Nordic Council of Ministers

Plastic characterization in northern fulmars *(Fulmarus glacialis)*

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Summary

Northern fulmars (*Fulmarus glacialis*, hereafter fulmar) are pelagic seabirds prone to ingest plastics, a phenomenon which has been well-documented in the scientific literature. However, so far most of the knowledge on the plastic ingestion by fulmars is on physical characteristics such as the type of plastics (industrial pellets, fragments, sheets, threads, foam), the size, mass, and colour, while information on the underlying polymer backbone of the plastics is lacking. By investigating this, an additional layer of information regarding the plastic ingestion by fulmars would be revealed and could potentially be useful in the development of effective monitoring and mitigation strategies, as well as policies for combating marine plastics pollution.

In this study, we combined the chemical polymer identification by Fourier-transform infrared (FTIR) spectroscopy with the physical characterisation of plastic particles ingested by fulmars sampled in the Faroe Islands and north-east (NE) Greenland. An important element of this project was to bring together international experts on plastics, seabirds, and FTIR spectroscopy for a workshop addressing knowledge gaps and the paths forward.

The frequency of occurrence of ingested plastics was high at both sampling locations. There was a significant regional difference in the make-up of the ingested plastics with regards to the physical categories; fulmars from the Faroe Islands had ingested significantly more pellets compared to the fulmars from NE Greenland. The majority of the plastic pieces ingested by fulmars from both locations were polyethylene, followed by polypropylene, and polystyrene and the chemical composition of the plastics did not differ significantly between the two populations. A workshop was successfully organised in Tromsø, bringing international experts together addressing a variety of topics and issues including the results from this study.

Norwegian summary – Sammendrag på norsk

Havhest (*Fulmarus glacialis*) er en pelagisk sjøfugl som ofte spiser plast, noe som er godt dokumentert i den vitenskapelige litteraturen. Men så langt består mesteparten av kunnskapen om plasten som havhesten spiser av fysiske karakteristikker som type plast (industrielle pellets, fragmenter, flak, tråder, skum), størrelse, vekt og farge, mens informasjon om den underliggende polymer-«ryggraden» til plasten mangler. Ved å undersøke dette vil ny informasjon om plasten spist av havhest avdekkes som potensielt kan brukes i forvaltningsøyemed.

I denne studien kombinerte vi identifisering av polymerer, ved bruk av Fourier-transform infrarød (FTIR) spektroskopi, med fysiske karakteristikker av plastpartikler spist av havhest fra Færøyene og nordøst-Grønland. Et viktig element i dette prosjektet var også å samle internasjonale eksperter på plast, sjøfugl og FTIR spektroskopi til en workshop om kunnskapshull og arbeitdet videre innenfor dette forskningsfeltet.

Flertallet av havhestene fra begge regionene hadde spist plast. Det var en statistisk signifikant regional forskjell i den fysiske profilen til plasten: Havhest fra Færøyene hadde spist betydelig flere industrielle pellets enn havhestene fra nordøst-Grønland. Hovedparten av plastpartiklene fra begge regionene besto av polyetylen, fulgt av polypropylen og polystyren. Den kjemiske sammensetningen til plasten var således ikke forskjellig mellom de to regionene. En workshop ble avholdt i Tromsø med deltakere fra seks forskjellige nasjoner hvor mange temaer og utfordringer ble diskutert, inkludert resultatene fra denne studien.

Introduction

The northern fulmar (*Fulmarus glacialis*, hereafter fulmar) is a pelagic seabird with a wide distribution in the northern hemisphere and is found across the north Atlantic, Arctic and northern Pacific oceans (Hatch 1993, Anker-Nilssen et al. 2000). Though fulmar populations have been increasing globally (Birdlife International 2020), the populations from Iceland and Norway remain endangered (Icelandic Institute of Natural History 2020, Norwegian Biodiversity Information Centre 2020), while populations from the Canadian Arctic have declined dramatically over the last 40 years (Mallory et al. 2020).

Fulmars belong to the group of seabirds (the Procellariiformes) identified as the most susceptible to plastic ingestion (Roman et al. 2019) and the most threatened (Paleczny et al. 2015). Due to their susceptibility to ingest plastics and to their wide distribution, fulmars are used as bioindicators of marine plastic pollution within the OSPAR framework (van Franeker et al. 2011, OSPAR 2015). OSPAR has also set a policy target, termed Ecological Quality Objective (EcoQO), specifying that less than 10% of fulmars should have 0.1 g or more of ingested plastics (OSPAR 2008).

The OSPAR commission provides guidelines for the sampling strategy, the bird dissection method, the stomach processing for plastic collection, and for the categorisation of debris (by number, weight, and type of plastic). More recently, Provencher et al. (2017) have suggested to expand the particle characterisation according to size, colour, and polymer type using, for instance, FTIR spectroscopy. Ascertaining the polymer type can function as an additional quality assurance and control step for validation of general visual characterisation of potential plastic particles ingested by fulmars. But it might also be relevant for tracking the source of these plastics, for establishing spatial and temporal trend analyses, and for performing impact assessments. From a biological perspective, knowledge of plastic chemical composition is needed to better understand exposure to and bioavailability of leaching chemicals from plastic (e.g. additives, impurities, and degradation products) and contaminants sorbed to the plastic from the surrounding environment.

So far there is little published information on the polymer composition of plastics ingested by fulmar. However, two recently published studies found that the majority of plastic particles ingested by fulmars were composed of polyethylene (PE) followed by polypropylene (PP) (Tanaka et al. 2019, Kühn et al. 2020b).

When ingested, some types of plastics may leach plastic constituents as well as sorbed contaminants (Tanaka et al. 2013, Kühn et al. 2020a, Neumann et al. In review). The propensity of a plastic to contain additives and contaminants depends on the type of plastic material and on its surface properties (e.g. weathering or build-up of an eco-corona) (Galloway et al. 2017, Hahladakis et al. 2018). Thus, polymer characterisation through FTIR spectroscopy can be an important step towards identifying the load of potentially harmful plastics ingested by fulmars. FTIR spectroscopy can also be used to assess the degree of weathering (Ioakeimidis et al. 2016, Tang et al. 2019) and thereby potentially indicate whether the ingested plastic pieces entered the sea relatively recently or not.

