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Note

First record of plastic debris in the stomach of a hooded seal pup from the Greenland Sea

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ABSTRACT

Plastic debris is globally found around the world and the remote Arctic is no exception. Arctic true seals are sentinel species of marine pollution and represent the link between marine food webs and Arctic apex predators like polar bears and humans. With regard to true seals, ingested macroplastics have never been reported in an Arctic species. We harvested 10 harp seals *Pagophilus groenlandicus* and 8 hooded seals *Cystophora cristata* from the breeding grounds in the pack ice of the Greenland Sea. The digestive tract was inspected exclusively for the presence of macroplastics (>5 mm). Two pieces of single-use plastic were found in the stomach of a weaned hooded seal pup. This study indicates that young Arctic marine predators may ingest macroplastics, and therefore may be at risk during their early stages of life due to human caused plastic pollution even in the remote Arctic pack ice.

1. Introduction

Plastic materials production reached 368 million tons in 2019 (Plastic Europe, 2019). Recent reports estimated that between 1.7 and 4.6% would enter the oceans (Jambeck et al., 2015) and a part of them could reach pristine and low populated areas such as the Arctic. Although observations are still rare, there is increasing recognition that marine plastic pollution has reached the Arctic Ocean (GESAMP, 2015). Indeed, plastic has been found in many compartments of the Arctic ecosystem: sea ice (Peeken et al., 2018), water (Lusher et al., 2015), beach (Bergmann et al., 2017), sediment (Kanhai et al., 2019) and biota (Iannilli et al., 2019; Morgana et al., 2018). However plastic studies in the region remain a small fraction of all publications on this matter, with roughly 10 scientific publications focusing on plastic pollution in the Arctic in 2019 against 4833 overall ("plastic pollution Arctic" *vs.* "plastic pollution" search in Web of Science). Data show that the European Arctic is not significantly less polluted than more populated areas further south (Halsband and Herzke, 2019).

Plastic debris comes from both local and long-distance sources (Bergmann et al., 2019; Cózar et al., 2017; Granberg et al., 2019; Grøsvik et al., 2018). In the Arctic, long-distance sources are numerous and concern both microplastics, *i.e.* plastic smaller than 5 mm (Arthur et al., 2009), and macroplastics, *i.e.* plastic particles larger than 5 mm in size. Both size classes are transported by currents and eventually end up in sinks, such as the seafloor or gyres for example (Moore et al., 2001; Woodall et al., 2014). Several models have shown that the Arctic will become an accumulation zone for plastic debris in the near future (Cózar et al., 2017; Eriksen et al., 2014; Van Sebille et al., 2012). Local sources of plastic pollution mainly consist in commercial shipping, fishing activities, tourism as well as wastewater due to the lack of treatment plants in the Arctic (Halsband and Herzke, 2019). Specifically, an analysis of beached macrodebris in Svalbard reported that fishing related plastics were dominant both in number of items and in weight (Falk-Andersson and Strietman, 2019).

Cut-offs of fishing nets are of particular concern since wildlife can get entangled in them (Falk-Andersson and Strietman, 2019). Many observations exist of Arctic animals such as seabirds, Greenland sharks and some whale species with ingested plastic debris (Moore et al., 2020; Nelms et al., 2019; Nielsen et al., 2014). Seals, which use coastal areas for hauling out and as resting places, could potentially be more exposed

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than other Arctic marine mammals. However, no clear evidence exists yet on the uptake of marine plastic by Arctic marine seals (Bourdages et al., 2020). Bourdages et al. (2020) investigated plastic ingestion in more than one hundred seals, including juveniles and adults of both sexes. No plastic debris (>425 μm) was found in all of the three studied species (*Phoca hispida*, n = 135; *Erignathus barbatus* n = 6; *Phoca vitulina*, n = 1) (Bourdages et al., 2020). By contrast, another marine mammal has been investigated in the frame of plastic pollution in the Canadian Arctic with different results. Seven belugas (*Delphinapterus leucas*) had all ingested plastics, with an average of 11 particles per individual (Moore et al., 2020). All those particles were microplastics (<5 mm) and as a maximum, seven different polymers were found in a single individual. Given that no macroplastic was found, it was assumed that the belugas did not ingest those microplastics deliberately but they would rather come from their preys, such as the polar cod (*Boreogadus saida*) (Moore et al., 2020).

True seals (*Phocidae*) are among the most important marine mammals in the Arctic ecosystem. They represent a valuable resource for local Indigenous communities, as well as for other top predator species such as the killer whale *Orcinus orca* or the polar bear *Ursus maritimus*. A drastic decrease in Arctic true seal populations, exacerbated by the heavy exposure to plastic pollution, would further threaten the survival of polar bears, already considered at high risk due to climate change (Moore and Huntington, 2008; Patyk et al., 2015). For these reasons assessing the potential accumulation of marine debris in true seals is of extreme importance.

