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Plastic in the European Arctic

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English summary

Marine plastic litter is a global problem. For the Arctic, which is far from the industrialized and highly populated areas, marine plastic litter is an ongoing and growing problem. The global plastic production reached 322 million tons in 2015, and is growing with ~4% per year. It is therefore likely that the contamination of the Arctic area with plastic litter will increase in the future. Plastic has been observed in all abiotic environments within the European Arctic. The concentration of plastics are comparable or even higher than in more urban and populated areas. There are also indications that the amount of plastic within the European Arctic is increasing. Human settlements within the Arctic also contribute to plastic pollution.

Most studies investigating plastic in Arctic species, have found plastic. OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) has set an Ecological Quality Objective, that less than 10 % of the monitored fulmar population should not have more than 0.1 gram plastic in their stomachs. In Svalbard, 22.5 % of fulmars have ≥ 0.1 g plastic in their stomachs. This is comparable to observations in Iceland (28%), but lower than other southern locations, such as the North Sea, where in 2007-2011 62% of the fulmar population had ≥ 0.1 g. However, the occurrence of plastic in fulmar stomachs is higher in Svalbard (87.5%) than Iceland (79.3%). In addition, floating plastic litter and plastic objects act as long-distance transport devices for invasive species to the Arctic.

There is a pressing need to address the many gaps in our knowledge of plastic in the Arctic environment and in the Arctic species. The high levels of micro- and small micro plastic found in sea ice and sediments highlight the importance of management action to reduce marine litter globally. We need to better understand how plastic impact our Arctic environment and the species living here.

Bearded seal with plastic strapping around the body in front of Tunabreen in Sassenfjorden, Spitsbergen, Norway. Photo: Stig Onarheim

Norsk sammendrag

Havplast er et globalt problem, og ingen havområder slipper unna. I Arktis, som ligger langt fra store industriområder og utslippskilder, er havplast et stort og økende problem. Den globale plastproduksjonen nådde i 2015 hele 322 millioner tonn, og vokser med ~ 4% per år. Det er derfor sannsynlig at mengden havplast i de arktiske områder vil øke i fremtiden. Plast i alle størrelser observeres i Arktis. Nivåene av den rapporterte plasten er sammenlignbar eller høyere i europeisk Arktis enn i mer urbane og befolkede områder lengre sør på kloden. Vi ser også tegn som tyder på at mengden plast i disse områdene øker og at bosetninger i Arktis er kilder for plastavfall på avveie.

De fleste studier som har undersøkt plast i arktiske marine arter har funnet plast. Det er ikke enkelt å redegjøre for direkte negative effekter av havplasten, utenom at dyr hekter seg fast i plast og blir skadet. OSPAR-konvensjonen (Convention for the Protection of the Marine Environment of the North-East Atlantic) har et økologisk kvalitetsmål som sier at mindre enn 10 prosent av den overvåkede populasjonen av sjøfuglen havhest bør ha mindre enn 0,1 gram plast i magen. På Svalbard har 22,5 prosent av alle havhestene ≥ 0,1 g plast i magen. Dette er sammenlignbart med observasjoner fra Island (28 prosent), men lavere enn andre mer sørlige steder, f.eks. havhestene i Nordsjøen der hele 62 prosent av havhestene hadde mer enn 0,1 g plast i magen. Forekomsten av plast i havhestmager er derimot høyere på Svalbard (87, 5 prosent) enn Island (79,3 prosent). Flytende havplast og plastobjekter fungerer også som langdistansetransport av sørlige eller nye arter til Arktis.

Det er et stort behov for å fylle de mange kunnskapshull knyttet til plast i det arktiske miljøet og i arktiske arter. De høye nivåene av mikro- og småmikroplast som finnes i sjøis og sedimenter understreker viktigheten av forvaltningsaksjoner for å redusere havplast globalt. Vi må få en bedre forståelse av hvordan plastforurensing påvirker Arktis og de artene som lever der.

Beached toy at Kapp Linnè, Spitsbergen, Norway. Photo: Silje M. Hagen

Plastic in the European Arctic

The problem: Global plastic pollution

Plastic debris has become ubiquitous in the world's oceans (Barnes et al., 2009; GESAMP, 2015), and is, according to the United Nations Environmental Programme UNEP, one of the world largest growing problems (UNEP, 2016). Ocean plastic debris poses a threat to marine organisms via entanglement, ingestion and as vector for alien species (Barnes, 2002; Barnes and Milner, 2005; Stelfox et al., 2016).

Production of plastics has increased twentyfold since 1964, reaching 322 million tons in 2015 (PlasticEurope, 2017). A further doubling in plastic production is expected the next 20 years, and almost a quadrupling by 2050. If a business-as-usual scenario is considered; by 2050 there will be by weight more plastic than fish in the oceans (World Economic Forum et al., 2016). Asia is the largest producer of plastic with 45% of the total world production, followed by Europe and USA with 40% (World Economic Forum et al., 2016). European demand for plastic was in 2015 49 million tons, 40% was used in packaging, 22% in consumer and household goods, and 20% in construction. The remaining 18% was shared between automotive, electronics and agriculture (PlasticEurope, 2017). Packaging is increasing the most, with 5% annually (World Economic Forum et al., 2016).