Aims of the study

In this study, our aims were (1) to analyse the plastics ingested by fulmars from Faroe Islands and north-east (NE) Greenland by visual characterisation and FTIR spectroscopy, (2) to evaluate whether there were geographical differences in the polymer composition from these two locations, and (3) to organise an international workshop on fulmars and seabirds in the context of plastic pollution, inviting external experts from Europe and North America.

Materials and methods

Ethics

The fulmars from north-east Greenland were collected according to Aarhus University research permit 2017 on seabirds in Greenland Sea, NE Greenland, from the Ministry of Fisheries and Hunting in Greenland (Document No. 5261991).

On the Faroe Islands, hunting fulmars is permitted year-round and the fulmars used in this study were obtained through an agreement with local hunters.

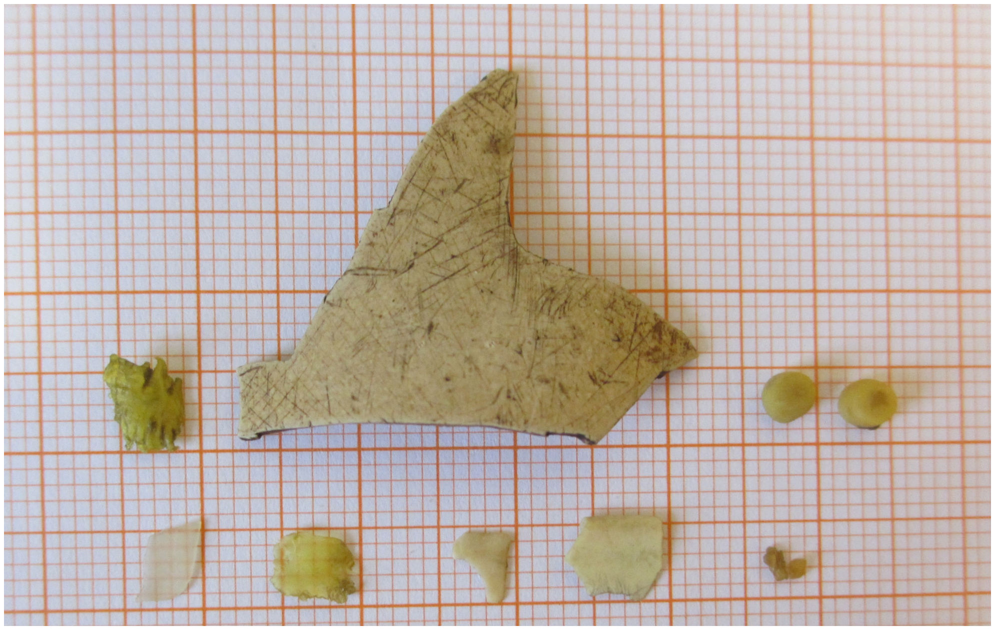
Sampling of fulmars and stomach extraction of plastic particles

In September 2017, 55 fulmar fledglings from the Faroe Islands were caught as part of a traditional hunt. Stomachs from these were saved and frozen at -20 °C and brought to Wageningen Marine Research, Den Helder, the Netherlands, where they were dissected according to the protocol detailed by van Franeker et al. (2011) which is in line with the OSPAR monitoring protocol (OSPAR 2015).

A total of 31 fulmars were shot at sea during the environmental research cruise in NE Greenland (NEG cruise) organised by Aarhus University in August–September 2017. The stomachs were dissected out and stored in individual plastic bags at -20 °C. The contents of these stomachs were assessed at Aarhus University, Roskilde, Denmark, firstly to quantify and identify ingested food items, and secondly to collect ingested plastic particles > 1 mm.

Suspected plastic pieces and other items of interest were placed in a petri dish and examined under a stereo microscope. Plastics were classified according to the OSPAR monitoring recommendations as pellets (industrial), or as user plastics: sheet, thread, foam, fragment, or other. The plastic particles were then air dried and weighed.

Figure 1: Plastic particles found in the stomach of a single adult fulmar caught off the shore of north-east Greenland in 2017.



Note: *The pieces are photographed on mm-paper.*

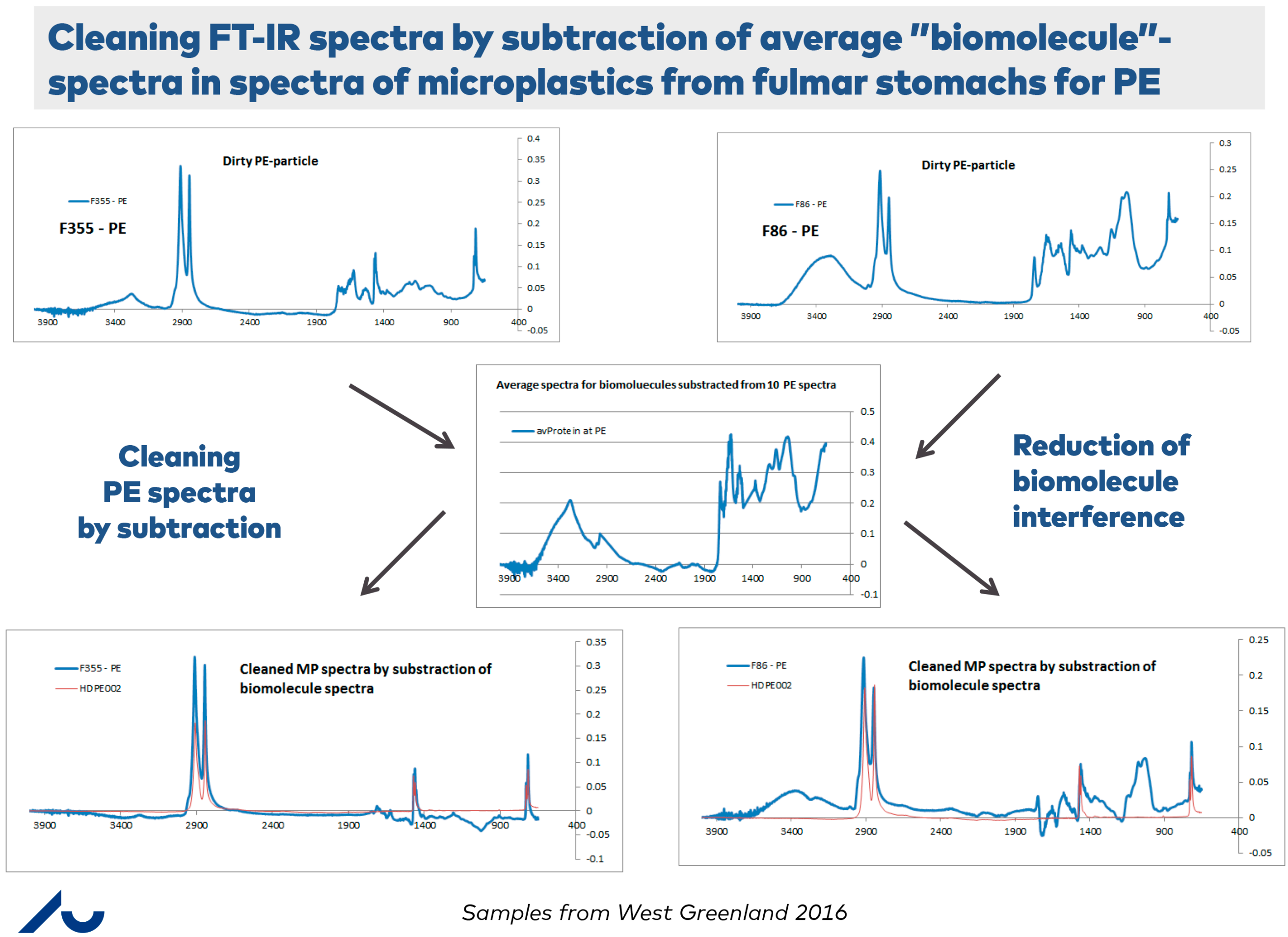
Source: *Amalie Ask, Norwegian Polar Institute.*