The hooded seal *Cystophora cristata* and harp seal *Pagophilus groenlandicus* are two of the most common true seals found in the Greenland Sea. Although the harp seal is considered as a "least concern" species by the International Union for Conservation of Nature (IUCN) with the Greenland Sea stock counting around 360,400 individuals (Kovacs, 2015), there is some evidence of a decline in pup production, from 110,530 in 2007 to 54,181 in 2018 (ICES, 2019). The northeast Atlantic hooded seal population has declined by 85–90% (1,136,000 in the 50s, 76,600 in 2019) (Kovacs, 2016), and has been protected since 2008 (Cumming, 2015; ICES, 2019). For these reasons, the last two decades have witnessed an increase in research efforts on these two species with focus on stock status and distribution (Folkow et al., 2004, 1996; Øigård et al., 2009; Stenson, 2014), shifts in reproduction (Biuw et al., 2018; Øigård et al., 2014), diet (Haug et al., 2004; Potelev et al., 2014; Tucker et al., 2013; Vacquie-Garcia et al., 2017), as well as physiological status (Folkow et al., 2010; Schots et al., 2017; Storeheier and Nordøy, 2001).

This study was part of a larger international network of scientific projects, including ecotoxicological and physiological studies. Due to the expanding interest on the effects of marine plastic litter on Arctic biota, and the fact that potential plastic ingestion has never before been investigated in harp and hooded seals, our objective was to conduct a first-time survey of possible macroplastic ingestion in these two pack ice breeding seal species.

2. Materials and methods

2.1. Ethical statement

The harp and hooded seals (n = 18) that were killed in the current study were taken as part of an extensive scientific sampling program for a number of studies that included toxicological, virological and physiological investigations on the same animals (Alvira-Iraizoz and Nordøy, 2019; de la Vega et al., 2020; Hoff et al., 2017; Malde, 2019; Schots et al., 2017; Sonne et al., 2018). Age classes and number of individuals of the two species were thus selected also based on the needs of these other studies. Permission for a scientific catch of harp *Pagophilus groenlandicus* and hooded seals *Cystophora cristata* was obtained from the Ministry of foreign affairs of Denmark (Utenrigsministeriet) in a verbal note (JTHAV J. nr. 2017-1054) and from the Norwegian Directorate of Fisheries (letter ref. 17/497). Such permits regulate the annual hunting of hooded and harp seals for scientific purposes only. The necessity of such sampling was given by the lack of other potential methods: (1) it is rare – if not impossible – to find stranded marine mammals in the Arctic Ocean; (2) Indigenous hunting in the area focuses mostly on other species; (3) the hooded seal cannot be harvested by commercial hunters; (4) the hunters are not interested in the digestive tract, which is usually thrown away after dissection; and finally (5) on commercial vessels there is limited capacity for storage of samples.

Seal handling and killing was conducted within the limits and ethical guidelines "for the treatment of marine mammals in field research" in accordance with the Norwegian Animal Welfare Act (LOV-2018-06-15-38, §12), Directive 2010/63/EU of the European Parliament (CELEX 32010L0063, Annex IV) and Norwegian Regulations for Use of Animals in Research (FOR-2017-04-05-451, Appendix C). More details about the followed protocols, ethical concerns, and links to all legal compliance, can be found in the Supporting Material.

2.2. Seal handling and biometrics

Sampling of seals was conducted on the pack ice of the Greenland Sea (69°10′N/16°36′W to 71°15′N/19°44′W) between the 6th and the 19th of April 2017, using the university vessel RV "Helmer Hanssen", during the breeding season of harp and hooded seals.

Sampling was conducted differently between age classes. Adults and juveniles of both hooded (n = 4) and harp seals (n = 5) were shot on ice with expanding ammunition (6.5 × 55 mm). They were subsequently brought on board with the help of a metallic crane. Seal pups (hooded seal, n = 4; harp seal, n = 5) were caught and sedated with an intramuscular (I.M.) injection of Zoletil Forte Vet. (100 mg/ml – tiletamine/zolazepam – 2.0–2.5 mg/kg). They were further catheterized into the extradural-intervertebral vein onboard the ship, to inject a lethal dose of pentobarbital (15–20 mg/kg).

Age estimation of sampled seals was conducted based on previous knowledge on breeding season in the area, standard length and observation of seals' coat color and patterns. Details of age estimation through coat coloring are given in the Supplementary material.

2.3. Macroplastic collection and analysis

Dissections were conducted on board, after all biometric information had been recorded. The entire digestive tract was brought in the wet laboratory of the vessel, where it was stretched out on the dissection table and carefully washed with mineralized water. A longitudinal and continuous cut was then made from the esophagus to the colon. All tracts were screened with the naked eye for the presence of macroplastic (exclusively for pieces >5 mm), prey and/or milk along the entire length of the digestive tract: from the esophagus, through the stomach, small intestine, caecum and colon (Fig. 1A). Five different people proceeded with the screening, starting from the stomach to the colon. One person would screen the entire digestive tract, while the others would help maintaining the organs well opened and stretched. This was repeated five times. Every time an item was found it was placed in clean petri dishes. At this stage, digested prey items, plastic and milk were separated. Finally, every item was rinsed again with mineralized water. The found plastic debris were photographed and are shown in Fig. 1B and C.