Despite the growing demand, on a global average just 14% of plastics are recycled effectively, while 40% end up in landfill and 32% in ecosystems such as the world's oceans (World Economic Forum et al., 2016). Leakage to the oceans is largest in Asia with 82%, while USA and Europe contribute with 2% and the rest of the world 16% (Jambeck et al., 2015; World Economic Forum et al., 2016). It is estimated that 8-12 million tons enter the oceans annually, with ~1 million tons as microplastic (EUNOMIA, 2016; Jambeck et al., 2015). For the plastic reaching the oceans 1% will be floating, 5% on the beaches and the remaining 94% will be found on the ocean floor (Cozar et al., 2014; Eriksen et al., 2014; EUNOMIA, 2016; Kusui and Noda, 2003; Pham et al., 2014; Ryan et al., 2014; Smith and Markic, 2013).

Marine litter and plastic defined

Marine debris is defined as any persistent manufactured or produced solid material discarded, disposed of or abandoned in the marine and coastal environment (Galgani et al., 2010). The term includes items made or lost by humans, and those deliberately discarded into or unintentionally lost in the marine environment. Including among others, items of plastic, wood, metal, glass, rubber, clothing and paper (Galgani et al., 2010). The majority of marine litter is plastic (Buhl-Mortensen and Buhl-Mortensen, 2017; GESAMP, 2015).

Plastics are usually synthesized from fossil fuels, but biomass can also be used as material to synthesize plastics (GESAMP, 2015). Plastic is a sub-category of the larger class of materials called polymers. Polymers are very large molecules that have characteristically long chained-like molecular architecture and therefore very high molecular weight. Globally, the market is dominated by six types of plastic: polyethylene (PE, high and low density), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including expanded EPS), polyurethane (PUR) and polyethylene terephthalate (PET). Especially PE, PP and PS are the most frequent polymer types found amongst microplastics within 42 microplastic studies (reviewed by Hidalgo-Ruz et al., 2012). Commonly, these are used in packaging.

Degradation of plastic is a very slow process. By far most plastics are non-biodegradable, but can be broken down into smaller fractions mechanically (Cole et al., 2011). The dominant degradation of plastic in the environment is through solar UV radiation, which facilitates oxidative degradation of polymers, also called photodegradation or photo-oxidation. During advanced stages of degradation, the plastic typically discolors, undergoes surface changes, become weak and brittle over time (GESAMP, 2015). Since the most common plastic types are of low density/positive buoyancy, they can travel long distances. The plastic can be colonized by organisms, biofouling, or be loaded with sediments, which will alter the plastics buoyancy and lead to sinking (Barnes et al., 2010; Zarfl and Matthies, 2010). In the bottom sediment the plastic can persist for centuries due to low UV-radiation, low temperatures and absence of wave action (Andrady, 2015).

Plastic found within the environment is often categorized according to size. Megaplastic are objects that are more than 1 meter, macroplastic are particles or objects from 1 m to 5 mm. Microplastics are defined as particles with a size or length ranging between 5 mm and 1 µm. Particles less than 1 µm are named nanoplastics (GESAMP, 2015). Microplastic can further be divided into large (5 mm to 1 mm) and small (1 mm to 1 µm). Microplastic can either be primary or secondary of origin, where primary microplastic particles are manufactured to be in the size range of microplastics and secondary microplastic particles are particles that are broken down or fragmented from larger plastic debris (Cole et al., 2011). When detecting microplastics in the environment it is not possible to distinguish if the particle is of primary or secondary origin. Nanoplastic is not discussed in this report since no articles or reports regarding nanoplastics were found within the European Arctic.

Plastic in the European Arctic

Within the European Arctic, in all abiotic environments, plastic has been observed (Table1 and 2). Even in remote locations with relatively low human impact, the densities of plastics found are comparable and even higher than in more urban and populated areas. Furthermore, Tekman et al. (2017) indicates that the densities of plastic in the European Arctic is increasing.

Surface

Plastic litter (>20 cm) floating on the sea surface was observed in several visual surveys (12 out of 44 surveys) from the Barents sea and Fram Strait (Bergmann et al., 2016). These densities were lower than in mid-latitude floating litter surveys. It is possible that sea ice hinders the spreading of floating litter to the Arctic and/or that the distance to more populated areas currently still limits the spreading of floating litter to Arctic regions (Bergmann et al., 2016).

