Quality Objective (EcoQO) by the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR).

In this study, we first aimed at providing data on plastic ingestion by fulmars collected in Svalbard in 1997 and help fill a knowledge gap on plastic pollution and polymer composition in Svalbard and in "old" samples, collected in the 1990s when studies on plastic pollution were scarce and plastic pollution was gravely unregulated. Second, we also aimed at confirming the hypothesis of a greater plastic occurrence in the gizzard than in the proventriculus and we here provide numbers for the gizzard and proventriculus separately for half of the sampling collection.

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## 2. Material and methods

### 2.1. Ethical statement

Sampling was made with the best professional practices to minimize as much as possible suffering. The fulmars were used for several purposes back in 1997, including baiting foxes in Svalbard and eventually for this study. The digestive tracts were not of any use at that time and were therefore saved and stored frozen since then. Even though nowadays such a purpose would probably not be approved by the Svalbard authorities, back in the 1990s, regulations and perceptions of sampling were different. The permission of the Governor of Svalbard was obtained as required for many species in that archipelago.

### 2.2. Sampling

Forty-three fulmars were shot from a boat in Kongsfjorden, Svalbard, in March 1997. They were all in their second year or older but the precise age class was not determined precisely. The birds were weighed and several measurements were taken. The lengths of the wing, the culmen, the gonys, the head and bill together, and the foot and tars together were reported and sex was determined (Table S1). The dissections were undertaken in Svalbard. Both the gizzard and proventriculus (hereafter called stomachs) of all individuals were dissected and sent to the Norwegian Polar Institute in Tromsø, Norway. They were kept frozen until April 2021.

### 2.3. Extraction of plastics

The stomach contents were extracted in the laboratory in Tromsø under a fume hood. For half of the stomachs, the gizzard and proventriculus contents were processed separately (n = 22) and those samples were selected randomly. A pre-filtered solution of 10 % KOH (w/w) (Dehaut et al., 2016; Karami et al., 2017) was added to the stomach contents (ratio 3:1 v/v; Rochman et al., 2015) in a glass beaker. The mixture was shaken at 100 rpm (rpm) overnight at room temperature since warming the mixture can lead to negative impacts on some polymers (Thiele et al., 2019; Treilles et al., 2020). After digestion, the stomach contents were gently poured into a stainless-steel sieve (20 μm). The contents, which consisted mainly of solid particles, were rinsed off in a filtration unit with milliQ water. It was then vacuum-filtered through a 5-μm filtering membrane made of cellulose acetate. The particles on the membranes were sorted under the fume hood as a selection for the following Fourier Transform InfraRed (FTIR) spectroscopic analyses.

This study focuses on particles larger than 1 mm to make our results comparable with data from studies which have used the OSPAR method. However, a KOH digestion method and a 20-μm sieve were used to allow the analyses of any smaller particles (between 20 μm and 1 mm) in the future.

### 2.4. Prevention of contamination

Although it is not expected that large microplastics (>1 mm) contaminate the samples, precautions were taken to avoid at least the contamination from long airborne fibres. Indeed, fibres as large as 3.9 mm can contaminate samples from the surrounding air (Torre et al., 2016). All solutions used were pre-filtered with a 5-μm filtering membrane made of cellulose acetate. Glassware and aluminium foil were used whenever possible. The only plastic materials used were the tubes where the filtering membranes were stored after the extraction of plastics, and the wash bottles used for the rinsing step with milliQ water. Nitrile gloves and a 100 % cotton lab coat were worn at all steps of the process, including the sorting. The samples were always covered by rinsed aluminium sheets when not handled.

### 2.5. FTIR analyses

All particles suspected to be made of plastic were selected for FTIR analyses. A subsample of the rest, i.e. particles assumed to be plant materials, stones, squid beaks, fish bones, and crustacean exoskeletons, for example, was analysed for each sample. The subsample size was 10 % of each category. If only one or two natural particles were present in a single sample, they were all analysed. The chemical composition of the extracted particles was assessed using a portable Fourier-transform infrared (FTIR) spectrometer "Cary 630" (Agilent Technologies, Santa Clara, USA) with a Diamond Attenuated Total Reflectance (ATR) sampling accessory. The spectral resolution was set at 8 $cm^{-1}$ and spectra were collected between 650 and 4000 $cm^{-1}$. Thirty-two scans were accumulated for each analysis. After each sample, the crystal was cleaned with 2-propanol on a wipe. Acquired spectra were compared to those in the ATR Demo reference library. A hit quality match between 0 and 1 was provided for the most similar spectra and only the polymers showing a match equal or superior to 0.7 were considered.

