DESKTOP STUDY ON MARINE LITTER INCLUDING MICROPLASTICS IN THE ARCTIC

PAME

Protection of the Arctic Marine Environment

ARCTIC COUNCIL

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Protection of the Arctic Marine Environment

Desktop Study on Marine Litter including Microplastics in the Arctic

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GRID ARENDAL

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Glossary

For the purpose of this Report, the following terms are defined. The definitions do not supersede, modify, or otherwise affect the meaning of these terms as they are, or may be, used in any multilateral instrument or in the national laws and regulations of the Arctic States.

Land-based sources – Sources of pollution that originate from activities on land. The particles or substances released from these sources are dependent on a pathway to reach the ocean.

Macro-plastic – Marine litter (see below) composed of plastic items greater than 5mm in size.

Marine debris – Any persistent, manufactured or processed solid material discarded, disposed of, lost or abandoned in the marine and coastal environment. Examples may include plastic, machined wood, textiles, metal, glass, ceramics, rubber and other persistent man-made material.

Marine litter – Marine debris.

Microplastics – Particles or fragments of plastic measuring less than 5 mm in diameter.

Microlitter – Particles or fragments of persistent, manufactured or processed solid material less than 5 mm in diameter

Plastic pellets – Plastic spherules or granules with sizes between 1 and 5 mm produced as feedstock for plastic production.

Sea-based sources - Sources of pollution that originate from activities at sea. These sources are not dependent on pathways to reach the ocean.

Executive Summary

The Arctic Council's working group Protection of Arctic Marine Environment (PAME) conducted the "Desktop Study on Marine Litter, including Microplastics in the Arctic" as part of the first phase of a Marine Litter Project included in the 2017-2019 Work Plan. This Study contains five sections: I. Rationale, Objectives and Geographic Scope; II. Applicable Governance Frameworks; III. Literature Review; IV. Knowledge Gaps; and V. Main Findings and Next Steps.

The development of the Desktop Study was driven by the need to better understand the state of knowledge of marine litter in the Arctic. The objectives of the Desktop Study are to: (i) evaluate the scope of marine litter in the Arctic and its effects on the Arctic marine environment; (ii) enhance knowledge and awareness of marine litter in the Arctic; (iii) enhance cooperation by the eight Arctic States to reduce negative impacts of marine litter on the Arctic marine environment; and (iv) contribute to the prevention and/or reduction of marine litter pollution in the Arctic and its impact on marine organisms, habitats, public health and safety, and to reduce the socioeconomic costs litter causes.

This Desktop Study improves our understanding of the status and impacts of marine litter, including microplastics, in the Arctic region. This kind of compilation has not previously been done for the entire Arctic region and is by no means comprehensive.

Section II contains a brief review of the governance frameworks applicable to combatting marine litter, including not only Arctic Council efforts, but also other international and regional instruments designed explicitly either to tackle marine litter or address pollution more broadly.

The core of the report, Section III, is a literature review that considers the sources, drivers, and pathways of marine litter, including microplastics, entering the marine environment, information on current knowledge of its distribution, how it interacts with and impacts marine biota, and efforts underway to monitor marine litter. In Section IV, the Study identifies a number of knowledge gaps before summarizing main findings and possible next steps in Section V.

The state of knowledge on marine litter, including microplastics, in the Arctic marine region primarily stems from information being more prevalent for areas where human activities are concentrated, including the Barents, Norwegian, and Bering Seas, or for specific research topics (e.g. seabirds). Few data are available for the Central Arctic Ocean and the coastal areas around it in Siberia, Arctic Alaska, mainland Canada, and the Canadian Arctic Archipelago.

Marine litter, including microplastics, in the Arctic derive from human activities on both land and at sea. From the limited analysis of macro-litter washed ashore on Arctic beaches or accumulating on the seafloor, most (50-100%) can be attributed to fishing activity, such as nets, floats, and other debris. The marine litter input associated with lacking or deficient waste management systems in coastal Arctic communities is also identified as a source, but there are no assessments of input associated with domestic or industrial waste further inland in the Arctic watershed. Another major data gap is a dearth of studies on marine litter sources to the Arctic distinguishing between sea-based activities (fishing, aquaculture, resource exploration and exploitation, shipping activities, etc.) and land-based activities.

Marine litter, including microplastics, is found in all Arctic marine environment compartments from beaches to the deep sea floor. Studies of marine litter, including microplastics, concentrations have used different sampling methods and are mostly reported using units of either occurrences, kilograms of litter per unit area, numbers of particles per unit of water volume, and/or dry sediment weight of microplastics. Measured values of beach litter range from 63 kg/km of plastic on the southeastern shores of Chukchi Sea coast up to 4,500 kg/km of plastic for the Kenai National Park in the Gulf of Alaska, which is sub-Arctic but can be a source for Arctic marine litter, including microplastics, via ocean currents (Polasek et al. (2017).