The ATR-FTIR spectra were obtained with a Thermo iS5 FTIR spectrometer interfaced with an iD7 ATR accessory with monolithic diamond crystal. The spectra were obtained as an averaged on 32 scans in the wavelength range 400–4000 cm^{-1}. The spectra were baseline-corrected using a Savitzky–Golay polynomial fitting. The nature of the polymer films was determined by confronting the obtained spectra with spectra from databases using the Omnic Spectra (Thermo) software.

3. Results

Details of sampling and dissection are shown in Table S1. Two

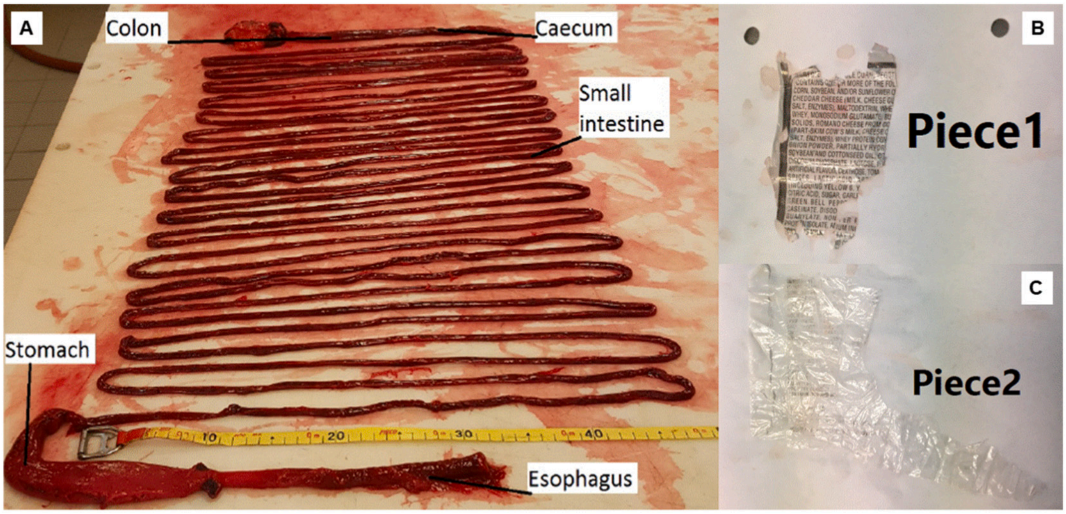

Fig. 1. (A) Ensemble of the digestive track of the hooded seal pup H5-17. (B) First piece of plastic debris found in the stomach; (C) second piece of plastic debris found in the stomach.

macroplastics together with three semi-digested amphipods *Themisto* spp., were found in the stomach of only one individual: a 20 day old hooded seal ("blueback pup" ID: H5-17; Graphical Abstract). These are represented as "piece 1" and "piece 2" in Fig. 1. Those macroplastics were light-plastic films. A "list of ingredients" was perceptible on both, suggesting that they might be degraded parts of a larger food package (Fig. 1). This was evidenced by a slightly visible list of food ingredients. The maximum measured length was 11.2 cm, while the maximum width was 7.0 cm. Piece 1 weighed 0.022 g, while piece 2 weighed 0.079 g. The edges were sharp, but most of the text was almost transparent and very difficult to read. The plastic was still lucid, normally colored with slight signs of degradation processes. No plastic debris was found in the other parts of the digestive tract of this animal nor in any adult or juvenile.

We found nematodes in adults' intestine from both species (Table S1) and milk at the end of the intestine of another hooded seal pup (ID: H1-17).

The ATR-FTIR spectra obtained for piece 1 and 2 in Fig. 1, respectively, are shown in Fig. 2. The IR spectrum associated with piece 1 matches with the spectrum of isotactic polypropylene (PP, with a match of 94%). The IR spectrum associated with piece 2 corresponds to the spectrum of polyethylene (PE, with a match 92%). However, the polyethylene appears to be oxidized as suggested by the observation of extra bands at 1030, 1661 and 3400 cm^{-1}, attributed to the presence of carboxylic acid functions on the PE chains.

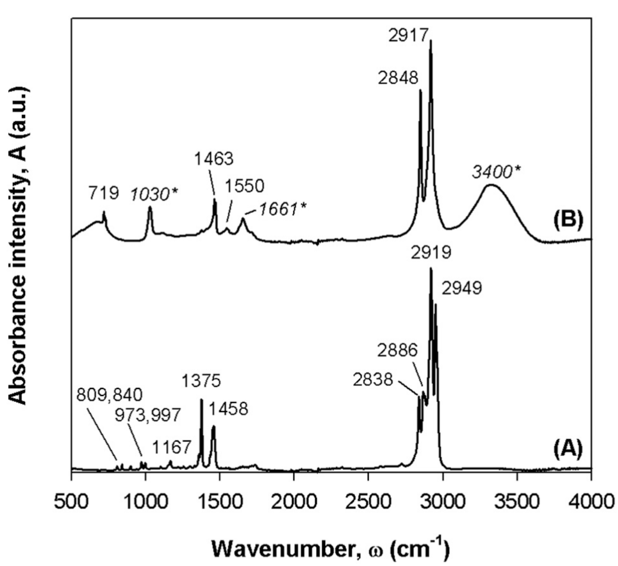

Fig. 2. (A) ATR-FTIR spectrum of piece 1 that corresponds to the spectrum of polypropylene (PP). (B) ATR-FTIR spectrum of piece 2 that corresponds to the spectrum of oxidized polyethylene (IR bands identified with an asterisk indicate the presence of carboxylic acid functions).