Microplastics are found ubiquitously in the surface waters of the Arctic Ocean (Lusher et al., 2015). Microplastic abundance in these surface waters were in the same order of magnitude, as those found in the North Pacific and North Atlantic (Lusher et al., 2015). Microplastics in the surface and sub-surface (6 meters depth) were mainly fibers (95 %). This suggests that microplastic in this area is probably breakdown products of larger plastic items such as fibers from shipping activity or fishing equipment, recreational and offshore industry (Lusher et al., 2015). Another source of microplastic in the Arctic is washing of textiles that can produce microfibers (Sundet et al., 2016). Warmer waters had more microplastics than cold, which could indicate transport of microplastic with the warmer water currents entering the Arctic Ocean (Lusher et al., 2015). Cozar et al. (2017) also found highest densities of plastic particles in these warmer water masses. A median of 6300 items/km^2 (plastic particles >0.5 mm, excluding fibers) was measured in the Greenland and Barents Sea. In addition, plastic particles were found in most (73%) of all surface ice free waters sampled in the circumpolar area (Cozar et al., 2017). Van Sebille and coworkers (2012) identified a potential formation of a garbage patch in the Barents Sea by modeling global drifter data. This garbage patch would be linked to the North Atlantic garbage patch by advected debris. Van Sebille and coworkers showed that all the oceans' big garbage patches "leaked" debris between patches, indicating the global scale of marine litter distribution (van Sebille et al., 2012). Lusher et al. (2015) observed no evidence of an accumulation zone, such as a garbage patch. However, Lusher and coauthors were most likely situated outside the accumulation zone indicated by Van Sebille et al., (2012).

In Svalbard similar amounts of microplastics were found inside Isfjorden, the bay Breibogen and at open sea south of Svalbard (Lusher et al., 2015; Sundet et al., 2017). No microplastic was observed in subsurface samples in Adventfjorden and Kongsfjorden (Sundet et al., 2017).

Pelagic

Microplastic in the water column (50 - 0 m depth) has been observed by Amelineau et al. (2016) in 2005 and 2014. Of the non-biological material collected by vertical tows of zooplankton net (50 m to surface, WP-2 net; mesh size 180µm) 16.7% was microplastic. The microplastic amount found in the water column was slightly lower than in surface waters from South-western Svalbard (Lusher et al., 2015) for both 2005; 0.99±0.62 items/m and 2014; 2.38±1.11 items/m (Amelineau et al., 2016). This doubling of detected microplastics from 2005 to 2014 might not be an increase in plastic by time, but an artefact of different sea ice cover during sampling between 2005 and 2014. Sea ice might reduce the concentration of microplastic in the surface and water column (Amelineau et al., 2016; Obbard et al., 2014). In July-August 2005 there was a greater sea ice cover than in July-August 2014 (Amelineau et al., 2016).

Benthic

Distribution and accumulation of marine debris on the sea floor is uneven and depends on hydrography, geomorphology, prevailing winds and human activity (Barnes et al., 2009; Buhl-Mortensen and Buhl-Mortensen, 2017). Shelf areas and slopes generally have lower densities than fjords and canyons. Litter accumulates in trenches and canyons, and more than 10 times higher litter abundance compared to the shelf has been observed in these areas (Buhl-Mortensen and Buhl-Mortensen, 2017).

Shelf sea

Distribution and abundance of benthic marine litter in the Barents Sea and Svalbard area have been analyzed by video transects from 2006 to 2017 (Buhl-Mortensen and Buhl-Mortensen, 2017). There is a gradient of densities from high at the coast decreasing further offshore. Furthermore, highest densities were found in the southern parts of the Norwegian Sea, as compared to the northern parts of the Barents Sea. Offshore levels of litter in the Barents Sea is assumed to be 194 items/km^2 (Buhl-Mortensen and Buhl-Mortensen, 2017). A conservative estimate of the total amount of litter in the Barents Sea south of Svalbard is around 79000 tons (Buhl-Mortensen and Buhl-Mortensen, 2017). All observed litter was assigned to general categories based on the make of the litter (i.e. plastic, glass, wood), or the previous function of the litter (i.e. fishing gear). The dominating category for the Barents Sea was "fishing gear" followed by the category "unspecified", and "plastic" when coast and offshore were combined (Buhl-Mortensen and Buhl-Mortensen, 2017).

Deep-sea

West of Svalbard the deep-sea observatory station Hausgarten was established in 1999, and from 2002 video transects have been run regularly (year; 2002, 2004, 2007, 2011, 2012, and 2014). Litter densities increased from 2002 to 2014 from 3523 to 6566 items/km^2 in 2014, and the majority of the items were plastic (Bergmann and Klages, 2012; Tekman et al., 2017). These deep sea litter densities are 20 to 40 times more than offshore shelf sea levels in the Barents Sea (Buhl-Mortensen and Buhl-Mortensen, 2017).