A seasonal variation in beach litter has been identified in the OSPAR maritime area of the North-East Atlantic region, where beach litter was monitored at 17 sites within the Atlantic Arctic in 2017. The amount of beach litter varied from a mean of 1,475 items per 100 m in the spring to 195 items per 100 m in the summer months. Plastic accounted for up to 94% of the material in the spring surveys (OSPAR. Pers. Comm.).

There is some evidence that marine litter, including microplastics, is transported into the Arctic by surface ocean currents from distant sources. The presence of microplastics in sea ice has also been documented, and the role of sea ice as a pathway for redistributing marine litter, including microplastics, in the Arctic Ocean has been investigated. The flow of sea ice from the inner Arctic toward the Fram Strait and the Greenland Sea, associated with the Transpolar Drift Current, has been proposed as a mechanism by which microplastics may be transferred toward the marginal ice zone (i.e. the transition between the open ocean and sea ice), where they are released into the water when sea ice melts. A lack of observational data on riverine input of marine litter, including microplastics, from the Arctic watershed into the Arctic Ocean is an identified knowledge gap. The large outflow of water from rivers into the Arctic is known to contribute other substances (e.g. nutrients) into the marine environment.

The frequency of interactions between marine litter and biota, in addition to the ecological and socio-economic impacts of these interactions in the Arctic, is challenging to determine. Other regions of the ocean also face this challenge due to the complexity of ecosystems. Knowledge on ingestion by seabirds has led to the identification of knowledge gaps regarding the residence time of plastic in the digestive tract (Avery-Gomm et al., 2017), the transfer of toxic substances associated to plastic to seabirds tissues and the effects that this may cause.

According to some studies the residence time of plastic in the gastro-intestinal tract of northern fulmars (*Fulmarus glacialis*) is short, with 75% of the plastic ingested being passed from the stomach to the gut within a month (van Franeker and Law, 2015). If this is so, plastic in the stomach contents of northern fulmars is a relatively robust indicator of local pollution levels. If sampling is carried out shortly after migration, the amount of plastic in the stomach contents may be an indicator of plastic pollution in their foraging areas along their migratory pathway, but this will not mask the trends in multiyear datasets of geographically distinct regions (van Franeker et al., 2011; Trevail et al., 2015b).

Some caution should still be used when interpreting plastic ingestion data, as the inference of environmental conditions based on plastic stomach contents has been a subject of discussion, and accurate measures of ingested plastic retention times are needed to better understand temporal and spatial patterns in ingested plastic loads within marine organisms (Ryan, 2015b). In addition, O'Hanlon et al., 2017 conclude in their review of the incidence of marine plastic debris in seabirds of the northeastern Atlantic that opportunistic sampling with limited or no coordination precludes the identification of temporal and spatial trends and therefore, the apparent trends derived from our review should be considered cautiously.

Studies of ingestion of surface plastic particles by northern fulmars show that levels of floating litter in the Atlantic Arctic and in the Gulf of Alaska are significantly lower than those in the North Sea and the Eastern North Pacific (Provencher et al., 2017). Despite this northwards decreasing trend, floating plastic is certainly present at high latitudes and much higher in the Atlantic sector of the Arctic than, for example in the Canadian Arctic, with almost 90% of the individuals with ingested plastic in the Svalbard region compared to 40% in the Canadian Arctic (Trevail et al., 2015a; Provencher et al., 2017).

Data on the ingestion of plastic debris by marine mammals is derived mostly from dietary studies and anecdotal records of the presence of plastic in beached or stranded individuals. No systematic assessment of the impact of ingestion of plastic debris by marine mammals has been published. Similarly, there are very few studies that have documented the ingestion of plastic by Arctic fish. The only known reports of debris ingested by invertebrates in the Arctic shows microplastic ingestion by blue mussels (*Mytilus edulis*) from Svalbard with 90% occurrence and an average of 9.5 items per individual (Sundet et al., 2016), and by snow crabs (*Chionoecetes opilio*) with a 20% incidence also in Svalbard (Sundet, 2014).