4. Discussion

The feeding behavior of marine mammals influences the rate of ingested plastic. In mysticetes and a few odontocetes that feed throughout the water column by capturing large quantities of food at a time, debris is probably ingested accidentally along with prey species, accidentally (Ryan, 2019). Other animals like turtles may actively feed on plastic due to the resemblance with their normal prey (*e.g.* jellyfish) (Schuyler et al., 2014). Until now, only four out of eighteen species of true seals have been found to ingest plastic debris (Kühn et al., 2015; Nelms et al., 2019, 2018; Unger et al., 2017). However, to our knowledge, this is the first record of plastic debris found in the digestive tract of an Arctic species of pinniped.

Morgana et al. (2018) analyzed subsurface water and fish samples from the Greenland Sea shelf break. Plastic particles were found at all sampled stations, mostly consisting of microplastics (94%). Both investigated species of fish were also contaminated by microplastics, 25% of all individuals on average (Morgana et al., 2018). Amélineau et al. (2016) found plastics in all gular pouches of little auks *Alle alle* and an average plastic concentration between 1 and 2.38 pieces m^{-3} of seawater, off East Greenland (Amélineau et al., 2016). In both matrices, a very low percentage of plastic pieces were macroplastics. Consequently, finding macroplastic pieces, although few, in a young seal was surprising.

Hooded seals from the Northeast Atlantic stock give birth in late March along the pack ice of the Greenland Sea. After weaning, blueback pups go through a postweaning fasting period of 3–4 weeks before they venture out to open seas in search of prey (Schots et al., 2017). During the postweaning fasting period, some shallow diving is performed (Folkow et al., 2010). During these first "training" dives, blueback pups may locate and eat small amounts of ice-associated crustaceans, such as *Themisto* spp., as confirmed by our findings of these in one seal pup. However, the presence of plastic in the stomach of a seal pup in such a remote location, was rather surprising. It shows how pups of Arctic seals can be exposed to plastic in their first days of life.

Plastics arrive to the Arctic Ocean from both local and long-distance sources (Grøsvik et al., 2018; Lebreton and Andrady, 2019; Wichmann et al., 2019). Among long-distance sources, macroplastics may come from highly populated latitudes further south and travel *via* North Atlantic Ocean currents northwards (Cózar et al., 2017; Mallory, 2008). However, local maritime activities in the Arctic like the extensive commercial fishing and – in lesser extent – tourism ships, constitute a more plausible source for the macroplastic found in our seal. The decrease in ice cover and thickness observed in the last few years in this region caused plastic scattering at the water surface (Peeken et al., 2018). At the same time, changes in temperature and local biological cycles (*e.g.* timing of algal blooms in spring) have caused a shift in prey distribution and biomass (Allsopp et al., 2012). The combination of these factors with the short hunting experience of such a young animal, may have led the seal pup to confuse the plastic debris for one of its prey, as it has already been suggested for porpoises (Baird and Hooker, 2000).

Macroplastic ingestion by marine megafauna can have diverse effects: directly, it might cause the blockage or rupture of the stomach (Baird and Hooker, 2000; De Stephanis et al., 2013; Jacobsen et al., 2010), inflammation and sensation of fullness that lead to malnutrition and starving of the animals (reviewed in Kühn et al., 2015). Indirectly, during plastic breakdown within the organisms, chemical additives commonly used in plastic products are released in the organism (Kühn and van Franeker, 2020). Those chemicals can induce endocrine disruption, developmental disorders, and reproductive abnormalities (Oehlmann et al., 2009; Rani et al., 2015) although this is being discussed in the scientific community (Koelmans et al., 2016, 2014).

Conversely to the hooded seal pup, adult and juvenile (1 year +) animals of both species did not contain plastic debris in their stomach or intestinal tract, in agreement with stomach content analysis of harbor, ringed and bearded seals from the Canadian Arctic (Bourdages et al., 2020). At this life stage both hooded and harp seals feed in pelagic or bentho-pelagic waters (Folkow et al., 2010, 2004, 1996), and thus are less exposed to floating plastics.

In addition to macroplastics, Arctic seals may ingest microplastics too. Indeed, sea ice behaves as both a sink of microplastics and, during melting season, as a source (Peeken et al., 2018). This may represent a long-term threat for these animals mostly due to the potentially toxic chemicals occurring in these particles and the possibility of bioaccumulation of toxins in the food chain (Fossi et al., 2016). Microplastics have been found in bigger animals (Besseling et al., 2015; Nelms et al., 2019; Zhu et al., 2019) with unknown consequences so far.

Marine mammals are already undergoing multiple stressors, especially in the Arctic (Routti et al., 2018), and possible plastic ingestion, environmental pollution, climate change causing less pack ice and entanglement in fishing gear, are some examples. There are very few data on plastic ingestion by marine mammals in the Arctic although this region is expected to experience an increasing rate of environmental plastic levels (Provencher et al., 2019). Given their potential role as indicator species, being on top of the food chain, marine mammals, including true seals, should be one of the next priorities of ecotoxicological research, but also more specifically for plastic pollution research.