### 2.6. Measurement and other characteristics

After the FTIR analyses, the plastic particles were measured with the ImageJ software on pictures taken before the spectroscopic analyses. As recommended by Hartmann et al. (2019), only the largest dimension was measured. Their colour and their shape were also recorded. We followed the recommendation of Provencher et al. (2017) to classify colours into eight categories: white/off, yellow, orange/brown, red/pink, blue/purple, green, grey and black. Regarding the shapes, we defined five categories: pellets (or nurdles), thread-like, fragment, foam and sheet (Provencher et al., 2017). Fibres were not included in the data (Kühn et al., 2021; van Franeker et al., 2011). The plastic particles were weighed per polymer and per bird with a Sartorius scale (0.0001 g accuracy).

### 2.7. Statistical analyses

Both the number and the mass of plastic were compared between sexes. First, a Shapiro-Wilk normality test was applied and revealed a non-normal distribution in both the number and the mass of plastic in both sexes ($p < 0.01$). Therefore, Mann-Whitney tests were performed to compare the mass and number of plastic particles among sexes ($p$-values set at 0.05).

## 3. Results

Among the 43 birds investigated, 91 % (all except 4) had at least one piece of plastic in their stomach. Overall, 442 plastic particles were extracted and analysed. A median of 5.0 plastic particles were found per stomach (1st quartile: 2.5, 3rd quartile: 14), with an average of 10.3 (±1.8 SE) (Table 1). In the samples where the proventriculus and the gizzard were processed separately ($n = 22$), most of the plastics were found in the gizzard ($n = 198$) compared to the proventriculus ($n = 5$). Some examples of ingested plastics are shown in Fig. 1. In total, the 442 ingested plastics represented a mass of 2.72 g. The median mass was 0.041 g of plastic per stomach (1st quartile: 0.015 g, 3rd quartile: 0.069 g), with an average of 0.070 g (±0.013 SE) per bird. Industrial plastics (pellets) represented 16 % (0.44 g) of the total plastic mass. Twelve percent of the fulmars had >0.1 g of plastics in their stomach (Table 2), exceeding the EcoQO threshold.

The hard fragment was the most represented shape, followed by thread-like, pellets (or nurdles), sheet-like and finally foam with 73.1 %, 14.0 %, 6.8 %, 5.9 % and 0.2 %, respectively (Fig. 2A, Table S2). Seven polymers were identified thanks to FTIR spectroscopy: polyethylene (PE, 70.3 %), polypropylene (PP, 21.4 %), polystyrene (PS, 4.9 %), polyamide (PA, 0.4 %), acrylonitrile butadiene styrene (ABS, 0.4 %), polyethylene terephthalate (PET, 0.2 %) and a polyhydroxyalkanoate (PHA,

**Table 1**
Summary of plastic burdens by sex. M: males, F: females, FO: frequency of occurrence, SE: standard error, EcoQ%: percentage of birds exceeding the Ecological Quality Objective (0.1 g).

| | n | FO (%) | Mass (g) | | | | Number | | | | EcoQ% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean ± SE | Min | Max | Median | Mean ± SE | Min | Max | Median | |
| M | 20 | 85 | 0.057 ± 0.022 | 0 | 0.405 | 0.016 | 7.1 ± 1.9 | 0 | 30 | 3.5 | 10 |
| F | 23 | 100 | 0.069 ± 0.014 | 0.001 | 0.297 | 0.054 | 13.1 ± 2.8 | 0 | 61 | 9 | 13 |
| All | 43 | 91 | 0.070 ± 0.013 | 0 | 0.405 | 0.041 | 10.3 ± 1.8 | 0 | 61 | 5.0 | 12 |

**Fig. 1.** Pictures of plastics found in fulmars' stomachs. Each picture represents one sample. The scale bar represents 5 mm. Some particles were smashed during the FTIR analyses and therefore some pieces in this figure are smaller than 1 mm.

0.2 %). The relative mass proportion of each polymer was similar to the number proportion (Fig. 2B). The most common colour was white (39 %) closely followed by yellow (35 %, Fig. 2C, Table S2). When considering threads only, blue and white were the dominant colours (25.8 % and 24.2 %, respectively) followed by green (21.0 %).