Research on pinniped entanglement reached a peak during the 1980s and 1990s in Arctic waters of Alaska and adjacent areas (Bering Sea and Gulf of Alaska) but monitoring has since been reduced. In the rest of the Arctic, knowledge is fragmented and covers only some groups or species. Interactions between biota and marine litter, including microplastics, in the Arctic have mostly focused on the individual level and information on the effects at the population level are lacking, even for the better-studied species. Potential consequences of ingestion and entanglement have been poorly studied and documented, with only a few studies establishing a link between an interaction with marine litter, including microplastics, and lethal or sublethal (e.g., body mass loss, reduced growth) effects.

Finally, understanding of the final fate of marine litter, including microplastics, in the Arctic is also limited and constitutes a gap in the understanding of systemic impacts. There have been no comprehensive studies of the socioeconomic impacts of marine litter in the Arctic.

This Desktop Study identifies potential next steps to further examine and address marine litter, including microplastics, in the Arctic Ocean and inform future work under the Arctic Council as summarized in Section V. There is a need for more comprehensive knowledge on Arctic-specific marine litter, including microplastics, sources, pathways, and distribution, as well as effects on the Arctic marine environment. Developing a Regional Action Plan (RAP) on marine litter in the Arctic is timely, recognizing that the RAP can be modified over time based on the state of knowledge. Developing a monitoring program as part of, or in parallel to, the development of a RAP is particularly valuable to establish a baseline of marine litter, understand changes in distribution and composition, and inform decision-making.

Background

Marine litter, particularly when made of plastic, is amongst the most pervasive problems affecting the marine environment globally (UNEP, 2009; UNGA, 2012; UNEP, 2016).

The presence of litter in the oceans is ubiquitous and has been recorded from coastal shallow waters to the seafloor of deepest oceanic trenches and basins. Litter can be deliberately discarded or abandoned in the sea; brought indirectly to the sea by rivers, sewage outfalls, storm water or wind; or accidentally lost. Gear or parts of it can be lost at sea because of wear and tear linked to normal operations, due to negligent practices and/or bad weather. The universal challenge of addressing and managing marine litter is a useful illustration of the global and transboundary nature of many environmental problems.

On a global scale, plastics account for 72 percent (in number of debris or particles) of all marine litter (Bergmann et al., 2017a), though variations are large with plastic making up between 60 and 90% of all marine litter depending on the region (UNEP, 2016). The remaining percentage includes paper, wood, textiles, metal, glass, ceramics, rubber and any other material that does not degrade within days or months. Most of the scientific attention placed on marine litter over the last years has been devoted to plastic items, particles and their fragments (Ryan, 2015a). As is the case for global literature on marine litter, plastic marine litter and microplastics gather most of the attention of this document due to the large focus on plastic in the literature reviewed. The search targeted literature related to the sources, pathways, distribution and interactions with biota of marine litter or debris and microplastics in the Arctic. There remain a number of knowledge and data gaps on marine litter and microplastics, including accurate quantification of the percentage of plastic litter versus other types of marine litter in this region.

It is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans since the onset of industrial production in the 1950s (UNEP and GRID-Arendal, 2016). Marine plastic litter consists of macro-plastic items (greater than 5mm in size) or microplastics (less than 5mm in size) including plastic fragments and plastics manufactured to be that size (i.e. pellets or microbeads).

The largest share of marine litter, including microplastics, is often attributed to the contribution from land-based sources associated with deficient waste management systems in densely populated coastal regions, leading to an estimated 4.6 to 12.7 million tonnes of plastic litter being added yearly to our oceans (Jambeck et al., 2015). While there is an increasing number of models estimating the contribution of plastic litter from land (Jambeck et al., 2015), including the contribution transported via rivers (Lebreton et al., 2017; Schmidt et al., 2017), there is no recent global estimate of the contribution from activities at sea (i.e. fishing, shipping, aquaculture, etc.), and therefore it is impossible to accurately rank land-based versus sea-based contributions. In any case, regional differences in relative contribution, for example, in the Northeast Atlantic, where shipping and fishing activities have been determined to be the most significant sources of litter (Galgani et al., 2010; van Sebille et al., 2016; Buhl-Mortensen and Buhl-Mortensen, 2017), indicate that the input associated with both land-based and sea-based activities deserves attention.

Even though the Arctic coastal region is sparsely populated and has limited terrestrial transport and industrial infrastructure, maritime activity in certain areas of the Arctic Ocean is intensive due to the numerous rich fishing grounds and growing shipping routes, providing for cost-effective transportation of goods into the Arctic and of resources out of the Arctic, especially for northern Norway and northwest Russia (Arctic Council, 2009). In addition, as for any other part of the world's oceans, marine litter, including microplastics, in the Arctic are not only a result of debris input resulting from activities within the Arctic seas or its coastal areas, but also linked to input arriving from inland areas through rivers, air currents and from distant oceanic areas through global oceanic circulation. The proportion between locally-originated litter and microplastics and those of distant origin is, at present, not known; however, the combined input brings marine litter and microplastics to the Arctic and threatens marine and coastal ecosystems and its services.

