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First documentation of plastic ingestion in the arctic glaucous gull (*Larus hyperboreus*)

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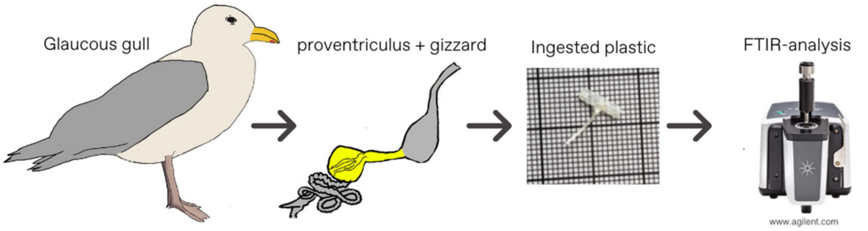
HIGHLIGHTS

- There are existing knowledge gaps on plastic ingestion in arctic gulls.
- Glaucous gulls (*Larus hyperboreus*) from Svalbard were examined for plastic.
- We documented plastic ingestion for the first time in glaucous gulls.
- The findings showed a low frequency of occurrence.
- Existing monitoring programs on glaucous gulls should include plastic identification and evaluation.

GRAPHICAL ABSTRACT



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ABSTRACT

Arctic wildlife is facing multiple stressors, including increasing plastic pollution. Seabirds are intrinsic to marine ecosystems, but most seabird populations are declining. We lack knowledge on plastic ingestion in many arctic seabird species, and there is an urgent need for more information to enable risk assessment and monitoring. Our study aimed to investigate the occurrence of plastics in glaucous gulls (*Larus hyperboreus*) breeding on Svalbard. The glaucous gull is a sentinel species for the health of the arctic marine ecosystem, but there have been no studies investigating plastic occurrence in this species since 1994. As a surface feeder and generalist living in an area with high human activity on Svalbard, we expected to find plastic in its stomach. We investigated for plastic >1 mm and documented plastic ingestion for the first time in glaucous gulls, with a frequency of occurrence of 14.3% ($n = 21$). The plastics were all identified as user plastics and consisted of polypropylene (PP) and polystyrene (PS). Our study provides new quantitative and qualitative data on plastic burden and polymer type reported in a standardized manner establishing a reference point for future research and monitoring of arctic gulls on national and international levels.

1. Introduction

Plastic pollution is posing an increasing global crisis, and it is threatening the health of our marine ecosystems. Plastics occur in all marine environmental compartments, also in remote areas, such as the Arctic (UNEP, 2016; Tirelli et al., 2020; Baak et al., 2021). The plastic in the Arctic derives from a combination of local and distant sources, but how the arctic conditions affect transport, bioavailability, and degradation is to date not fully understood (reviewed in Halsband and Herzke, 2019). Consequently, arctic seabirds are increasingly exposed to plastic pollution, resulting in the potential for ingestion and entanglement (reviewed in Collard and Ask, 2021). The potential for adverse effects from plastic pollution on seabirds on individual and population levels is of concern and climate change will further exacerbate the spreading of plastic pollution in the Arctic (Ford et al., 2022). Arctic seabirds are already vulnerable to several other environmental threats, such as rising temperatures and ocean acidification; offshore oil and gas activity; increased shipping traffic which overlaps with

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key seabird areas; commercial fisheries; altered and destroyed habitats; and hazardous chemical pollution (Huntington, 2009; Letcher et al., 2010; Humphries, 2012; Dietz et al., 2019; IPCC, 2019; Linnebjerg et al., 2021).

According to decades of research, the highest level of plastic occurs in the Procellariiformes (e.g., the northern fulmars (*Fulmarus glacialis*)) due to unselective surface-feeding and stomach morphology (Van Franeker and Meijboom, 2002; Provencher et al., 2014; Poon et al., 2017). Trevail et al. (2015) found that plastic ingestion in northern fulmars breeding in Svalbard (Norway) had increased over the years and that the results contradicted the established trends of a decrease with latitude and distance to dense human populations. Poor waste management and high human activity including tourism lead to a high pollution pressure on Svalbard (Bergmann et al., 2022 and references therein).