5. Conclusions

Within this short communication we report the first finding of plastic debris in the stomach of a seal pup of an Arctic species: the hooded seal. These preliminary findings have shown that Arctic seal pups are in contact with macroplastics immediately at the beginning of their feeding activities. Plastic in the pack ice of the Greenland Sea may have its origin from lower latitudes, brought into the Arctic by northwards currents, or alternatively, from deposits from ship traffic in the area (tourist-or fishing vessels).

Such outcome raises concern on the potential toxic impact of plastic marine pollution in Arctic wildlife and underlines the importance of going further in assessing the exposure and effects of plastic at a larger scale, considering that Arctic inhabitants, including Arctic pack ice seals, now are subjected to a number of other stressors that may pose a serious threat to these animals.

CRediT authorship contribution statement

Marianna Pinzone: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Erling S. Nordøy:** Resources, Writing – review & editing, Validation, Supervision, Funding acquisition. **Gauthier Eppe:** Investigation, Formal analysis. **Cédric Malherbe:** Investigation, Formal analysis, Data curation. **Krishna Das:** Conceptualization, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **France Collard:** Writing – review & editing, Visualization, Validation.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.112350.

References

Allsopp, M., Santillo, D., Johnston, P., 2012. Climate change impacts on Arctic wildlife. GreenPeace Int. 1–20.

Alvira-Iraizoz, F., Nordøy, E.S., 2019. Evidence of seawater drinking in fasting subadult hooded seals (*Cystophora cristata*). J. Anim. Behav. Biometeorol. 7, 52–59. https://doi.org/10.31893/2318-1265jabb.v7n2p52-59.

Amélineau, F., Bonnet, D., Heitz, O., Mortreux, V., Harding, A.M.A., Karnovsky, N., Walkusz, W., Fort, J., Grémillet, D., 2016. Microplastic pollution in the Greenland Sea: background levels and selective contamination of planktivorous diving seabirds *. Environ. Pollut. 219, 1131–1139. https://doi.org/10.1016/j.envpol.2016.09.017.

Arthur, C., Baker, J., Bamford, H., 2009. Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris, Technical Memorandum NOS-OR&R-30.

Baird, R.W., Hooker, S.K., 2000. Ingestion of plastic and unusual prey by a juvenile harbour porpoise. Mar. Pollut. Bull. 40, 719–720.

Bergmann, M., Lutz, B., Tekman, M.B., Gutow, L., 2017. Citizen scientists reveal: marine litter pollutes Arctic beaches and affects wild life. Mar. Pollut. Bull. 125, 535–540. https://doi.org/10.1016/j.marpolbul.2017.09.055.

Bergmann, M., Mützel, S., Primpke, S., Tekman, M.B., Trachsel, J., Gerdts, G., 2019. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Sci. Adv. 5, 1–11. https://doi.org/10.1126/sciadv.aax1157.

Besseling, E., Foekema, E.M., Van Franeker, J.A., Leopold, M.F., Kühn, S., Bravo Rebolledo, E.L., Heße, E., Mielke, L., IJzer, J., Kamminga, P., Koelmans, A.A., 2015. Microplastic in a macro filter feeder: humpback whale *Megaptera novaeangliae*. Mar. Pollut. Bull. 95, 248–252. https://doi.org/10.1016/j.marpolbul.2015.04.007.

Biuw, M., Nilssen, K.T., Haug, T., Stenson, G., 2018. Report From Surveys to Assess Harp And Hooded Seal Pup Production in The Greenland Sea Pack-ice In 2018.

Bourdages, M.P.T., Provencher, J.F., Sudlovenick, E., Ferguson, S.H., Young, B.G., Pelletier, N., Murphy, M.J.J., D'Addario, A., Vermaire, J.C., 2020. No plastics detected in seal (Phocidae) stomachs harvested in the eastern Canadian Arctic. Mar. Pollut. Bull. 150, 110772. https://doi.org/10.1016/j.marpolbul.2019.110772.

Cózar, A., Martí, E., Duarte, C.M., García-de-Lomas, J., Van Sebille, E., Ballatore, T.J., Eguíluz, V.M., Ignacio González-Gordillo, J., Pedrotti, M.L., Echevarría, F., Troublè, R., Irigoien, X., 2017. The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the thermohaline circulation. Sci. Adv. 3, 1–9. https://doi.org/10.1126/sciadv.1600582.

Cumming, D.H.M., 2015. Seal Range State Policy and Management Review. Gland, Switzerland.

de la Vega, C., Mahaffey, C., Tuerena, R.E., Yurkowski, D.J., Ferguson, S.H., Stenson, G. B., Nordøy, E.S., Haug, T., Biuw, M., Smout, S., Hopkins, J., Tagliabue, A., Jeffreys, R.M., 2020. Arctic seals as tracers of environmental and ecological change. Limnol. Oceanogr. Lett. https://doi.org/10.1002/lol2.10176.