Fourier-transform infrared (FTIR) spectroscopy

The polymer composition of the visually identified plastic particles were analysed individually using Fourier-transform infrared (FTIR) spectroscopy at Aarhus University, Roskilde, Denmark between February and April 2019 for the samples from the Faroe Islands and from NE Greenland. The spectrometer used was the portable 4500a with an attenuated total reflection (ATR) diamond crystal (Agilent Technologies, CA, USA). The spectral range was 4000–650 cm^{-1}, 64 scans were performed for establishing background, 32 scans were performed when analysing samples, and resolution was set to 2 cm^{-1}.

The polymer assignments of the analysed particles were based on comparison with a FTIR spectral library developed at Aarhus University consisting of both various relevant polymers as well as different types of natural organic materials. A threshold level for HQI at 0.7 was applied for positive polymer identification after pre-processing the spectral data using the following steps: Smoothing, baseline correction, normalisation, and in the end subtraction with a spectrum previously isolated from gut-fluid exposed plastics in fulmars for reducing the influence of a potential interfering biological protein-like signal (Figure 2).

Figure 2: Example on improvements in FTIR spectra of polyethylene (PE) microplastics by reducing signals of interferences with subtraction of an average "biomolecule"-spectrum on plastics isolated from fulmar stomachs from Greenland.



Statistical analysis

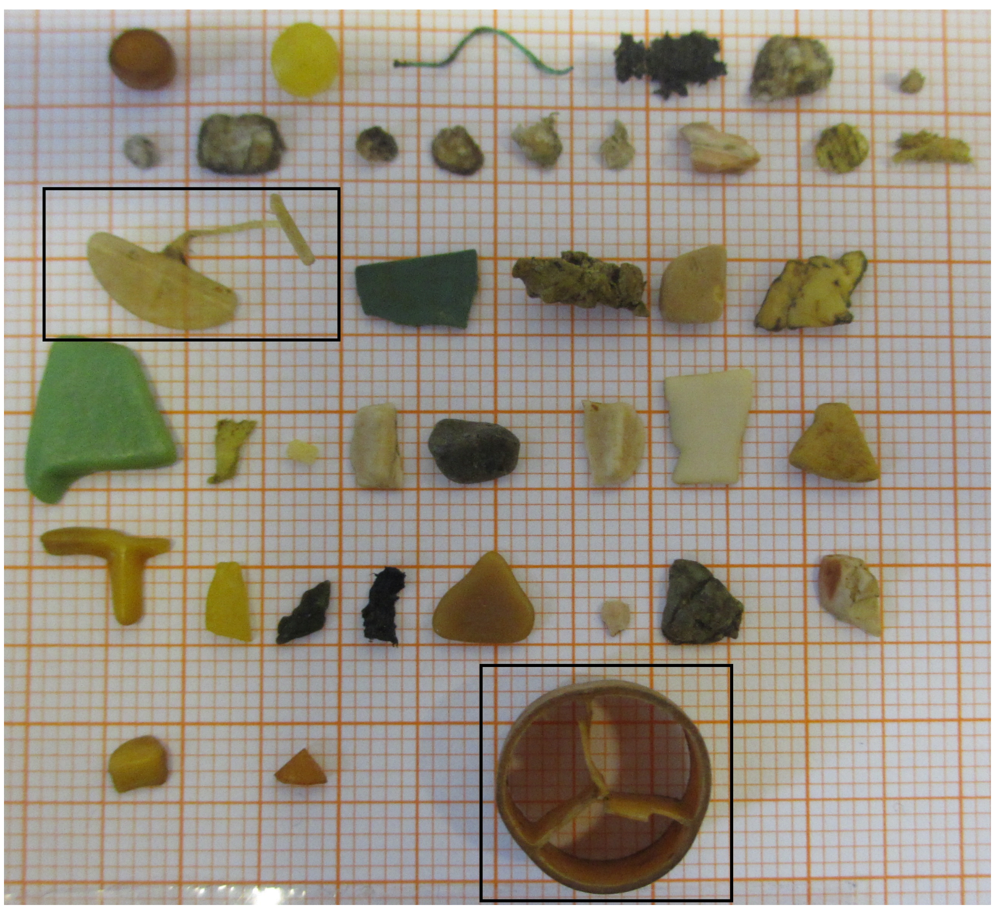
All statistics were performed in R version 3.5.2. The percentage of fulmars with ingested plastics is termed the frequency of occurrence (FO). The binomial confidence interval using the Jeffrey's method was used when calculating the 95% confidence intervals for the FO of ingested plastics, as recommended by Provencher et al. (2017). The mean, standard deviation, standard error of the mean, median, and range of mass and number of pieces are based on the entire data set, including birds without any ingested plastics. Geographical differences in ingested plastics were examined using contingency tables. Statistical significance was set at $p<0.05$.