Another surface-feeding seabird that breeds in Svalbard is the glaucous gull (*Larus hyperboreus*). The species belongs to the Laridae family in the Charadriiformes order, in which several species are known to ingest plastic (O'Hanlon et al., 2017). Morphological characteristics of the gastrointestinal tract (GIT) influence the accumulation of plastics as some seabird species can regurgitate hard objects, like the gulls, while others, like the Procellariiformes, have a narrow sphincter between the proventriculus and the gizzard that does not allow them of ridding themselves of ingested plastics to the same degree and mainly depend on excreting the plastic through feces (Ryan, 1987; Acampora et al., 2014; Ryan, 2019). Gulls may therefore have a lower level of accumulated plastic in their stomach than the Procellariiformes, while the ingestion rate may still be the same or higher (Jardine et al., 2021).

The glaucous gull is a top predator and one of the largest gulls breeding in the Arctic. The circumpolar Arctic holds the entire worlds breeding population of glaucous gulls of which some of the populations are declining significantly (e.g., Bjørnøya) while others are stable or increasing (e.g., Greenland) (Petersen et al., 2015). The overall population in Svalbard is now considered to be vulnerable (Norwegian Red List, 2021) and this may relate to the Svalbard archipelago being one of the most polluted polar regions in terms of anthropogenic chemicals (Verreault et al., 2010 and references therein). The glaucous gulls in Svalbard have exceeded the effects threshold for several persistent organic pollutants (reviewed in Gabrielsen, 2007) and are annually monitored for chemical contaminants (Gabrielsen, 2007; Letcher et al., 2010; Dietz et al., 2019). However, the research field of plastic is relatively young, and we lack important knowledge about plastic ingestion and effects in these arctic gulls, including the potential exposure to toxic plastic-derived chemicals. There has been one previous report of a single particle assumed to be plastic in a glaucous gull in Alaska (Day, 1980), but the particle was lost before it could be thoroughly examined. Three other studies have also examined the diet and stomach content of glaucous gulls, two from Svalbard in the '80s (Mehlum and Giertz, 1984; Lydersen et al., 1989) and one from Frans Josef Land in the early '90s (Weslawski et al., 1994), but none recorded plastic occurrence. The lack of recent data on plastic ingestion in glaucous gulls urges for a study dedicated to examining plastic ingestion in this species. The arctic countries, through the work under the Arctic Council, are responsible for the conservation of the glaucous gull species (Petersen et al., 2015). In this context, gaining better knowledge on the potential threat that plastic, once ingested, can pose for glaucous gulls will yield a greater understanding of the multiple stressors exerted on these birds.

The aim of the present study was to provide new knowledge on plastic ingestion in glaucous gulls in Svalbard. To do so, we investigated adult individuals near Longyearbyen, an arctic settlement with high human activity and an open landfill. Based on the omnivorous feeding ecology of the glaucous gull and the sampling location, we expected to find plastic in their stomachs. In recent years, research on plastic pollution in seabirds has been complemented by polymer identification. This study is the first study on plastic ingestion combined with polymer identification for glaucous gulls in the Arctic (Fig. 1).

2. Methods

The methodology implemented in our study aligns with the recommendations in Provencher et al. (2017) and Provencher et al. (2019) in relation to sample collection, processing, and reporting plastic ingestion.

2.1. Sampling species and study location

There are four subspecies of glaucous gulls (*Larus hyperboreus*), and the Svalbard population belongs to the subspecies L. *h. gunnerus*. The sampling took place in May 2018 as part of an ongoing research project registered in the Research in Svalbard (RiS) database (RIS 10654). Adult glaucous gulls were shot with a shotgun from a buster boat in the Adventsfjord outside of Longyearbyen in Svalbard (78°23′N, 15°59′E). The birds were dissected in the field, and the stomachs were wrapped in aluminum foil and individually bagged. The below-zero temperatures allowed the samples to quickly cool down before they were stored in a −20 °C freezer. In total, stomachs from 21 adult glaucous gulls were analyzed in this study.

Longyearbyen is a human settlement of around 2500 people located in the innermost part of Adventfjorden that counts one open landfill. Statistics retrieved from Visit Svalbard (https://www.visitsvalbard.com/dbimgs/Årsstatistikk2019_generell(2).pdf) show that in 2019, Longyearbyen had around 80,000 guest nights and over 60,000 cruise passengers visiting.