Section I: Rationale, Objectives and Geographic Scope

I.1 Rationale

The Arctic Council of Ministers adopted the Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-based Activities (Arctic RPA) in 1998 (PAME, 1998) and updated it in 2009 (PAME, 2009). The Arctic RPA is a dynamic programme of action that uses a step-wise approach for its implementation and recognizes the continually evolving situation in the Arctic environment and the need for an integrated approach. It is the regional extension of the United Nations' Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-Based Activities, and as such provides a framework for addressing the main pollution source categories and responding to global concerns. The eight source categories covered by the Arctic RPA are persistent organic pollutants (POPs), heavy metals, physical alteration and destruction of habitats, radionuclides, petroleum hydrocarbons, sewage and nutrients, sediment and litter.

The summary assessment of the 2009 update of the Arctic RPA highlights that marine litter results from multiple source activities and mixed origin, both within and outside the Arctic. The assessment also notes the impacts and links to demographic, urban and industrial development, emphasizing the connection between marine litter and municipal and household solid waste management. However, at the time, the Arctic RPA ranked marine litter as low priority for action due to the assessment's indication of a lack of immediate regional threat associated to it (PAME, 2009).

At the global level, governments attending the first UN Environment Assembly (UNEA), held in June 2014, noted with concern *"the serious impact which marine litter, including plastics stemming from land and sea-based sources, can have on the marine environment, marine ecosystem services, marine natural resources, fisheries, tourism and the economy, as well as the potential risks to human health"*. The first and three subsequent UNEA resolutions have requested the United Nations Environment Programme to undertake further studies, have called for further action, and recognized that "that measures need to be taken and adapted as appropriate to local, national and regional situations" (UNEA Resolution 2/11, 2016).

In February 2017, PAME agreed to include the project plan for the “Desktop Study on Marine Litter including Microplastics in the Arctic” in the PAME 2017-2019 Work Plan in recognition of the growing concern associated to marine litter. The project plan envisaged a stepwise approach including two phases: the first one devoted to scoping and outreach with this Desktop Study as one of its major deliverables, and the second one, conditional to the main findings and outcomes of the Desktop Study, devoted to the development of a framework for an Arctic Regional Action Plan on Marine Litter.

I.2 Objectives

The main objective agreed at the onset of the Desktop Study on Marine Litter including Microplastics in the Arctic project is:

- ✓ To evaluate the scope of marine litter in the Arctic, and its effects on the Arctic marine environment;
- ✓ Enhance knowledge and awareness of marine litter in the Arctic;
- ✓ Enhance cooperation by the eight Arctic Council member governments to reduce negative impacts of marine litter to the Arctic marine environment; and,
- ✓ Contribute to the prevention and/or reduction of marine litter pollution in the Arctic and its impact on marine organisms, habitats, public health and safety; and reduce the socioeconomic costs it causes.