Results

The sampled fulmars had ingested a variety of plastics, as illustrated by the pellets, thread, sheet, foam, and fragments ingested by a single individual caught in NE Greenland (Figure 3).

Of the 55 Faroese fulmar fledglings, 48 had ingested plastics corresponding to an FO of 87.3% (with a 95% confidence interval (CI) of 76.6–94.1%). Of the 31 fulmars from NE Greenland, 28 had ingested plastics corresponding to an FO of 90.3% (CI: 76.4–97.2%). Summary statistics for the mass and number of pieces ingested are presented in Table 1.

Figure 3: Total stomach plastics content of a fulmar from north-east Greenland.



Note: *The pieces in the black squares have been assigned to the "other" category. The pieces are photographed on mm-paper.*

Source: *Amalie Ask, Norwegian Polar Institute.*

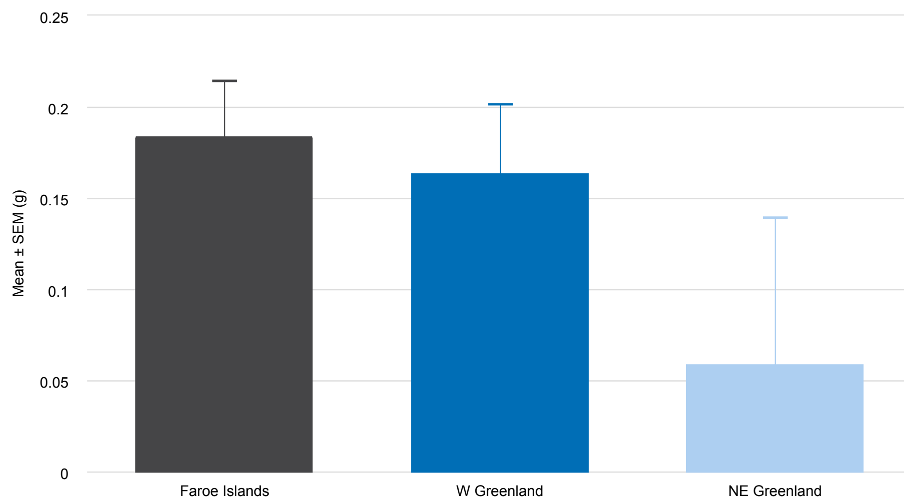
Comparison of the composition of the total numbers of different visually identified categories showed a statistically significant difference between the Faroe Islands and NE Greenland (2x4 contingency table, $p < 0.001$). This difference was primarily due to a significantly lower contribution of industrial pellets to plastic pieces in the fulmars collected in NE Greenland.

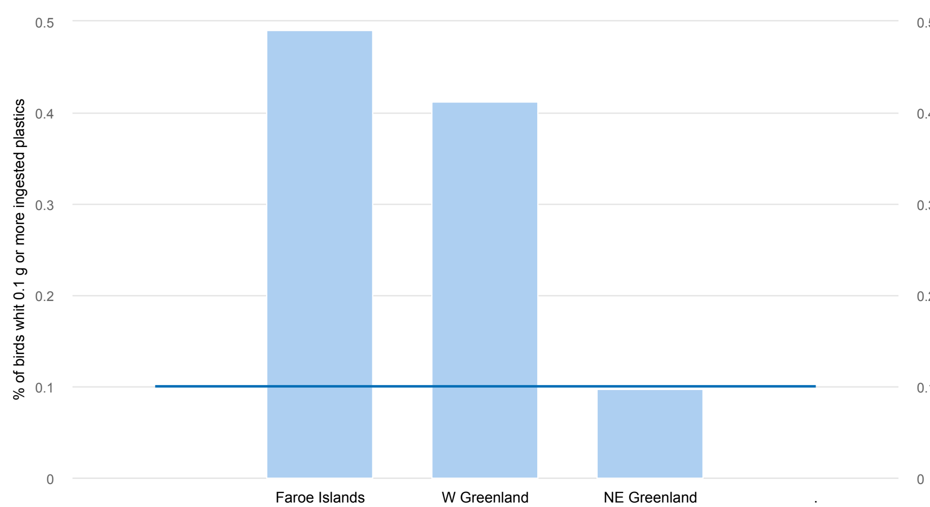
Table 1: Composition of ingested plastic pieces by their visual categories.

		Mass (g)				Number of pieces			
		Mean ± SD	SEM	Median	Range	Mean ± SD	SEM	Median	Range
FAE	**Total plastics**	0.183 ± 0.23	0.031	0.098	0–1.190	11.4 ± 13.2	1.78	9	0–79
	Industrial	0.032 ± 0.05	0.007	0.002	0–0.198	1.36 ± 1.99	0.268	1	0–9
	User	0.151 ± 0.22	0.03	0.084	0–1.162	10.0 ± 12.7	1.71	6	0–77
	Sheet	0.003 ± 0.01	0.001	0	0–0.060	1.67 ± 9.02	1.22	0	0–67
	Thread	0.003 ± 0.01	0.002	0	0–0.087	0.64 ± 1.38	0.186	0	0–6
	Foam	0.007 ± 0.04	0.005	0	0–0.279	0.86 ± 2.07	0.279	0	0–11
	Fragment	0.137 ± 0.22	0.029	0.062	0–1.160	6.82 ± 7.31	0.985	5	0–36
	Other	0.002 ± 0.01	0.001	0	0–0.055	0.04 ± 0.19	0.026	0	0–1
NEG	**Total plastics**	0.058 ± 0.13	0.023	0.02	0–0.636	6.16 ± 8.29	1.49	3	0–39
	Industrial	0.007 ± 0.02	0.003	0	0–0.052	0.26 ± 0.58	0.103	0	0–2
	User	0.051 ± 0.12	0.021	0.011	0–0.584	5.90 ± 8.06	1.45	3	0–37
	Sheet	0.001 ± 0.004	0.0007	0	0–0.020	0.81 ± 2.04	0.366	0	0–11
	Thread	0.001 ± 0.001	0.0003	0	0–0.007	0.39 ± 0.62	0.111	0	0–2
	Foam	0.001 ± 0.003	0.0005	0	0–0.014	0.32 ± 1.45	0.26	0	0–8
	Fragment	0.042 ± 0.09	0.016	0.01	0–0.400	4.29 ± 6.17	1.11	2	0–25
	Other	0.006 ± 0.03	0.006	0	0–0.167	0.097 ± 0.40	0.071	0	0–2

Note: *Mass and number of pieces of plastics ingested by fulmars from the Faroe Islands (FAE, n = 55 birds) and north-east Greenland (NEG, n = 31 birds). The summary statistics are given as mean ± standard deviation (SD), standard error of the mean (SEM), median, and range. The maximum number in the range represents ingestion by a single individual.*

Figure 4: Mean mass of ingested plastics by the fulmars collected from west Greenland in 2016.