2.2. Stomach dissection and processing of samples

The frozen stomachs (proventriculus and gizzard) were later analyzed for ingested plastic following the protocol for stomach processing by the North Sea Fulmar Study (OSPAR, 2015), as this is the recommended best practice in Provencher et al. (2017). The method focuses on plastic larger than 1 mm, and samples are not prone to contamination from air and water. Nevertheless, a white cotton lab coat was used to prevent contamination from clothing, and only equipment in glass or metal was used. The stomachs were thawed and gently cut open and thoroughly rinsed over a 1 mm mesh sieve. Because we only searched for plastic pieces larger than 1 mm, using cold fresh tap water was sufficient according to the protocol. The contents of the proventriculus and gizzard were analyzed separately, and the diet material was written down. All pieces were first identified by visual examination of the sieve. Then a Leica M60 stereomicroscope (magnification range 6.3×–40×) was used to examine the surface characteristics to determine if a piece could potentially be plastic. All the pieces suspected to be plastic were collected, dried, and weighed using an analytic Sartorius scale to an accuracy of ±0.0001 g, and the length was measured in mm using a digital caliper including two decimals. The plastic pieces were categorized into size groups following the definitions by Barnes et al. (2009), as recommended by Provencher et al. (2017); microplastics (1–5 mm), mesoplastics (>5–20 mm), macroplastics (>20–100 mm), and megaplastics (>100 mm). The plastic pieces were visually sorted as either industrial plastic (nurdles used as raw material in plastic production) or user plastic from consumer and commercial sources (sheet, thread, foam, fragment, and other), according to van Franeker et al. (2011). The plastic pieces were assigned a color using a color wheel and grouped into eight broad color groups, following the guidelines by Provencher et al. (2017); off-white/clear; grey-silver; black; blue-purple; green; orange-brown; red-pink; yellow. After cutting and scraping the plastic pieces that had biofouling for the FTIR analysis (explained below), the assigned color was considered to be the original color.

2.3. Fourier-transform infrared spectroscopy (FTIR)

A Cary 630 FTIR spectrometer with Diamond Attenuated total reflectance (ATR) accessory (Agilent, CA, USA) was used to collect spectra from 4000 cm^{-1} to 650 cm^{-1}. The resolution was set at 8 cm^{-1}. The ATR diamond crystal was cleaned, and a background scan was performed between each sample. The pieces were placed on the crystal covering the entire

Fig. 1. The general breeding distribution for glaucous gulls and the sampling site for the individuals in our study (Longyearbyen, Svalbard). AMAPs geographical cover is outlined.

surface area of the crystal and clamped down to ensure good contact between the crystal and the sample. The absorption bands of the sample were recorded and compared to the reference spectra in the demo library of the computer by a similarity search algorithm. The match between the sample spectrum and the reference spectrum is given a score in the Hit Quality Index (HQI) between zero and one, where one is a perfect match. The polymers were identified as a given plastic polymer if the HQI was ≥0.7.

2.4. Data reporting

All data were collected and presented, using abundance values (including all individuals examined), as recommended in Provencher et al. (2017) and Provencher et al. (2019). Thus, the frequency of occurrence (FO) for plastic ingestion was reported with 95% confidence interval using "Jeffreys interval". All biometric and other numeric data were compiled in Microsoft Excel, and the statistics were carried out in R version 1.4.1103 (R Development Core Team, 2021) using R Studio. The package pastecs (Grosjean and Ibanez, 2018) with stat.desc were used to obtain the desired metrics. The frequency of occurrence with a 95% confidence interval was calculated using the Epitool online calculator (see: https://epitools.ausvet.com.au/ciproportion).

3. Results

In total, 21 adult glaucous gulls sampled in May 2018 were analyzed for plastics >1 mm. Of those, eight were males, and 13 were females. The birds were in good condition with a mean body mass of 1689 ± 352 g, and half of the birds had natural food items in their stomachs such as seeds and crustaceans. With plastic found in 3 of 21 individuals, the frequency of occurrence of plastic in their stomach was 14.3% (CI [4.2%; 33.4%]), with all plastic items found in the gizzard. Some of the birds had stomach ulcers, and these were birds both with and without plastic. In total, we found three pieces of user plastics and individual glaucous gulls contained either no or 1 piece of plastic with a mean number of 0.14 ± 0.35 (Table 1). The first plastic piece was a piece of white foam weighing 1.4 mg and measuring 3.17 mm (microplastic). The white foam piece was identified as polystyrene (PS). The second piece was a clear swift tack for a price tag weighing 13.6 mg and measuring 11.2 mm (mesoplastic). The swift tack was categorized as "other" and identified to be polypropylene (PP). The third piece was a white hard fragment that weighed 143.5 mg and measured 16.3 mm (mesoplastic) and was identified to be PP. The color of the plastic pieces was exclusively in the category off-white/clear.