Plastic loads were compared between sexes and females showed significantly higher numbers of ingested plastic than males (Mann-Whitney test, $W = 464$, $p = 0.0427$) while no significant difference in plastic mass could be shown (Mann-Whitney test, $W = 489$, $p = 0.0601$).

The plastic pieces measured 6.1 mm ± 4.9 SD on average and had a median of 4.7 mm. The smallest one was 1.1 mm and the largest was a thread of PE and measured 39.8 mm. The majority (54.3 %) of the extracted plastic particles were microplastics (≤5 mm, Fig. 3). All pieces larger than 14 mm but one were threads.

## 4. Discussion

Even though the OSPAR protocol was not followed in this study to extract the particles from the birds' stomachs, the plastics found were categorized according to the OSPAR recommendations in order to make our results comparable to previous and future studies following the OSPAR guidelines. We chose to use KOH to be able to also extract plastics smaller than 1 mm – in the scope of another study – and to ease the FTIR identification. Despite that discrepancy, we believe our results are completely comparable with other results acquired through the OSPAR protocol. The use of KOH is a common and efficient way to extract plastic particles, including those larger than 1 mm and consequently, does not hamper the comparison with previous and future studies using the OSPAR protocol. We strongly believe that, if we had used the OSPAR extraction protocol, we would have retrieved the same data eventually.

### 4.1. Plastic ingestion by seabirds from the 1970s

Our data showed that seabirds in the Arctic were already exposed to plastic pollution in the 1990s. This is not surprising as plastic ingestion by seabirds was already documented in 1973 in Leach's petrels *Oceanodroma leucorhoa* collected both in 1962 and 1964 (Rothstein, 1973). Five out of fourteen birds (frequency of occurrence (FO) 36 %) had at least one plastic particle in their stomach. In the 1980s, plastic ingestion by seabird has also been documented several times in several regions of the world (e.g. Day et al., 1985; Day and Shaw, 1987; Furness, 1983,

**Table 2**
Numbers and masses of plastic polymers in each sample. N: number, m: mass, PE: polyethylene, PP: polypropylene, PS: polystyrene, PA: polyamide, ABS: acrylonitrile butadiene styrene, PET: polyethylene terephthalate, PHA: polyhydroxyalkanoate. Samples ID ending with G, P and SC are content from the gizzard, proventriculus and both altogether, respectively. Samples ID from F1 to F23 refer to females. F24 to F44 refer to males.