Sea ice

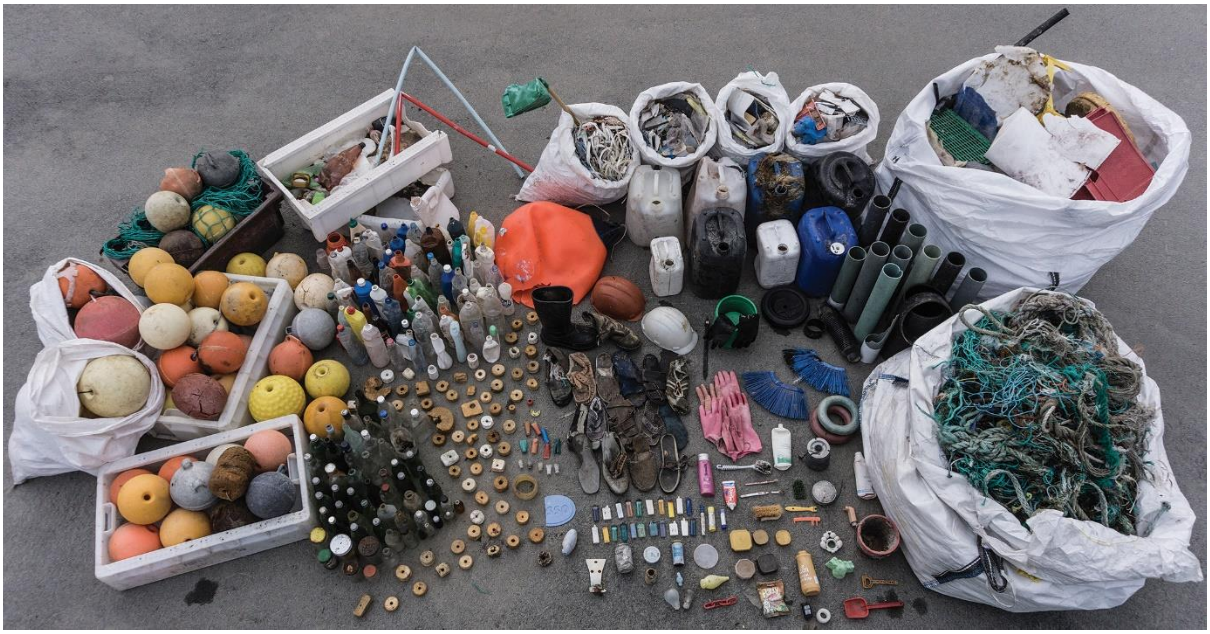
Sea ice entraps plastic particles as it forms due to the concentrating effect of the scavenging phenomenon that accompanies sea ice growth (Obbard et al., 2014). Quantities of 38 to 234 particles per liter have been observed in multiyear sea ice in a transect over the Arctic Ocean (Obbard et al., 2014). This is considerably higher than the concentrations in the most highly polluted oceanic gyres, and about three orders of magnitude higher than the highest measured density in the subsurface (Lusher et al., 2015)

Ghost fishing

Ghost fishing is when fishing gear continues to fish after the gear has been lost, abandoned or discarded. In the Arctic no ghost fishing and entanglement of marine megafauna such as marine mammals, reptiles and elasmobranchs have been published (Stelfox et al., 2016). Never the less, in Svalbard old fishing nets and fishing gear with entangled dead seabirds, dead and alive Svalbard reindeers (*Rangifer tarandus platyrhynchus*), and seals have been observed.

Beached plastic

The Governor of Svalbard is yearly monitoring the beach Brucebukta (since 2001) and Luftskipodden (since 2012) for marine litter. Since 2011 the amount and weight of detected plastic have been reported to OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic). In Brucebukta, the average weight of plastic on a 100 meter transect has been 13 kg (median 4 kg) since 2001. The plastic collected from Brucebukta does not suggest any trends, increasing or decreasing, with time in quantity of beached plastic (MOSJ, 2016). The majority of the plastic is related to fisheries (MOSJ, 2016). It is not possible to compare Brucebukta to other OSPAR beaches because of the difference in catchment as Brucebukta is situated on the inside of Prins Karls Forland and therefore a very sheltered beach without heavy input of marine litter. As a contrast, Rekvika in Troms county, Norway, has an yearly average catchment of 200 kg (pers. com. Bo Eide, Tromsø kommune). The common feature of the OSPAR beaches in Svalbard and in Northern Norway is the dominance of marine litter originating from fisheries.



Sorted beached marine litter. Photo: Vegard Stürzinger

The Governor of Svalbard organizes the initiative “Clean up Svalbard” that yearly cleans several beaches for marine litter around the archipelago. In 2016, a portion of the gathered litter was analyzed for type and origin. Plastic was the most abundant material of the collected litter. The most abundant plastic litter was fishery-related items such as trawl nets and cut rope. There was also a large number of household items, such as bottles and containers (Nashoug, 2017).

Sediments

Shore line

In sediment sampled above the high tide mark in Breibogen, Northern Svalbard, considerable amounts of microplastic, both fibers and fragments, were found (Sundet et al., 2017). Below the high tide mark no microplastics were observed. The difference in microplastic density was probably that microplastic had been washed over the high tide mark by wave and wind action. If the microplastic would not be washed out with the next tide, it would accumulate. In Adventfjorden, nearby Longyearbyen, Svalbard, less microplastic fibers were observed in the tidal zone (two stations: 6.3 and 0 fibers/kg) than above the high tide mark in Breibogen and in shallow water bottom sediments collected in Adventfjorden (Sundet et al., 2016).