Table 1

Showing mass (mg) and number of pieces of plastics found in stomachs of adult glaucous gulls ($n = 21$ individuals) sampled in Svalbard in May 2018. Summary statistics are calculated using abundance values and given as mean ± standard deviation (SD), standard error of the mean (SEM), median, and range (min-max).

	Mass (mg)				Number of pieces			
	Mean ± SD	SEM	Median	Range	Mean ± SD	SEM	Median	Range
Total plastics	7.55 ± 31.30	6.83	0	0–143.5	0.14 ± 0.35	0.08	0	0–1
Industrial nurdles	0	n.a	n.a	n.a	0	n.a	n.a	n.a
User plastic:								
Sheet	0	n.a	n.a	n.a	0	n.a	n.a	n.a
Thread	0	n.a	n.a	n.a	0	n.a	n.a	n.a
Foam	0.07 ± 0.30	0.07	0	0–1.40	0.048 ± 0.22	0.048	0	0–1
Hard fragment	6.83 ± 31.31	6.83	0	0–143.50	0.048 ± 0.22	0.048	0	0–1
Other	0.65 ± 2.97	0.65	0	0–13.60	0.048 ± 0.22	0.048	0	0–1

4. Discussion

4.1. Plastic occurrence

To the best of our knowledge, our study is the first one to document plastic occurrence in glaucous gulls in Svalbard and the Arctic in general if we exclude an anecdotal and incomplete find in Alaska (Day, 1980). Lydersen et al. (1989) documented plastic ingestion in black-legged kittiwakes (*Rissa tridactyla*) from Svalbard back in 1984 (5%, $n = 20$). Based on the feeding ecology of glaucous gulls, it is reasonable to assume that glaucous gulls too have been ingesting plastics for decades, at least on Svalbard.

So far, few studies have investigated plastic exposure in gulls (Wilcox et al., 2015). A recent review on plastic ingestion suggested that gulls are at low risk for plastic ingestion in the Arctic (FO 0–27%), but the lack of recent studies calls for new knowledge (Baak et al., 2021). Studies on herring gulls (*Larus smithsonianus*), great black-backed gulls (*Larus marinus*), and Iceland gulls (*Larus glaucoides*) sampled at a landfill in Newfoundland (Canada), showed a FO of 48–100% (Seif et al., 2018; Jardine et al., 2021). These two studies also presented a scaled fulmar EcoQO for their study species in their results, but the Fulmar EcoQO threshold values are arbitrary and therefore not scalable to other species outside established monitoring programs. Despite being collected in the high Arctic, the glaucous gulls in our study were sampled in an area with high human activity and near human settlements (including an open landfill) and were therefore expected to have a high FO. The high availability of natural food for the glaucous gulls on the western part of Svalbard may have contributed to the low occurrence of plastic debris in their stomachs if we assume that the plastic was actively eaten. When plastic is ingested passively or via prey, the exposure will not be negatively affected by high food access. Regional differences in plastic pollution and migration strategy will affect the seasonal plastic loading in a given species (Baak et al., 2021). The glaucous gulls breeding in Svalbard usually arrive at the breeding site in March/April. Given their ability to regurgitate indigestible food items, we can assume that our findings are representative of the sampling location as the birds were collected in May.

Despite the dominating presence of plastic pollution from fisheries in arctic waters (Bergmann et al., 2017; Grøsvik et al., 2018), the present study did not detect any plastic resembling fishing gear. The plastics we found in the stomachs of adult glaucous gulls were all in the category of user plastic, but this does not exclude marine human activities as a potential source. Although no data on the occurrence of industrial plastics in glaucous gulls are available, a study by Seif et al. (2018) examined 284 pieces of debris in other gulls and found only one single industrial pellet. The investigation of plastic in seabirds since the 1980s has shown a change in the global plastic composition where industrial plastic is declining, and user plastics dominate (Ryan, 2008; Ask et al., 2020; Kühn et al., 2021).