| Sample ID | PE | | PP | | PS | | PA | | ABS | | PET | | PHA | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | m (g) | N | m (g) | N | m (g) | N | m (g) | N | m (g) | N | m (g) | N | m (g) | N | m (g) |
| F1G | 16 | 0.1909 | 10 | 0.0257 | 1 | 0.001 | 0 | 0 | 3 | 0.0024 | 0 | 0 | 0 | 0 | 30 | 0.2200 |
| F2SC | 1 | 0.0157 | 2 | 0.0215 | 1 | 0.0006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0378 |
| F3SC | 1 | 0.0209 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0209 |
| F4G | 10 | 0.0846 | 1 | 0.0032 | 1 | 0.0006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0.0884 |
| F4P | 1 | 0.0031 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0031 |
| F5G | 4 | 0.0172 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0005 | 0 | 0 | 0 | 0 | 5 | 0.0177 |
| F5P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F6SC | 3 | 0.0112 | 1 | 0.0163 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0275 |
| F7G | 11 | 0.1502 | 2 | 0.0441 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | ND | 0 | 0 | 14 | 0.1943 |
| F7P | 1 | 0.0948 | 1 | 0.0080 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.1028 |
| F8G | 1 | 0.0013 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0013 |
| F9SC | 9 | 0.0633 | 5 | 0.0084 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0.0717 |
| F10G | 3 | 0.0172 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.0172 |
| F11G | 7 | 0.0365 | 1 | 0.0027 | 1 | 0.0015 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.0407 |
| F12SC | 5 | 0.0476 | 5 | 0.0007 | 1 | 0.0012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0.0495 |
| F13G | 14 | 0.0594 | 13 | 0.0163 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 0.0757 |
| F14SC | 17 | 0.0661 | 1 | 0.0006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0.0667 |
| F15G | 0 | 0 | 2 | 0.0458 | 7 | 0.0035 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.0493 |
| F16SC | 4 | 0.0382 | 2 | 0.0244 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0.0626 |
| F17G | 9 | 0.0612 | 0 | 0 | 1 | 0.0008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0.0620 |
| F17P | 2 | 0.0014 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.0014 |
| F18SC | 3 | 0.0312 | 5 | 0.0224 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0.0536 |
| F19G | 11 | 0.0184 | 2 | 0.0017 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0.0201 |
| F20SC | 46 | 0.0184 | 12 | 0.045 | 2 | 0.0014 | 1 | 0.0185 | 0 | 0 | 0 | 0 | 0 | 0 | 61 | 0.0833 |
| F22SC | 4 | 0.0582 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0582 |
| F23SC | 16 | 0.124 | 9 | 0.0311 | 6 | 0.0024 | 0 | 0 | 0 | 0 | 1 | 0.0023 | 0 | 0 | 32 | 0.1598 |
| F24G | 1 | 0.0086 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0029 | 0 | 0 | 0 | 0 | 2 | 0.0115 |
| F25SC | 1 | 0.0008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0008 |
| F26G | 1 | 0.0159 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0159 |
| F27G | 3 | 0.0129 | 0 | 0 | 0 | 0 | 1 | 0.0005 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0134 |
| F28G | 10 | 0.0585 | 3 | 0.0257 | 1 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0.0852 |
| F28P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F29SC | 10 | 0.0478 | 2 | 0.0035 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0.0513 |
| F30SC | 28 | 0.244 | 2 | 0.0196 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0.2636 |
| F31SC | 14 | 0.0577 | 3 | 0.0031 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 0.0608 |
| F32G | 2 | 0.0053 | 1 | 0.0008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.0061 |
| F33G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F34G | 18 | 0.286 | 3 | 0.1189 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 0.4049 |
| F35SC | 4 | 0.0479 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0479 |
| F36SC | 3 | 0.0235 | 1 | 0.0025 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0260 |
| F37G | 2 | 0.0163 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.0163 |
| F38G | 1 | 0.0017 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0017 |
| F39SC | 4 | 0.0152 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0005 | 5 | 0.0157 |
| F40G | 11 | 0.0858 | 6 | 0.0138 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 0.0996 |
| F42SC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F43SC | 3 | 0.0143 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.0143 |
| F44G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 315 | 2.1732 | 95 | 0.5058 | 22 | 0.014 | 2 | 0.019 | 5 | 0.0058 | 3 | 0.0315 | 1 | 0.0005 | 442 | 2.7206 |

1985; Moser and Lee, 1992; Ryan, 1987). In 1984, direct ingestion of plastics had already been reported in 50 species of seabirds globally, whose more than half are Procellariiformes (Day et al., 1985). Moser and Lee (1992) reported a FO of 86 % in northern fulmars (n = 44) back in 1992, making it the species with the second highest FO, behind Sabine's gull *Xema sabini* (n = 1). Given the numerous species investigated, coming from many different regions, comparisons and conclusions are impossible to make and this points out the need for more data from the past decades. It also highlights how exposed birds were at that time already and stresses the need for a better understanding of the impacts of plastic ingestion. Since it has been contaminating seabirds for decades, and therefore through many generations, if plastic ingestion impacts the exposed birds, this could have dramatic consequences at the population levels and could play a role in the decline of seabird species, including in the Arctic.

### 4.2. Plastic ingestion by fulmars from Svalbard

One could have expected an increase in the number of ingested plastics because plastic production is increasing globally (Geyer et al., 2017; PlasticsEurope, 2020) and so does marine plastic pollution (Barnes et al., 2009). Surprisingly, there seems to be a similarity in the FO and an increase in both the number and mass of ingested plastics over the years or decades. This assumption has to be treated carefully as few studies investigated the Svalbard region (Table 3).

Also, the most recent study collected fledglings as half of their sampling set while this study investigated second-year or older birds only and Trevail et al. (2015) mainly sampled sub-adults. The plastic burdens in fulmars from Svalbard are known to differ among age classes as shown by Tulatz et al. (submitted); a higher number and mass of ingested plastic were found in fledglings. The same observation was made with birds from Greenland (van Franeker et al., 2022). Besides the plastic burden, it seems the type of ingested plastic has changes over the years. While fragments always constituted the dominant shape, user