De Stephanis, R., Giménez, J., Carpinelli, E., Gutierrez-Exposito, C., Cañadas, A., 2013. As main meal for sperm whales: plastics debris. Mar. Pollut. Bull. 69, 206–214. https://doi.org/10.1016/j.marpolbul.2013.01.033.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9, 1–15. https://doi.org/10.1371/journal.pone.0111913.

Falk-Andersson, J., Strietman, W.J., 2019. Svalbard Beach Litter Deep Dive (Svolvaer).

Folkow, L.P., Mårtensson, P.E., Blix, A.S., 1996. Annual distribution of hooded seals (*Cystophora cristata*) in the Greenland and Norwegian seas. Polar Biol. 16, 179–189. https://doi.org/10.1007/BF02329206.

Folkow, L.P., Nordøy, E.S., Blix, A.S., 2004. Distribution and diving behaviour of harp seals (*Pagophilus groenlandicus*) from the Greenland Sea stock. Polar Biol. 27, 281–298. https://doi.org/10.1007/s00300-004-0591-7.

Folkow, L.P., Nordøy, E.S., Blix, A.S., 2010. Remarkable development of diving performance and migrations of hooded seals (*Cystophora cristata*) during their first year of life. Polar Biol. 33, 433–441. https://doi.org/10.1007/s00300-009-0718-y.

Fossi, M.C., Marsili, L., Baini, M., Giannetti, M., Coppola, D., Guerranti, C., Caliani, I., Minutoli, R., Lauriano, G., Finoia, M.G., Rubegni, F., Panigada, S., Bérubé, M., Urbán Ramírez, J., Panti, C., 2016. Fin whales and microplastics: the Mediterranean Sea and the Sea of Cortez scenarios. Environ. Pollut. 209, 68–78. https://doi.org/10.1016/j.envpol.2015.11.022.

GESAMP, 2015. Sources, Fate and Effects of Microplastics in the Marine Environment: A Global Assessment.

Granberg, M., von Friesen, L.W., Bach, L., Collard, F., Strand, J., Gabrielsen, G.W., 2019. Anthropogenic Microlitter in Wastewater and Marine Samples From Ny-Ålesund, Barentsburg and Signehamna. Svalbard, Stockholm.

Grøsvik, B.E., Prokhorova, T., Eriksen, E., Krivosheya, P., Horneland, P.A., Prozorkevich, D., 2018. Assessment of marine litter in the Barents Sea, a part of the joint Norwegian-Russian ecosystem survey. Front. Mar. Sci. 5, 1–11. https://doi.org/10.3389/fmars.2018.00072.

Halsband, C., Herzke, D., 2019. Plastic litter in the European Arctic: what do we know? Emerg. Contam. 5, 308–318. https://doi.org/10.1016/j.emcon.2019.11.001.

Haug, T., Nilssen, K.T., Lindblom, L., 2004. Feeding habits of harp and hooded seals in summer and winter. Polar Res. 23 (23), 35–42.

Hoff, M.L.M., Fabrizius, A., Czech-Damal, N.U., Folkow, L.P., Burmester, T., 2017. Transcriptome analysis identifies key metabolic changes in the hooded seal (*Cystophora cristata*) brain in response to hypoxia and reoxygenation. PLoS One 12, 1–21. https://doi.org/10.1371/journal.pone.0169366.

Iannilli, V., Pasquali, V., Setini, A., Corami, F., 2019. First evidence of microplastics ingestion in benthic amphipods from Svalbard. Environ. Res. 179, 108811. https://doi.org/10.1016/j.envres.2019.108811.

ICES, 2019. ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP). ICES Sci. Reports 1 (193 pp.).

Jacobsen, J.K., Massey, L., Gulland, F., 2010. Fatal ingestion of floating net debris by two sperm whales (*Physeter macrocephalus*). Mar. Pollut. Bull. 60, 765–767. https://doi.org/10.1016/j.marpolbul.2010.03.008.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347 (80), 768–771.

Kanhai, L.D.K., Johansson, C., Frias, J.P.G.L., Gardfeldt, K., Thompson, R.C., Connor, I. O., 2019. Deep-Sea Research Part I Deep sea sediments of the Arctic Central Basin : a potential sink for microplastics. Deep. Res. Part I 145, 137–142. https://doi.org/10.1016/j.dsr.2019.03.003.

Koelmans, A.A., Besseling, E., Foekema, E.M., 2014. Leaching of plastic additives to marine organisms. Environ. Pollut. 187, 49–54. https://doi.org/10.1016/j.envpol.2013.12.013.

Koelmans, A.A., Bakir, A., Burton, G.A., Janssen, C.R., 2016. Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environ. Sci. Technol. 50, 3315–3326. https://doi.org/10.1021/acs.est.5b06069.

Kovacs, K.M., 2015. *Pagophilus groenlandicus*, Harp Seal. IUCN Red List Threat. Species 2015 e.T41671A45231087. https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T41671A45231087.en.

Kovacs, K.M., 2016. Cystophora cristata, Hooded Seal. IUCN Red List Threat. Species 2016 e.T6204A45225150 (doi:T6204A45225150).

Kühn, S., van Franeker, J.A., 2020. Quantitative overview of marine debris ingested by marine megafauna. Mar. Pollut. Bull. 151, 110858. https://doi.org/10.1016/j.marpolbul.2019.110858.