In spite of our small sample size, the glaucous gulls contained one piece of styrofoam, one hard fragment, and one swift tack for price tags, representing two different polymer types (see below). This illustrates that they can ingest various types of plastics of micro-and *meso* size. The debris ingested by gulls in Newfoundland was also mostly mesoplastics (Seif et al., 2018) and mainly in the white/clear category (45%). Similarly, the color composition that dominated the samples in our study was clear and white, further not supporting the preference of colorful prey as a reason for plastic ingestion by gulls.

The plastics in the stomachs of glaucous gulls were polypropylene (PP) and polystyrene (PS), and these are two of the most produced types of polymers (Plastics-Europe, 2020). An important observation from Kühn et al. (2021) was that the available plastic category seemed to be the driving factor of the polymer types found in the birds and not the preference for the polymer type itself. Knowledge on polymer identity is valuable when assessing the behavior and fate of marine plastics (Cincinelli et al., 2017; Jung et al., 2018), as well as plastic-associated contaminants that could be absorbed by the seabird (Provencher et al., 2019; Tanaka et al., 2019).

4.2. Future research

In 2021, the Conservation of Arctic Flora and Fauna (CAFF) suggested the northern fulmars, thick-billed murres, and black-legged kittiwakes as indicator species of plastic pollution in the Arctic (Baak et al., 2021). AMAP has in their Litter and Microplastics Guidelines (AMAP, 2021) suggested that regurgitated pellets from gulls are collected in future waste management actions. Regurgitated pellets can provide useful information on point sources of pollution as pellets contain large enough plastic pieces to easily detect with existing methods (Hammer et al., 2016). Glaucous gulls are currently annually monitored in Svalbard (as part of the MOSJ and SEAPOP program), and as well in Canada, Alaska, and Russian Federation (CAFF, 2017). AMAP (2021) has suggested that regurgitated pellets are collected in connection to such existing programs and recommended that the monitoring programs include plastic-derived contaminants as well. The physical properties of plastics, especially microplastic and nanoplastic, enable strong chemical adsorption to hydrophobic pollutants, but we still lack in-situ knowledge on the potential plastic mediated pathway for chemicals to arctic biota (Rowlands et al., 2021). The toxic effect from ingested plastic may have a great negative impact at the individual-, population- and ecosystem levels (Tanaka et al., 2013, 2019, 2020). Lavers et al. (2019) recommended taking the research further by including physiological parameters in the plastic ingestion studies. This will paint a more nuanced picture of the effects of plastic on individuals. For regions where glaucous gulls are not sampled regularly, opportunistic studies taking advantage of collaborations with local hunters in areas where traditional hunting of glaucous gulls is practiced (e.g., Greenland) can be very useful. The methodological development of non-invasive techniques (e.g., biomarkers, ultrasound) to prevent birds from being culled should be prioritized.

5. Conclusion

The present study provided a snapshot of the status of plastic occurrence in adult glaucous gulls breeding in the Arctic, showing a low FO that may be explained by plentiful access to natural food items and the ability to regurgitate indigestible items. Our data will establish an updated pollution status for future research and monitoring of the vulnerable glaucous gull population in Svalbard and serve as a reference value for glaucous gull populations in the circumpolar Arctic. As human population and activity increase in the arctic regions and climate is changing faster than anywhere else in the world, the future pressure on arctic seabirds is cause for concern and international research cooperation. Our study has provided new quantitative and qualitative data on plastic loading and polymer type reported in a standardized manner. Non-invasive methods should nevertheless be further investigated as the preferred method, and the research on the ecotoxicology of ingested plastic should be intensified.

CRediT authorship contribution statement

Conceptualization: SCB, GWG.
Formal analysis: SCB.
Funding acquisition: GWG.
Investigation: SCB.
Methodology: SCB, GWG, AA.
Project administration: SCB, GWG.
Resources: DH, GWG.
Supervision and Validation: GWG, SB, DH.
Writing original draft: SCB.
Review & Editing: SCB, GWG, SB, DH, FC, AA.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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