Shallow water

In Adventfjorden, Svalbard, microplastic was observed in sediments, 40-70 meters depth (Sundet et al., 2016). The dominating microplastic types were fibers, and a density of 9.2 fibers/kg was reported. They observed a trend of an increasing amount of fibers closer to shore. However, the large variation in fiber count between parallel samples made interpretation of the data difficult (Sundet et al., 2016).

No microplastic, fibers or fragments, where found in sediment samples from Breibogen, at 40-60 meters depth in 2016 (Sundet et al., 2017).

Deep-sea

Substantial quantities of microplastics have been found in the deep sea, with densities exceeding those observed at the surface and sub-surface of the seas (Bergmann et al., 2017; Woodall et al., 2014). South west of Svalbard at 1000 and 2000 m depth on the slope, 15 and 10 fibers per 50 ml sediments were observed (Woodall et al., 2014). Higher microplastic densities than any other benthic regions investigated have been found at the deep sea station at Hausgarten (2340-5570 m depth) (Bergmann et al., 2017). They observed that 80% of their detected microplastic particles were smaller than 25 µm, which is a size class most other studies do not sample (Bergmann et al., 2017). Nevertheless, the density of larger microplastic particles was still high compared to other locations. The amount of microplastic particles were positively associated with chlorophyll α, suggesting that algae might play a role in the downward transport to the deep sea in this area, either as biofouling or as microplastic adsorbed to aggregating algae (Bergmann et al., 2017).

Plastic in organisms

Most marine species that have been investigated globally so far, were affected by marine plastic litter, either as entanglement or ingestion (Kühn et al., 2015). Within the European Arctic few marine species have been investigated for plastics (Table 3).

Marine mammals

In the Arctic no entanglement data of marine megafauna, such as marine mammals, have been published (Stelfox et al., 2016). However, entanglement has been observed for several seal species, such as Harbour seals (*Phoca vitulina*) and bearded seals (*Erignathus barbatus*) around Svalbard (pers. com. Kovacs and Lydersen, Norwegian Polar Institute). To the best of the author's efforts, no publications describing ingestion of plastic in marine mammals from the European Arctic were found.

Seabirds

No reports of entanglement of seabird species have been found, though numerous pictures exists to confirm that entanglement of seabirds to ghost nets and other plastic debris do happen.

The foraging mode of birds is assumed to play a role in the amount of plastic found ingested. Diving birds, such as auks and seaducks, are expected to have relatively low levels of ingested plastic, while surface-feeding birds are more susceptible to ingest plastic (Poon et al., 2017; Provencher et al., 2014). Species physiology is also considered to play an important role in the accumulation of plastics in seabirds. Differences in the ability to regurgitate will affect how species accumulate plastics in their gastrointestinal tract. Species that do not regurgitate, such as the northern fulmar (*Fulmarus glacialis*), are regarded to retain more plastic in their intestine than regurgitation species, such as gulls (Provencher et al., 2014).

Arctic tern found dead with beak entangled in fishing gear. Photo: Governor of Svalbard

Poon et al. (2017) observed a higher incidence of ingestion, mass and number of ingested debris in surface feeders than pursuit feeders. The absence of debris in the pursuit feeders was likely due to the majority of plastics at sea are less dense than sea water and are therefore predominately found floating at the surface (Barnes et al., 2009). Species that dive to obtain their food are less likely to ingest floating debris, though they may still ingest plastic found deeper in the water column and may be more susceptible to entanglement with larger marine plastic debris (Stelfox et al., 2016).

Ingestion of plastic has been studied in several Arctic bird species, all foraging at sea (Table 3). Fulmars are the most studied species within the European Arctic with regards to ingested plastic. Highest frequencies of ingested plastic are found in fulmars (Gjertz et al., 1985; Lydersen et al., 1985; Mehlum and Gjertz, 1984; Trevail et al., 2015; van Franeker, 1985). However, the highest frequency of detected plastic were in little auk (*Alle alle*) gular pouches. All gular pouches contained microplastics (Amelineau et al., 2016). This is of high concern since it implies that the chicks of little auks are exposed to microplastics (Amelineau et al., 2016).

Marine fish

Plastic debris noted as fishing gear or fishing line has been found in stomach analyses of Greenland shark (*Somniosus microcephalus*) from south Greenland with a frequency of 8.3% (Nielsen et al., 2014), and 3% from Svalbard (Leclerc et al., 2012). No micro-, meso- or macroplastic were observed in Atlantic cod (*Gadus morhua*) from northern Norway, Varanger and Lofoten area (Brate et al., 2016).