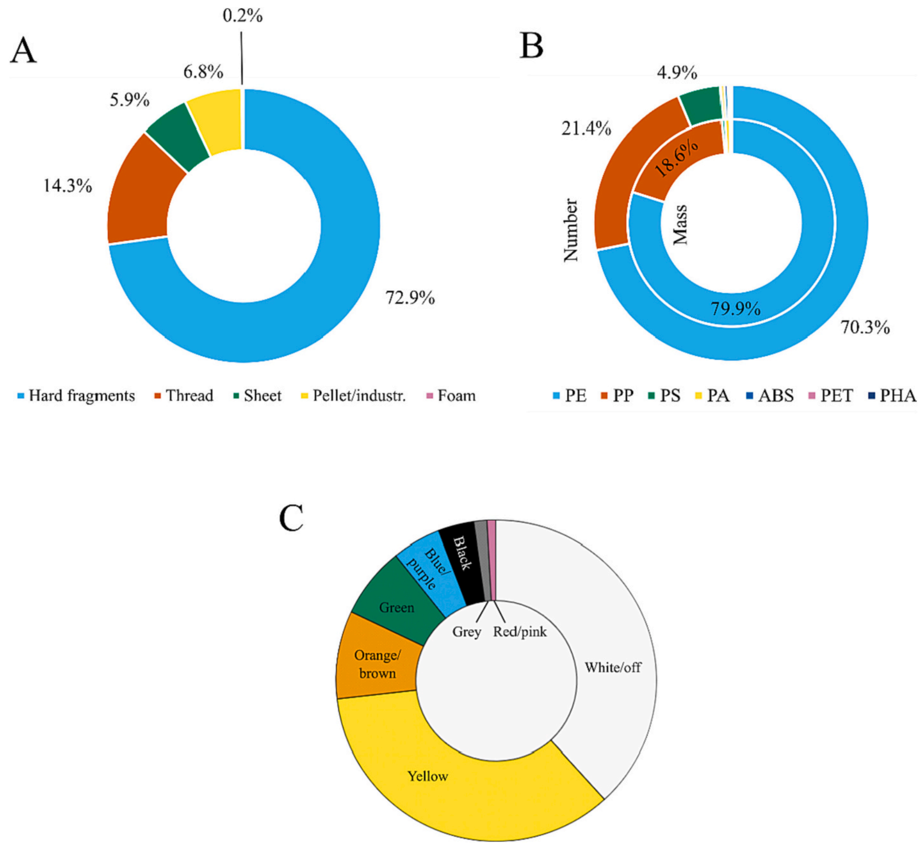


**Fig. 2.** Proportion of (A) shapes, (B) polymers and (C) colours among the ingested plastics. ABS: acrylonitrile butadiene styrene, PA: polyamide, PE: polyethylene, PET: polyethylene terephthalate, PHA: polyhydroxyalkanoate, PP: polypropylene, PS: polystyrene.

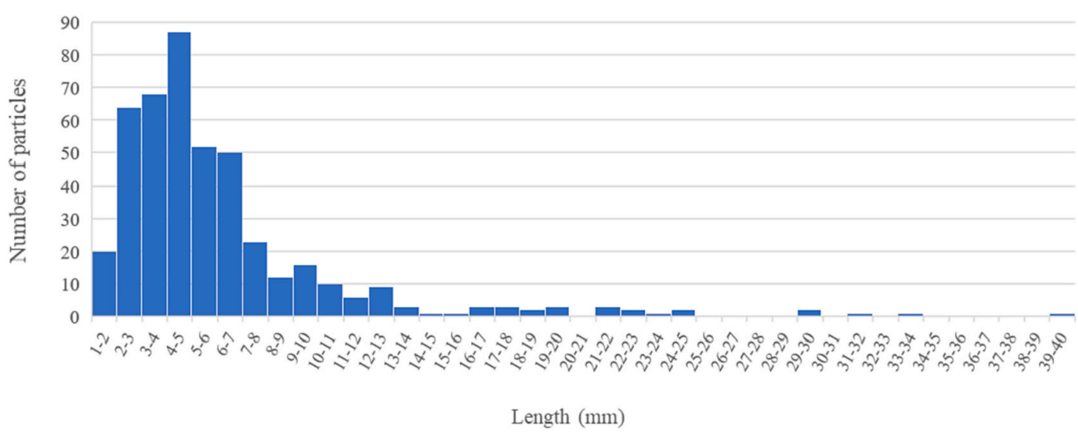


**Fig. 3.** Number of plastic pieces in total for each size class.

**Table 3**
Summary of data on plastic ingestion by the fulmar in Svalbard. FO: frequency of occurrence.

| Sampling year | FO (%) | Plastic burden | Study |
|---|---|---|---|
| 1980 | 82 | 4–5 items/ind. | Van Franeker 1985 (Bjørnøya) |
| 1997 | 91 | 10.3 items/ind.<br>0.070 g/ind. | This study |
| 2013 | 87.5 | 15.3 items/ind.<br>0.08 g/ind. | Trevail et al., 2015 |
| 2020 | 95 | 36.1 items/ind.<br>0.21 g/ind. | Tulatz et al. (submitted) |