***Note: A)** Mean ± standard error of the mean (SEM) of the weight of ingested plastics in grams from fulmars of the Faroe Islands (2017, n = 55), west Greenland (2016, n = 63), and north-east Greenland (2017, n = 31). **B)** The percentage of fulmars which had ingested more than 0.1 g of plastics, with the horizontal line at 10% indicating the EcoQO set by OSPAR.*

Figure 4A shows the mean (± standard error of the mean) mass of ingested plastics by the fulmars, and also includes data on fulmars collected from west Greenland in 2016 (unpublished data, included here for comparison, courtesy of J. Strand). In Figure 4B, the percentages of fulmars which had ingested more than 0.1 g of plastics – thus exceeding the EcoQO – are shown per region, again including fulmars from west Greenland.

The dominant polymer was polyethylene (PE), followed by polypropylene (PP) and polystyrene (PS) in both the Faroe Islands and NE Greenland birds. The specific percentages are shown in Table 2. No significant differences in polymer compositions were found between the two populations (2x4 contingency table, $p > 0.5$).

Table 2: Percentage of plastics ingested by fulmars identified as polyethylene (PE), polypropylene (PP), polystyrene (PS), or other, by FTIR spectroscopy.

Polymer	Faroe Islands (%)	North-east Greenland (%)
PE	66	62
PP	27	31
PS	6	6
Other	1	1

Note: *The total number of plastic pieces analysed were 582 for Faroe Islands and 173 for north-east Greenland.*

Parts of the results included here have already been published in a MSc thesis by Ask (2019).

Plastics and northern fulmars: a two-day workshop

Objective and topics

We aimed to conduct an interactive two-day workshop on plastic ingestion by fulmar and the role of this species as an environmental indicator, with a focus on the importance of polymer characterization and the use of FTIR spectroscopy. This workshop was located in Tromsø, Norway, and the discussions were planned to be centred around:

- The characterization of ingested plastics (visual vs FTIR spectroscopy)
- Alternative sampling techniques (e.g. stomach flushing)
- Data interpretation, e.g. how can the data provided by fulmar stomach plastic content be better collected/analysed for use in management?
- Indicator use within AMAP/OSPAR assessments
- Plastics as vectors for chemical exposure

Workshop attendance

The workshop was held in Tromsø, Norway, 24–25 February 2020. Table 3 lists the attendees and their affiliations. The agenda is included in Appendix A.

Table 3: List of attendees at workshop in Tromsø 24–25 February 2020.

Attendee	Affiliation
Amalie Ask	Norwegian Polar Institute, organizer
Geir W. Gabrielsen	Norwegian Polar Institute, organizer
France Collard	Norwegian Polar Institute
Svenja Neumann	Norwegian Polar Institute
Ingeborg Hallanger	Norwegian Polar Institute
Dorte Herzke	Norwegian Institute for Air Research
Nina Dehnhard	Norwegian Institute for Nature Research
Jakob Strand	Aarhus University
Susanne Kühn	Wageningen University
Marine Cusa	Liverpool John Moores University
Jóhannis Danielsen	Faroe Marine Research Institute
Jennifer Provencher	Environment and Climate Change Canada

Main workshop outcomes

This workshop brought together a panel of experts who discussed several issues and came to the following conclusions:

1. Mandatory data for monitoring purposes need to be kept as simple as possible. For instance, identifying the polymer composition of ingested plastic particles should not be mandatory in monitoring.
2. Parental transfer of plastics to chicks is an important topic and should be investigated further.
3. Plastic-associated chemicals in eggs need to be measured.
4. Studies on ingestion and impact of plastic pollution on Arctic seabirds should also cover other species like black-legged kittiwakes (*Rissa tridactyla*), black guillemot (*Cepphus grylle*), Brünnich's guillemot (*Uria lomvia*), and common guillemot (*Uria aalge*).
5. Alternative sampling techniques need to be carefully considered. For example, if stomach flushing is done, it should only be performed by a trained and experienced person. Ultrasound and x-ray imaging may also have potential for non-lethal methods, but these will require evaluation before being implemented.

Figure 5: Picture from the workshop

From left to right: Jóhannis Danielsen, Svenja Neumann, Nina Dehnhard, Susanne Kühn, Jakob Strand, Amalie Ask, Marine Cusa, France Collard, Jennifer Provencher, Geir W. Gabrielsen, and Dorte Herzke.

Source: *Elin Vinje Jenssen, Norwegian Polar Institute.*

Discussion

Ingested plastics

In accordance with previous studies of plastic ingestion by fulmars from Iceland, Svalbard, and the Canadian Arctic which found a high frequency of occurrence (FO) of ingested plastics (Trevail et al. 2015a, Trevail et al. 2015b, Poon et al. 2017), our results demonstrated a high FO of ingested plastics at both sampling locations.

User-type plastics accounted for the majority of plastics ingested by fulmars from both the Faroe Islands and NE Greenland, in accordance with previous findings (Mallory 2008, Provencher et al. 2009, Avery-Gomm et al. 2012, Kühn and van Franeker 2012, Bond et al. 2014, Avery-Gomm et al. 2018). However, we also found a significant difference in the composition of the ingested plastics when comparing the visual categories. This was particularly obvious for the ingestion of plastic pellets which was significantly lower in NE Greenland fulmars compared to Faroese fulmars. This, combined with the better EcoQO performance observed for NE Greenland fulmars, indicates that the fulmar population in NE Greenland is, perhaps unsurprisingly, predominantly foraging in regions that are less exposed to pollution inputs. Indeed, the water masses off the coast of NE Greenland are largely influenced by the East Greenland Current which transports water down from the Arctic Ocean (Rudels et al. 2002).