Marine invertebrate

Within the European Arctic ingested plastic has been reported for blue mussels (*Mytilus edulis*) with 90% occurrence and an average of 9.5 items per individual, and Iceland cockle (*Clinocardium* *ciliatum*) with no microplastic detected (Table 3) (Sundet et al., 2016). As a comparison, blue mussels from Skallneset, Norway, exposed to the Barents Sea, showed 4.3 items per individual (Lusher et al., 2017). In snow crabs (*Chionoecetes opilio*) 20% had plastics in their gut (Sundet unpublished).

Terrestrial mammals

Svalbard reindeer are reported to die due to entanglement in derelict fishing gear and other marine litter on the beaches of Svalbard, Norway (Nashoug, 2017; Øritsland, 1986).

Svalbard reindeer entangled in derelict fishing gear. The reindeer had to be put down by the Governor of Svalbard. Photo: Governor of Svalbard

Terrestrial birds

To the best of the author's efforts, no publications describing entanglement or ingestion of plastic in terrestrial birds species from the European Arctic was found, though a dead goose entangled in derelict trawl-net has been observed.

Fresh water fish

To the best of the author's efforts, no publications describing entanglement or ingestion of plastic in fresh water fish species from the European Arctic was found.

Effects of plastic

Apart for entanglement, direct effects of ingested plastic are not easy to pinpoint. OSPAR has set an Ecological Quality Objective, e.g. less than 10 % of monitored fulmar population should not have more than 0.1 gram plastic in the stomach (van Franeker and Law, 2015). Plastic objects in beached fulmars have been monitored in the Netherlands since 1979, and since 2002 in other North sea countries (van Franeker and Law, 2015). In Svalbard 22.5% of fulmars have ≥ 0.1 g plastic in their stomachs (Trevail et al., 2015). This is comparable to observations in Iceland (28%), but lower than other southern locations, such as the North Sea, where in 2007-2011 62% of the fulmar population had ≥ 0.1 g (van Franeker and Law, 2015). However, the occurrence of plastic in fulmar stomachs are higher in Svalbard (87.5%) than Iceland (79.3%) (Trevail et al., 2015). No other seabird species with detected plastic in their stomachs seem to exceed the ecological quality objective, though weight of the detected plastic is often not provided.

There is also a negative economic aspect of marine litter which is not easy to evaluate. Plastic litter in the environment is perceived as esthetically unpleasant and incompatible with nature. This will decrease the recreational values of areas with marine litter, which could reduce income to the travel and tourism industries. Further, derelict fishing gear or rope can entangle in propellers and rudders of vessels, which would lead to lost cruising time and a cost for removal of entangled objects.

Plastic as vector for contaminants

It has been proposed that ingested plastic might act as a vector for contaminants into the organism and contribute to increased contaminant burden within the organism. Chemical partitioning models predict that the adsorbed chemicals on ingested (micro) plastics are not likely to constitute a relevant exposure pathway nor contribute to the chemical bioaccumulation in the tissue of organisms under natural conditions (Koelmans et al., 2016). An experimental study using Norwegian lobster (*Nephrops norvegicus*) found that the bioaccumulation of polychlorinated biphenyls (PCB) from PCB spiked polyethylene or polystyrene microspheres was probably not relevant from a risk assessment perspective (Devriese et al., 2017). Due to lack of a thermodynamic gradient between the organic contaminants adsorbed to the plastic and the lipid in the biota under field conditions, microplastics are only one of many factors involved in the bioaccumulation of toxic substances in tissues and organs (Koelmans et al., 2016). A huge variety and high levels of contaminants and additives have been found on plastic debris, such as like UV stabilizers, antioxidants, phthalates or brominated flame retardants (Gauquie et al., 2015; Jang et al., 2016; Rani et al., 2015). The leaching of the additives from plastic to the environment and into the food chain may pose a greater risk to the ecosystem health than the sorption and desorption processes of these additive and other hydrophobic contaminants from plastic after ingestion (Devriese et al., 2017).

In fulmars from Svalbard, no difference was observed in contaminant concentration between birds with no plastic in their digestive system to birds with plastic in their digestive system (Ask et al., 2016; Trevail et al., 2014). For fulmars it has been proposed that ingested plastic in stomachs will contribute only a little to the overall contaminant exposure, taking the normal diet of fulmars into account (Herzke et al., 2016).

Invasive species

Floating debris is the most common seagoing transport system and is responsible for the widespread distribution of many marine animals that hitch a ride (Barnes and Milner, 2005). Floating plastic litter and plastic objects can act as long-distance transport devices for invasive species to the Arctic waters (Barnes, 2002). Floating plastic can act as a new pelagic habitat for microorganisms and invertebrates (Reisser et al., 2014), increasing dispersion of microorganisms. The low temperature of the Arctic is the most important barrier to invasion by marine-borne alien organisms. However, with a warming of the Arctic Ocean and reduction in sea ice cover this barrier is weakened (Barnes, 2002). Of all collected plastic debris in 2002 in Kongsfjorden, Svalbard, 7% had individuals of the exotic barnacle *Semibalanus balanoides* and colonies of the bryozoan *Membranipora membranacea* (Barnes and Milner, 2005).