plastics were found in 36 % of the fulmars sampled in 1980 on Bear Island (van Franeker, 1985), in 7 % of fulmars from this study, in 23 % in fulmars sampled in 2013 (Trevail et al., 2015) and 49 % in fulmars sampled in 2020 (Tulatz et al. submitted). There seems to be no clear time trend but exposure to user plastics may depend on the foraging area. Differences in sampling time and sampling type might also play a role in the abundance of ingested plastic, due to the impact the breeding season has on ingested plastic burden caused by feeding chicks (Tulatz et al., submitted). Simultaneously, the sampling technique is highly important for the evaluation of the occurrence of ingested plastic; collection of birds from by-catch of fishing boats or beached birds, may be starving and/or in bad body condition and perhaps with partial stomach content, while collecting birds alive, at sea or in the nest, will most likely provide the whole stomach content and healthy birds.

As mentioned earlier, few data exist from the 1990s and comparisons with other studies are challenging. Provencher et al. (2014) mentioned unpublished data from 1997 too where 51 % of the fulmars (n = 35) had plastic in their stomach with an average of 1.7 plastic per individual. Those birds were sampled in the Faroe Islands but their age is unknown. This is a lower FO and a lower burden than in our study, perhaps showing the importance of the sampling location and that Svalbard may have been more contaminated than the Faroes back in the 1990s. The birds from this study were collected in March, before the breeding season. The sampling time of the year is not mentioned for the birds collected in the Faroes and could therefore also explain the difference with our results if those were adults, sampled right after the breeding season.

### 4.3. Differences between sexes

In this study, males were shown to have significantly fewer plastic pieces in their stomachs than females. Even though not significant with a *p*-value set at 0.05, females had also a higher plastic mass than males. If the *p*-value was set at 0.1, both the number and the mass would have been significantly different among the sexes. Similarly, if the *p*-value were set at 0.01, the opposite would have been concluded, with no significant difference between the sexes. Therefore, the difference between sexes should be interpreted with precaution. A *p*-value of 0.05 was chosen according to other studies on plastic ingestion by fulmars (Kühn et al., 2021; Mallory et al., 2010; Trevail et al., 2015; van Franeker et al., 2022). The difference between males and females could be explained by the sampling time of the year. The birds were collected in Spring when males are fighting for nest sites and may spit stomach oil at each other or predators. Spitting unloads the proventriculus and plastic could therefore be spat away with oil (van Franeker et al., 2022). This is in accordance with previous studies investigating differences in plastic burden between sexes (e.g. Baak et al., 2020b; van Franeker et al., 2022) and such information should therefore be reported in future studies as it would help to understand the dynamics of plastic contamination in fulmars and to define more defined guidelines for biomonitoring.

### 4.4. Polymer composition

Polyethylene largely dominated plastic polymers found in this study, followed by polypropylene and polystyrene when looking at the numbers or polyamide when considering the mass of ingested plastics. PE and PP are the two most produced polymers in Europe, representing 30.3 % and 19.7 %, respectively (PlasticsEurope, 2021). Both polymers are also less dense than seawater and float at the surface until their density increases by microorganisms' colonisation. They are therefore more available for fulmars, a species which feeds at the sea surface. Comparisons with previous studies are challenging as polymer identification is rarely described in studies focusing on the fulmar (Kühn et al., 2021). However, polymers of plastic ingested by fulmars from several regions have been investigated recently and their results are slightly different from ours. Even though PE and PP dominated the samples, as in our study, PE showed a smaller proportion in mass (<30 % against >70 in our samples) in fulmars collected in the 1990s in the Netherlands. Similarly, only 50 % of the plastic ingested by fulmars collected in Svalbard, but in 2013, were made of PE (Kühn et al., 2021). It seems to be the opposite for PP, found in higher loads by Kühn et al. (2021). Those differences could be explained by a difference in the sampling year or the sampling location. Neumann et al. (2021) found very similar proportions of PE and PP (73.6 % and 17.9 %, proportions related to the number of particles) than in this study even though the fulmars came from Norway and not Svalbard, and were collected between 2013 and 2016, not in 1997. Kühn et al. (2021) showed that the polymer proportions differed among shape categories. Several factors seem to play a role in the polymer distribution of plastics in fulmars. Therefore, we suggest including polymer identification in biomonitoring programmes as it would help evaluate the effectiveness of mitigation measures (Kühn et al., 2021). In addition, some plastic polymers are more hazardous than others (Lithner et al., 2011). Providing such data is therefore valuable also in the frame of the seabird's health.