It is important to acknowledge that the stomachs of the fulmars from the Faroe Islands were squeezed and, in some cases, torn when the hunters removed them from the carcasses. This has led to some ingested plastics having been lost during this process and, consequently, the data presented herein are not complete. Nevertheless, while this process led to pieces being lost, it will not have introduced any non-ingested plastics to the stomachs and therefore does not change the finding that Faroese fulmars had ingested significantly more pellets compared to the birds from NE Greenland.

Most of the ingested plastics was composed of PE, followed by PP, and PS for fulmars from both sampling locations. Tanaka et al. (2019) analysed fragments and pellets ingested by Faroese fledglings caught in 2010 and also found that the majority was composed of PE (fragments: 71%; pellets: 59%), followed by PP (fragments: 18%, pellets: 21%). They also investigated plastics regurgitated by laysan and black-footed albatrosses (*Diomedea immutabilis* and *Phoebastria nigripes*, respectively) and found that 3% of the pieces were composed of PS. This is lower than in our study, but reasonable given that most pieces identified by us as PS were categorised as foam, which Tanaka et al. (2019) did not analyse. Kühn et al. (2020b) performed a regional comparison of polymer identity of ingested plastics in fulmars from the North Atlantic (the Netherlands, the Faroe Islands, Iceland, and Svalbard). Similar to the current study, they found that the majority of the ingested plastics in all four locations were PE followed by PP.

No significant difference was found between the polymer composition of the plastics ingested by the fulmars from the two locations. This indicates that the visual characterisation of plastic categories can provide a better assessment of composition of plastics pieces relevant for e.g. source tracking than the chemical polymer assignments. The chemical polymer identification can, however, still be relevant for both validation of the visually identified plastics (especially relevant for some more uncertain pieces) and addressing the issues related to exposure to contaminants from different types of plastic materials, e.g. studying relationships between plastic ingested and contaminant loads in individual birds.

Parental transfer

The Faroese fulmars in this study were all fledglings and caught within a few days after leaving the nest. While there was a window where the fledglings could have ingested some plastic themselves, their stomach plastic content was likely predominantly the result of parental transfer. Indeed, a study by Acampora et al. (2017) found plastic in regurgitates from unfledged fulmar chicks. These results are worrying as some fulmar chicks ingesting a lot of plastic might not reach the energy acquisition required for their development, calling for further research on this important issue.

Geography, plastic load, and sampling time

So far most plastic studies on fulmars have been done on beached birds. This presents a problem and uncertainties regarding the origin of the birds and therefore the origin of the plastics found in their stomachs. In an attempt to work around these uncertainties, fulmars caught by long line fishing or hunting have been used in several studies. This provides an exact date and location for where the bird was collected and narrows down the possible foraging area to some extent and thereby the uncertainties regarding the origin of the plastics found in the stomach.

However, given the potentially wide distribution of the fulmar throughout the year the possible foraging area is still quite large. To add to this problem the lack of knowledge regarding retention time of various types of plastics in the proventriculus, gizzard, and guts of the birds increases the probability that plastics found in the stomach originated from somewhere far away from the point of collection.

The development of small and lightweight instruments, so-called light-loggers or GLS (global location sensor) technology, has provided scientists with the means to monitor bird movements throughout the year and since 2014 the fulmar has been one of many species tracked by the international seabird tracking programme SEATRACK. This has revealed that the fulmar spreads out over a large part of the North Atlantic throughout the year, especially during autumn and winter.

Using genetics, Colston-Nepali (2019) showed that a big portion of fulmars collected for studies in the Labrador Sea actually originated from the Faroe Islands. This is also supported by the tracking data from the Faroes since 2015 during autumn and winter (Figures 6–7).

Figure 6: Autumn distribution from 2015 to 2018 of northern fulmars tagged on the Faroe Islands (n=19).