Sources of plastic

Marine litter is linked to human activities and especially marine traffic has been identified as a major source of litter to the marine environment. In the Svalbard area, most of the marine litter analyzed was associated with fishery related activities, and most of the identified fishing gear originated from trawlers (Nashoug, 2017). This is due both to trawling being the dominant fishing method, and to higher rates of gear loss from trawlers compared to other fishing vessels (Nashoug, 2017). The dominance of fishing-related objects is relatively unique for the northern parts of Norway, Barents Sea region and Arctic. In more southern areas, household related objects dominate the plastic in marine litter (Nashoug, 2017).

Human settlements within the Arctic are also sources of microplastic to the Arctic environment. Considerable amounts of microplastic, mostly fibers, have been detected in the effluent from the sewers in Longyearbyen, 97 fibers/l. These fibers are most likely from synthetic clothing such as fleece (Sundet et al., 2016). However, the microplastic from the sewers in Longyearbyen did not settle into the benthic sediments, which indicate that these fibers are floating and being transported through Adventfjorden and out to the ocean through Isfjorden (Sundet et al., 2016). Further studies showed similar amounts of microplastics at sea at 6 meter's depth in the vicinity of the settlement Longyearbyen and Ny-Ålesund to a non-inhabited area, Breibogen and Isfjorden (Sundet et al., 2017). This could indicate that the fibers from the effluent in Longyearbyen are found in the surface above 6 meter's depth.

Future perspectives

Despite the remoteness, the Arctic is not free of plastic. Plastic litter is a problem manifesting itself globally (Eriksen et al., 2014). The global plastic production reached 322 million tons in 2015, and is growing with ~4% per year (PlasticEurope, 2017). It is therefore likely that the plastic litter contamination of the Arctic area will increase in the future (Jambeck et al., 2015; Tekman et al., 2017; van Sebille et al., 2012). The published knowledge on plastics within the European Arctic has been summarized in this report. However, there are huge knowledge gaps that ought to be filled in the coming years. We have tried to list some of these knowledge gaps here.

Environment

- Validate the observations of plastic within sea ice and in the water column
- A 6th gyre has been proposed in the Barents Sea, there is a need for validation through observational data.

- Chlorophyll has been correlated with microplastic in the deep water sediments. Elucidation of the role of algae, algae blooms and ice algae on the vertical transport of microplastic from surface waters to bottom sediments is needed.
- Chemical studies on transfer of plastic additives to the environment are lacking.

Size of plastic

- There are no studies on nanoplastics and small microplastics within the region, and very scarce data in general.
- There is a lack of publications on the smaller size class of microplastic within the European Arctic.

Biota

- Today there is very little to no information on ingestion of plastic in marine invertebrates, marine and fresh water fish, marine and terrestrial mammals, as well as most seabird species, except fulmars, and terrestrial bird species within the European Arctic.
- With the high densities of microplastic in ice cores, how exposed and affected are the species living within/at/by the sea ice and ice edge?
- Chemical studies on the transfer of plastic additives to biota are largely lacking.
- There are no studies on the possible negative effects of nano- and microplastic from the region.
- Today the possibility for biomagnification of nano- and microplastic is largely unknown.

Methods

- There is a need for common sampling protocol and standardized methods for quantitative analyses of microplastic in the environment and biota.
- There is a need for monitoring of plastics within the European Arctic, in addition to the OSPAR-beaches. It is also advisable to have a beach within the OSPAR system that is less sheltered than Breivika, but as accessible, for yearly reporting of beached litter.

There is also a pressing need for a consensus for reporting quality control in studies including plastics, especially microplastics. Many studies fail to inform of the procedures used to hinder contamination of their samples, lack field- and analytical-blank samples, do not state what the blank samples contained if included, and/or how these blank samples were treated, e.g. if the results were blank-corrected or not. Even though the scientific field of microplastic is in its infancy it is important to include quality control of the presented data to assure the quality and robustness of the sampling. Quality assurance in the reporting of microplastic densities should be as much a matter of course as it is in any other branch of ecotoxicology.

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Table 1 Abundance of microplastic observed in seawater and sea ice within the European Arctic. Range, min to max, (average).

	Location	Year	Density n/m^3 If not identified differently	Sampling method	Reference
Surface	Transect from Tromsø up to 78.07°	2014	0 – 1.31 (0.34 ±0.31 SD)	Manta net	(Lusher et al., 2015)
	Greenland and Barents Sea	2013	0.063 n/m^2	Manta net	(Cozar et al., 2017)
Sub-surface	Transect from Tromsø up to 78.07°	2014	0 – 11.5 (2.68 ±2.95 SD)	On-board seawater pump, depth 6 m	(Lusher et al., 2015)
	Kongsfjorden, Svalbard	2016	0	On-board seawater pump, depth 2 m	(Sundet et al., 2017)
	Adventfhorden, Svalbard	2016	0		
	Isfjorden, Svalbard	2016	1-2		
	Breiboden, Svalbard	2016	1-2		
Vertical tow	Greenland Sea	2005	0.15 – 2.64 (0.99±0.62)	WP-2; opening 0.25 m^2 mesh 180µm, 50m to surface	(Amelineau et al., 2016)
		2014	0.81 – 4.52 (2.38±1.11)		
Sea ice	Arctic basin	2005, 2010	38 – 234 n/l	Ice cores	(Obbard et al., 2014)

Table 2 Abundance of microplastic observed in sediments within the European Arctic. Range, min to max, (average).