### 4.5. Colour of ingested plastic particles

Maritime shipping in the Arctic is increasing due to a growing population requiring more supplies, a growth of tourism activities and exploration for undiscovered natural gas and oil sources (Arctic Council, 2009). In addition, the consequences of climate change in the Arctic also support the assumption that maritime shipping will keep on increasing in the Arctic (Arctic Council, 2009). In this study, hard fragments and threads were the most common shapes. Hard fragments come from the fragmentation of bigger pieces while threads are suspected to find their origin in fishing gear (Murray and Cowie, 2011), i.e. ropes and nets, especially green threads (Liboiron et al., 2016, 2019). Commonly, fishing nets are often green or of clear colours (Hanamseth et al., 2018), which represent 42.6 % of all the threads found in this study. Since white plastic pieces can become more yellow due to solar radiation exposure (Andrady, 2015) and perhaps due to the stomach oil produced by fulmars, yellow threads could have been of light colours originally. If yellow threads are included in the clear colour category, the percentage goes up to 54.4 %. This supports our assumption that fishing activities pollute the Arctic with plastics, whose are ending up in seabirds' stomachs represented by the fulmar in this study. Fishing and other maritime activities are a source of plastic pollution (Bergmann et al., 2022; Grøsvik et al., 2018) and their development will consequently likely lead to an increase in marine plastic pollution.

### 4.6. Biomonitoring

Biomonitoring is an important tool that is lacking in the Arctic about plastic pollution as it only exists in Iceland since 2018 (Snæþórsson, 2021). This pollution increases globally and the Arctic could be a sink for plastic litter from both local and distant sources (e.g. Bergmann et al., 2017a, b; Van Sebille et al., 2012). Plastics impact Arctic wildlife and this pollution needs to be monitored. As in the North Sea area, the northern fulmar seems to be a good candidate for which we already have data from several Arctic regions and several decades. However, attention must be paid to many parameters that influence the ingestion of plastics by those birds. Indeed, the age, sex, location, season, foraging areas among others (e.g. Mallory, 2008; van Franeker et al., 2022) seem to impact the ingestion of plastics and can therefore lead to bias. It is important to report as many details as possible (e.g. particle size, sex, age, location in the gut tract) to place the data in the context of population dynamics (Roman et al., 2020). Despite the lack of precise age classification, we believe these data are very valuable in the framework of biomonitoring as there are few reports of plastic ingestion by seabirds in the Arctic. This study falls within the search for an appropriate candidate to monitor plastic pollution in the Arctic, as demanded by several international expert groups, e.g. the Arctic Monitoring and Assessment Programme (AMAP) and the Protection of the Arctic Marine Environment (PAME) groups (AMAP, 2021; PAME, 2019).

## 5. Conclusion

We provided evidence that northern fulmars from Svalbard were already highly contaminated in plastic in 1997. We showed that a similar percentage of birds had ingested plastic in 1997 compared to more recent years and this study highlights the importance of studying the impacts of such ingestion as seabirds seem to have been ingesting plastics for decades, even in remote places such as Svalbard. Several generations of fulmars were then exposed to plastics with unknown consequences both at an individual and at a population level. We also want to highlight the need for a biomonitoring programme in the Arctic and this study shows that the fulmar is a relevant candidate, as already shown for the North Sea and supported by other studies and reports.

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## CRediT authorship contribution statement

**France Collard:** Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Georg Bangjord:** Resources, Writing – review & editing. **Dorte Herzke:** Resources, Writing – review & editing. **Geir W. Gabrielsen:** Resources, Writing – review & editing.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: France Collard reports financial support was provided by The Fram Centre. Dorte Herzke reports financial support was provided by Research Council of Norway.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2022.114333.

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