Kühn, S., Bravo Rebolledo, E.L., van Franeker, J.A., 2015. Marine Anthropogenic Litter. In: Gutow, L., Klages, M. (Eds.), Bergmann, M. Springer International Publishing, Marine anthropogenic litter, pp. 75–116.

Lebreton, L., Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. Palgrave Commun. 5, 1–12. https://doi.org/10.1057/s41599-018-0212-7.

Lusher, A.L., Tirelli, V., O'Connor, I., Officer, R., 2015. Microplastics in Arctic polar waters: the first reported values of particles in surface and sub-surface samples. Sci. Rep. 5 https://doi.org/10.1038/srep14947.

Malde, A., 2019. Development of Diving Capacity and Behaviour in Harp Seal (*Pagophilus groenlandicus*) Weanlings From the Greenland Sea Stock (Master Thesis). UiT - The Arctic University of Norway.

Mallory, M.L., 2008. Marine plastic debris in northern fulmars from the Canadian high Arctic. Mar. Pollut. Bull. 56, 1501–1504. https://doi.org/10.1016/j.marpolbul.2008.04.017.

Moore, S.E., Huntington, H.P., 2008. Arctic marine mammals and climate change: impacts and resilience. Ecol. Appl. 18, 157–165.

Moore, C.J., Moore, S.L., Leecaster, M.K., Weisberg, S.B., 2001. A comparison of plastic and plankton in the North Pacific Central Gyre. Mar. Pollut. Bull. 42, 1297–1300. https://doi.org/10.1016/S0025-326X(01)00114-X.

Moore, R.C., Loseto, L., Noel, M., Etemadifar, A., Brewster, J.D., MacPhee, S., Bendell, L., Ross, P.S., 2020. Microplastics in beluga whales (*Delphinapterus leucas*) from the Eastern Beaufort Sea. Mar. Pollut. Bull. 150, 110723. https://doi.org/10.1016/j.marpolbul.2019.110723.

Morgana, S., Ghigliotti, L., Estévez-Calvar, N., Stifanese, R., Wieckzorek, A., Doyle, T., Christiansen, J.S., Faimali, M., Garaventa, F., 2018. Microplastics in the Arctic: a case study with sub-surface water and fish samples off Northeast Greenland. Environ. Pollut. 242, 1078–1086. https://doi.org/10.1016/j.envpol.2018.08.001.

Nelms, S.E., Galloway, T.S., Godley, B.J., Jarvis, D.S., Lindeque, P.K., 2018. Investigating microplastic trophic transfer in marine top predators. Environ. Pollut. 238, 999–1007. https://doi.org/10.1016/j.envpol.2018.02.016.

Nelms, S.E., Barnett, J., Brownlow, A., Davison, N.J., Deaville, R., Galloway, T.S., Lindeque, P.K., Santillo, D., Godley, B.J., 2019. Microplastics in marine mammals stranded around the British coast: ubiquitous but transitory? Sci. Rep. 9, 1–8. https://doi.org/10.1038/s41598-018-37428-3.

Nielsen, J., Hedeholm, R.B., Simon, M., Steffensen, J.F., 2014. Distribution and feeding ecology of the Greenland shark (*Somniosus microcephalus*) in Greenland waters. Polar Biol. 37, 37–46. https://doi.org/10.1007/s00300-013-1408-3.

Oehlmann, J., Schulte-Oehlmann, U., Kloas, W., Jagnytsch, O., Lutz, I., Kusk, K.O., Wollenberger, L., Santos, E.M., Paull, G.C., VanLook, K.J.W., Tyler, C.R., 2009. A critical analysis of the biological impacts of plasticizers on wildlife. Philos. Trans. R. Soc. B Biol. Sci. 364, 2047–2062. https://doi.org/10.1098/rstb.2008.0242.

Øigård, T.A., Haug, T., Nilssen, K.T., Salberg, A.B., 2009. Estimation of pup production of hooded and harp seals in the Greenland Sea in 2007: reducing uncertainty using generalized additive models. J. Northwest Atl. Fish. Sci. 42, 103–123. https://doi.org/10.2960/J.v42.m642.

Øigård, T.A., Haug, T., Nilssen, K.T., 2014. Current status of hooded seals in the Greenland Sea. Victims of climate change and predation? Biol. Conserv. 172, 29–36. https://doi.org/10.1016/j.biocon.2014.02.007.

Patyk, K.A., Duncan, C., Nol, P., Sonne, C., Laidre, K., Obbard, M., Wiig, Ø., Aars, J., Regehr, E., Gustafson, L.L., Atwood, T., 2015. Establishing a definition of polar bear (*Ursus maritimus*) health: a guide to research and management activities. Sci. Total Environ. 514, 371–378. https://doi.org/10.1016/j.scitotenv.2015.02.007.

Peeken, I., Primpke, S., Beyer, B., Gütermann, J., Katlein, C., Krumpen, T., Bergmann, M., Hehemann, L., Gerdts, G., 2018. Arctic sea ice is an important temporal sink and means of transport for microplastic. Nat. Commun. 9 https://doi.org/10.1038/s41467-018-03825-5 (12 pp.).