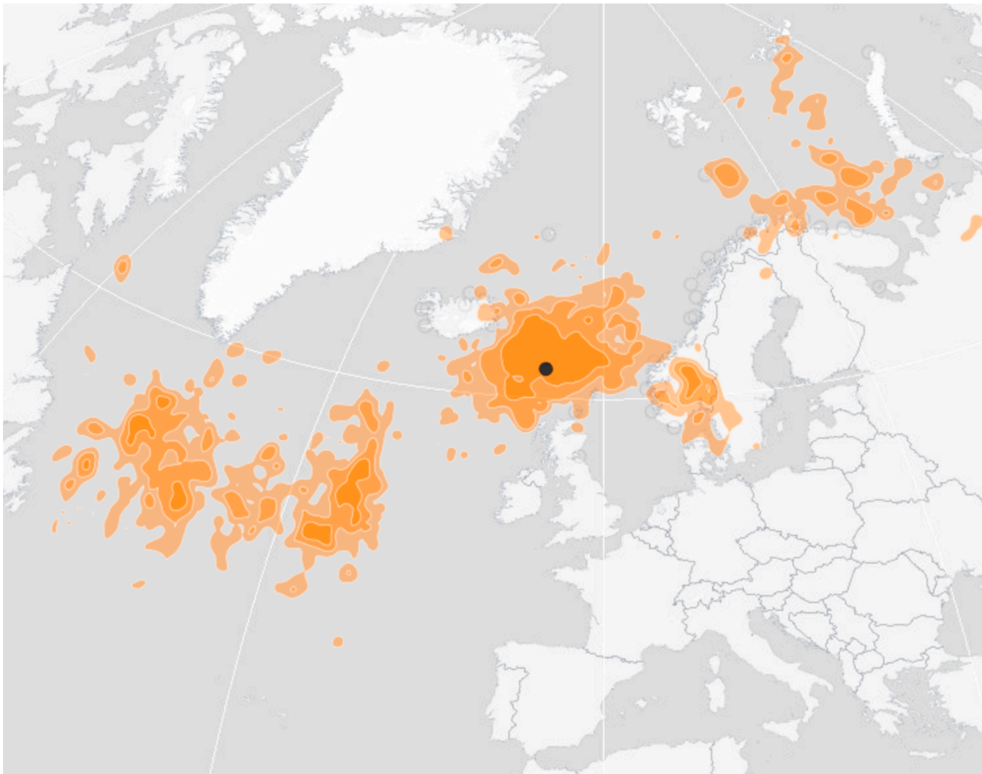
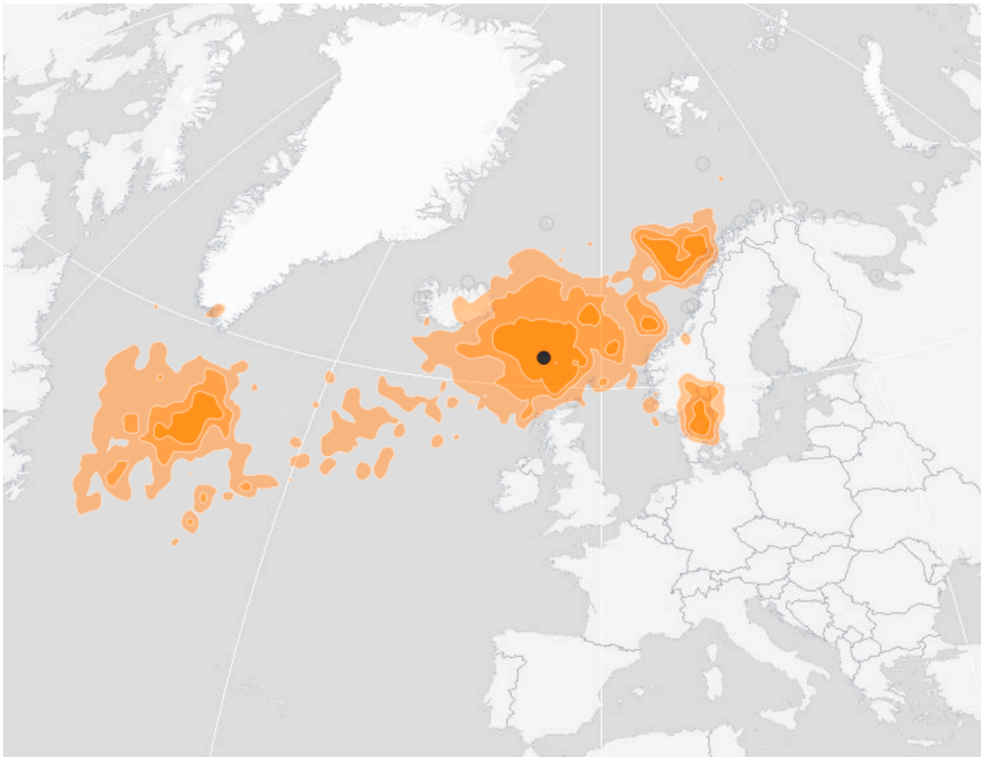
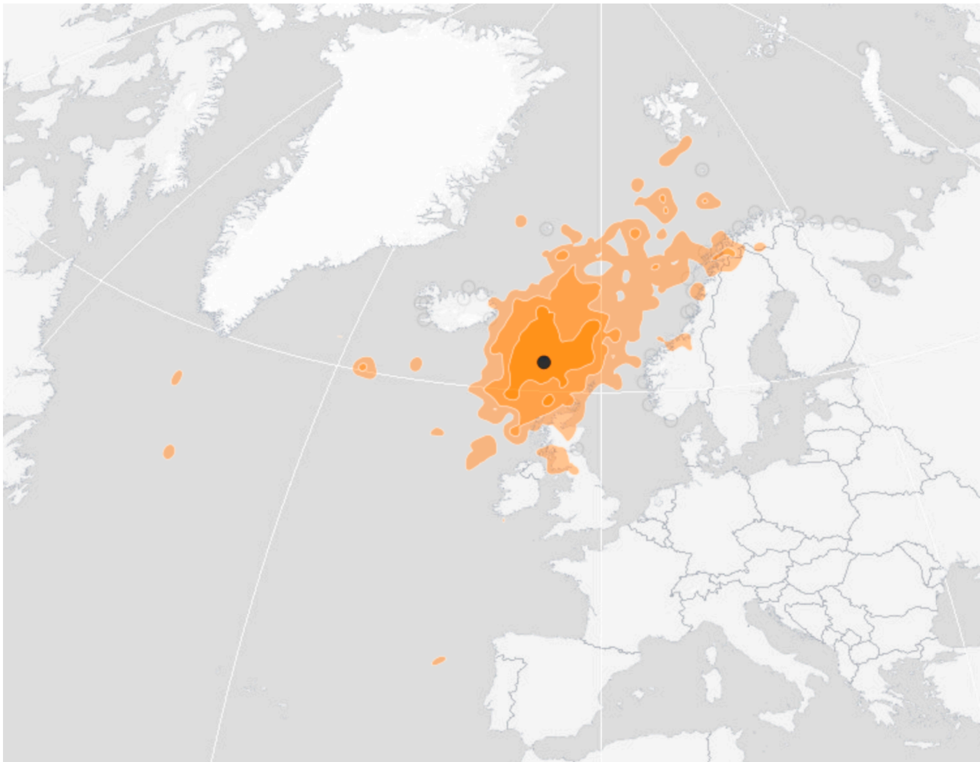


Figure 7: Winter distribution from 2015 to 2018 of northern fulmars tagged on the Faroe Islands (n=19).



Although many seabird species are spread over vast oceanic areas for most of the year, they aggregate on land during the breeding season. During this time of the year the fulmar is restrained in time by the need to return to feed the chick on a regular basis. This means that this also is the time of year where they are most restricted in their distribution which is evident when looking at the summer distribution on e.g. the Faroe Islands (Figure 8) compared to autumn and winter (Figures 6 and 7).

Figure 8: Spring distribution from 2015 to 2018 of northern fulmars tagged on the Faroe Islands (n=18).



During the workshop it was therefore agreed that sampling should be done during summer.

Recommendations and future directions

There was agreement in the workshop that future studies should not neglect investigating the effect of plastic ingestion on seabird eggs and chicks. Additionally, suitable endpoints should be used to investigate potential sub-lethal effects of the plastics ingestion for example, immunological and reproductive endpoints. Furthermore, the longevity of fulmars needs to be considered, as there can be a cumulative effect of stressors over time.

Another agreement from the workshop was that polymer determination should not be mandatory in monitoring programmes as it adds a further financial and methodological burden, though it should be noted that these measurements remain relevant. Indeed, polymer identity can be useful as part of supplementary and more investigative monitoring activities which aim to provide additional information on the composition of plastics, thereby investigating potential sources of plastic pollution.