	Location	Year	Density	Depth (m)	Sampling method	Sample	Replicates (n)	Reference
Shore line	W Svalbard, Adventdalen	2015	$\bar{x}$ 0 – 6.3 fibers/kg	Not given	Shovel	~1 l	3	(Sundet et al., 2016)
	N Svalbard, Breibogen	2016	59 n/l sediment	Above high tide mark	Shovel	~2 l	2	(Sundet et al., 2017)
			0 n/l sediment	Below high tide mark	Shovel	~2 l	2	
Shallow water	W Svalbard, Adventfjorden	2015	$\bar{x}$ 9.2 fibers/kg sediment	40-70	Van Veen grab	~1 l	3	(Sundet et al., 2016)
	N Svalbard, Breibogen	2016	0 n/kg sediment	40-60	Van Veen grab	0.50 l	6	(Sundet et al., 2017)
Deep-sea	SW Svalbard	2010	10 fibers/50 ml sediment	1000	Megacorer/ boxcorer	Ø=10 cm, top 1 cm	Not given	(Woodall et al., 2014)
		2010	15 fibers/50 ml sediment	2000				
	W Svalbard, Hausgarten	2015	42 - 6595 (4356±675 SE) n/kg sediment	2300-5600	Multicorer	Ø=10 cm, top 5 cm	3 – 6*	(Bergmann et al., 2017)

* Depending on station

Table 3 Plastic ingested by organisms in the European Arctic/Svalbard area.

Species	Location	Year	Incidence of plastic ingested	Average mass plastic per individual	Item /ind.	References
Seabirds						
Northern fulmar, *Fulmarus glacialis*	Svalbard, Norway	1982-1984	29%			(Gjertz et al., 1985; Lydersen et al., 1985; Mehlum and Gjertz, 1984)
		2013	87.5%	0.08±0.02 g	15.3	(Trevail et al., 2015)
	Bjørnøya, Svalbard, Norway	1983	82%		4.5	(van Franeker, 1985)
	Jan Mayen, Svalbard, Norway	1983	79%		4.7	(van Franeker, 1985)
Brünnich's guillemot, *Uria lomvia*	Svalbard, Norway	1982-1984	20%			Gjertz et al., 1985; Lydersen et al., 1985; Mehlum and Gjertz, 1984)
	SW Greenland	1988-1999	6%		0.11	(Falk and Durinck, 1993)
	NW Greenland	1997	0%			Falk unpublished in (Provencher et al., 2014)
	W Greenland	2006	0%			(Muzaffar, 2009)
Little Auk, *Alle alle*	Svalbard, Norway	1982-1984	11.6%			(Gjertz et al., 1985; Lydersen et al., 1985; Mehlum and Gjertz, 1984)
	W Greenland	1988-1989	0%			Falk and Durinck unpublished in (Provencher et al., 2014)
	NW Greenland	1997-1998	8.7%			(Pedersen and Falk, 2001)
	Greenland	2013	14%	0.018±0.02 g		(Fife et al., 2015)
	E Greenland	2005*	100%		9.99	(Amelineau et al., 2016)
		2014*	100%		8.99	(Amelineau et al., 2016)
Kittiwake, *Rissa tridactyla*	Svalbard, Norway	1982-1984	1.9%			(Gjertz et al., 1985; Lydersen et al., 1985; Mehlum and Gjertz, 1984)
Common eider, *Somateria mollissima*	W Greenland	1999-2002	0%			(Jamieson et al., 2006)
	W Greenland	2012	0%			Merkel unpublished in (Provencher et al., 2014)
King eider, *S. spectabilis*	W Greenland	2000-2002	0%			Jamieson unpublished in (Provencher et al., 2014)
Fish						
Greenland shark, *Somniosus microcephalus*	Greenland	2012	8.3%**			(Nielsen et al., 2014)
	Svalbard	2008-2009	3%***			(Leclerc et al., 2012)
Atlantic cod, *Gadus morhua*	Northern-Norway		0%			(Brate et al., 2016)

Mollusca						
Iceland cockle, *Clinocardium ciliatum*	Svalbard, Norway	2015	0%[a]			(Sundet et al., 2016)
Blue mussel, *Mytilus edulis*	Svalbard, Norway	2015	90%[a]		9.5[a]	(Sundet et al., 2016)
Crustacea						
Snow crab, *Chionoecetes opilio*	Barents Sea		20%			J. Sundet unpublished

[a] only fibers

* Detected in gular pouches.

**Noted in article as “fishing gear”

*** Noted in article as “a small piece of metal and fishing line”

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