Plastic Europe, 2019. Plastics - The Facts 2019 (Brussels).

Potelev, V., Nilssen, K.T., Svetochev, V., Haug, T., 2014. Feeding habits of harp (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) during late winter, spring and early summer in the Greenland Sea. NAMMCO Sci. Publ. 2, 40. https://doi.org/10.7557/3.2970.

Provencher, J.F., Ammendolia, J., Rochman, C.M., Mallory, M.L., 2019. Assessing plastic debris in aquatic food webs: what we know and don't know about uptake and trophic transfer. Environ. Rev. 27, 304–317. https://doi.org/10.1139/er-2018-0079.

Rani, M., Shim, W.J., Han, G.M., Jang, M., Al-Odaini, N.A., Song, Y.K., Hong, S.H., 2015. Qualitative analysis of additives in plastic marine debris and its new products. Arch. Environ. Contam. Toxicol. 69, 352–366. https://doi.org/10.1007/s00244-015-0224-x.

Routti, H., Jenssen, B.M., Tartu, S., 2018. Ecotoxicologic stress in Arctic marine mammals, with particular focus on polar bears. Marine Mammal Ecotoxicology: Impacts of Multiple Stressors on Population Health. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812144-3.00013-9.

Ryan, P.G., 2019. Ingestion of plastics by marine organisms. In: Takada, H., Karapanagioti, H.K. (Eds.), Hazardous Chemicals Associated With Plastics in the Marine Environment. Springer International Publishing, Cham, pp. 235–266. https://doi.org/10.1007/698_2016_21.

Schots, P.C., Bue, M.E., Nordøy, E.S., 2017. Hooded seal (*Cystophora cristata*) pups ingest snow and seawater during their post-weaning fast. J. Comp. Physiol. B Biochem. Syst. Environ. Physiol. 187, 493–502. https://doi.org/10.1007/s00360-016-1048-3.

Schuyler, Q.A., Wilcox, C., Townsend, K., Hardesty, B.D., Marshall, N.J., 2014. Mistaken identity? Visual similarities of marine debris to natural prey items of sea turtles. BMC Ecol. 14, 14. https://doi.org/10.1186/1472-6785-14-14.

Sonne, C., Andersen-Ranberg, E., Rajala, E.L., Agerholm, J.S., Bonefeld-Jørgensen, E., Desforges, J.P., Eulaers, I., Jenssen, B.M., Koch, A., Rosing-Asvid, A., Siebert, U., Tryland, M., Mulvad, G., Härkönen, T., Acquarone, M., Nordøy, E.S., Dietz, R., Magnusson, U., 2018. Seroprevalence for Brucella spp. in Baltic ringed seals (*Phoca hispida*) and East Greenland harp (*Pagophilus groenlandicus*) and hooded (*Cystophora cristata*) seals. Vet. Immunol. Immunopathol. 198, 14–18. https://doi.org/10.1016/j.vetimm.2018.02.005.

Stenson, G., 2014. The Status of Harp and Hooded Seals in the North Atlantic 16.

Storeheier, P.V., Nordøy, E.S., 2001. Physiological effects of seawater intake in adult harp seals during phase I of fasting. Comp. Biochem. Physiol. - A Mol. Integr. Physiol. 128, 307–315. https://doi.org/10.1016/S1095-6433(00)00311-1.

Tucker, S., Stenson, G.B., Don Bowen, W., Iverson, S.J., 2013. Fueling phocids: divergent exploitation of primary energy sources and parallel ontogenetic diet switches among three species of subarctic seals. Mar. Mammal Sci. 29, 428–447. https://doi.org/10.1111/mms.12009.

Unger, B., Herr, H., Benke, H., Böhmert, M., Burkhardt-holm, P., Dähne, M., Hillmann, M., Wolff-Schmidt, K., Wohlsein, P., Siebert, U., 2017. Marine debris in harbour porpoises and seals from German waters. Mar. Env 130, 77–84. https://doi.org/10.1016/j.marenvres.2017.07.009.

Vacquie-Garcia, J., Lydersen, C., Biuw, M., Haug, T., Fedak, M.A., Kovacs, K.M., 2017. Hooded seal *Cystophora cristata* foraging areas in the Northeast Atlantic Ocean—investigated using three complementary methods. PLoS One 12, 1–23. https://doi.org/10.1371/journal.pone.0187889.

Van Sebille, E., England, M.H., Froyland, G., 2012. Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environ. Res. Lett. 7 https://doi.org/10.1088/1748-9326/7/4/044040.

Wichmann, D., Delandmeter, P., Van Sebille, E., 2019. Influence of near-surface currents on the global dispersal of marine microplastic. J. Geophys. Res. Ocean. 124, 6086–6096. https://doi.org/10.1029/2019JC015328.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1 https://doi.org/10.1098/rsos.140317.

Zhu, J., Yu, X., Zhang, Q., Li, Y., Tan, S., Li, D., Yang, Z., Wang, J., 2019. Cetaceans and microplastics: first report of microplastic ingestion by a coastal delphinid. Sousa chinensis. Sci. Total Environ. 659, 649–654. https://doi.org/10.1016/j.scitotenv.2018.12.389.