Project conclusion

Our study demonstrates that northern fulmars from the Faroe Islands and north-east Greenland had high a frequency of occurrence of ingested plastics. While user-type plastics dominated at both locations, there was a significant difference in the physical composition of the plastics with more pellets being ingested by Faroe Islands fulmars compared to NE Greenland fulmars. At both locations most of the plastic pieces were composed of the polymers polyethylene, followed by polypropylene, and polystyrene, and no significant regional difference in the polymer profile was found. Thus, the polymer composition of the plastics does not seem to be bring significant insight in assessing regional differences of the ingested plastics make-up. It may, however, be more relevant for temporal assessments, e.g. to follow mitigative actions on some specific types of polymers used for e.g. single use plastics or expanded polystyrene foams, though this will require further research. Overall, this project successfully investigated the use of plastic polymer characterization as part of plastic ingestion investigation through northern fulmars and established through empirical work and via a panel of experts that differences in regional and life-history stages must be further investigated.

Acknowledgements

We wish to thank the Nordic Council for financing the study, Susanne Kühn and Jan van Franeker for teaching Amalie Ask how to dissect fulmar stomachs and analysing their contents, and Fionn Murphy for teaching Amalie Ask how to perform FTIR spectroscopy. We also thank Anders Mosbech, the North-East Greenland cruise aboard R/V Dana organised by Aarhus University, and the DANCEA funded project SUMAG2 for supporting with samples of fulmars from NE Greenland. Gunn Sissel Jaklin is gratefully acknowledged for her help with correcting the language.

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Appendix A

Agenda of workshop held in Tromsø, Norway.

Monday 24th February	
08:45 – 09:15	Registration with the reception desk at the Fram Centre and mingling. Coffee/tea served.
09:15 – 09:35	Welcome by Geir W. Gabrielsen. Introduction of participants
09:35 – 10:35	Setting the scene on using fulmars as monitors of plastic pollution. A discussion on the aims of using fulmars as monitors of plastic pollution
10:35 – 11:00	Coffee, tea and fruit break
11:00 – 12:00	Presentation: "Pre-processing of FT-IR spectra can improve confidence in polymer assignment of ingested plastic particles" by Jakob Strand with following discussion
12:00 – 13:00	Lunch
13:00 – 14:30	How important is polymer characterization of ingested plastics?
14:30 – 14:50	Coffee and cake break
14:50 – 16:00	Alternative sampling techniques
19:00 –	Dinner at Kafè Globus

Tuesday 25th February	
08:45 – 09:15	Registration with the reception desk and mingling. Coffee/tea served.
09:15 – 10:35	Discussion of topics not adequately covered the day before or other topics that have surfaced
10:35 – 11:00	Coffee, tea and fruit break
11:00 – 12:00	Summary and final thoughts
12:00 – 13:00	Lunch

Appendix B

Day 1 – 24/02/2020

G.W. Gabrielsen opened the workshop.

The first question that arose and was discussed regarded the status of fulmar populations across the north Atlantic. The conclusion based on the experience and observations from the experts around the table was that it depends on the site. Fulmars are declining in some areas, stable in others, and for some regions there are no reliable data available.

N. Dehnhard showed data from the SEATRACK programme on the winter movements of fulmars tagged in different colonies across the North-East Atlantic. J. Provencher supplemented this with information from her work on genetic assignment to identify the origin of bycatch/beached birds. Based on this, her team found that beached birds in southern Canada are often breeding in the Faroe Islands, whereas bycatch birds from Arctic Canada are also typically breeding within Arctic Canada and probably Greenland. Thus, depending on where you sample the birds, their "plastic signal" could be coming from different areas.

A brief discussion on the residence time of plastics in fulmar guts followed. S. Kühn talked about her lead on artificial fulmar stomach experiments and reported that plastic additives seem to leach in stomach oil.

J. Provencher talked about some of her team's work involving the sampling of seabird faeces and faecal precursor to investigate whether it could be used as a non-lethal sampling technique.

J. Strand gave a presentation on the use of FTIR spectroscopy to identify plastics polymers and the value of pre-processing.

The discussion moved on to what should be included in a record database on plastic ingestion and other impacts in seabirds, e.g. if the international ICES DOME database can also host and secure data from circumpolar areas. The conclusion was that mandatory data for monitoring purposes need to be as simple as possible, e.g. like in the current OSPAR database for data on fulmars. THE ICES DOME database can also be adapted to contain data for additional biometric and plastic relevant data including chemically determined polymer IDs.

Minimum data to be recorded essentially follow the OSPAR guidelines, including particle colour, size, polymer type, and mass, in addition to a more detailed categorisation of the type of plastics (i.e. more detailed than just "user" vs "industrial"). Having this data at the level of each plastic piece is not feasible and it should be broadened to the level of individual fulmars instead. However, there should also be standard protocols and forms for finer details to be recorded that won't necessarily be included in the database.

There was also agreement that future studies should focus also on eggs and chicks. Additionally, suitable endpoints should be used to investigate potential sub-lethal effects of the plastics ingestion, for example, immunological endpoints. Had there been effects on survival and reproduction, we would likely already have seen them, thus we need to refine our study questions. Furthermore, the longevity of fulmars needs to be considered, as there is a cumulative effect of stressors over time.

J. Provencher presented the plastics work done by the Arctic Council. Three main groups under the Arctic Council are involved in plastics: CAFF (AMBI), AMAP (LMEG), PAME (Microplastics expert group).

Day 2 – 25/02/2020

Day 2 began with a discussion on FTIR, NIR and Raman spectroscopies. It was decided that polymer determination should not be mandatory in monitoring programmes, but it is still relevant to study and report, when feasible. Polymer ID can be relevant in supplementary and more investigative monitoring activities that can provide additional information on the composition of microplastic and thereby also a stronger relationship to potential sources that potentially also can provide more aspects into future temporal trend assessments.

The members then considered which avian species in addition to fulmars should be examined with regard to plastics ingestion. Black-legged kittiwakes and the guillemot species were suggested as they represent very different foraging strategies. Additionally, it is also possible to get eggs from these species in most areas.

Alternative sampling techniques were then discussed. Stomach flushing has previously been tested, but it is difficult and can lead to mortalities if done incorrectly. Ideally one person should be trained to do it (Jan van Franeker is OK with doing this) and be the one performing all the stomach flushing.

Ultrasound and x-ray imaging may have potential, but they need to be further examined and evaluated for their efficacies.

About this publication

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