I.3 Definitions and Geographic Scope

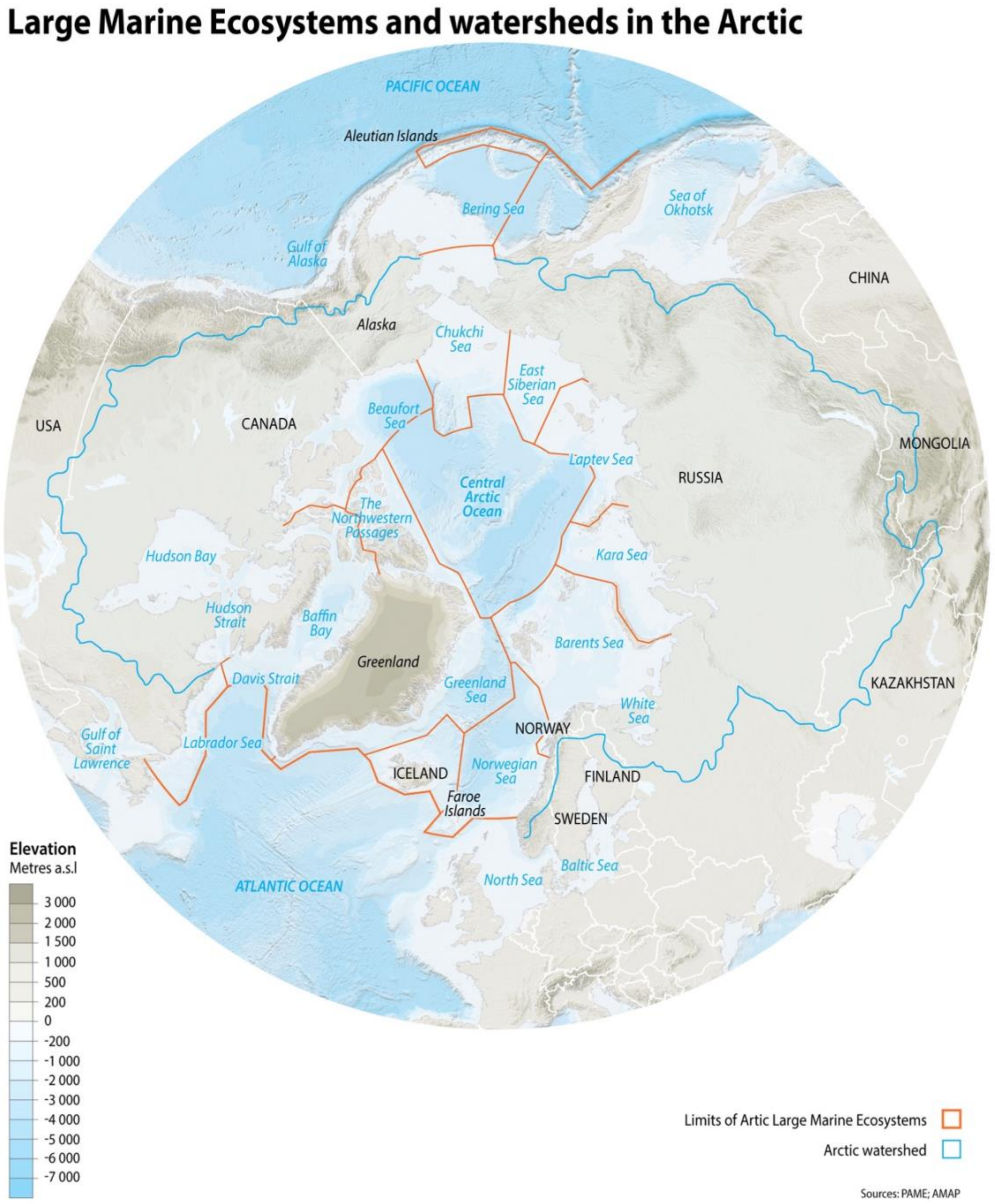
Marine litter, also known as marine debris, has been defined as *“any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment”* (UNEP 2009). Examples may include plastic, machined wood, textiles, metal, glass, ceramics, rubber and other persistent man-made material.

The terms macro-litter and macroplastics, meso-litter and mesoplastics, and micro-litter and microplastics are descriptive terms providing for a practical convention to enable comparability of monitoring data by size fractions. The macro- attribute designates fragments or objects between 1 m and 2.5 cm and meso- is used for the range 2.5 cm to 0.5 cm.

Microplastics are routinely defined as small particles or fragments of plastic measuring less than 5 mm in diameter (GESAMP 2015). The microplastic upper limit size is subject to discussions as the 5 mm threshold does not match the chemical or mathematical definition for the micro range that consider as microparticles those with sizes up to 100 or 500 micrometers, and therefore 10 times smaller than particles routinely referred as microplastics. The literature included in this Desktop Study uses the 5 mm upper limit for microplastic. Primary microplastics are plastic microparticles purposefully manufactured for industrial and domestic purposes while secondary microplastics are created by the weathering and fragmentation of larger plastic objects (UNEP, 2016).

The geographic scope of this Desktop Study is analogous to the one used in the Arctic Ocean Review Report (PAME, 2013). Accordingly the Arctic marine area for this Desktop Study is comprised of *"the central Arctic Ocean, and in addition, the surrounding seas: the Bering Sea, the East Siberian Sea, the Chukchi Sea, the Beaufort Sea; the Northwestern Passages, Hudson Strait and Hudson Bay; the Baffin Bay, Davis Strait and Labrador Sea; the Greenland Sea, the waters around Iceland and the Faroe Islands, and northern parts of the Norwegian Sea; the Barents Sea, the Kara Sea, and the Laptev Sea.".*

The map of the Arctic Large Marine Ecosystems (LMEs) below (Figure I.1), as adopted by the Arctic Council at the Kiruna Ministerial Meeting in 2013, is used to illustrate the geographical coverage.


Large Marine Ecosystems and watersheds in the Arctic

Sources: PAME; AMAP

Figure I.1

Because of the interconnectivity of the world oceans, as well as the buoyancy of items such as some plastics, certain types of fishing gear, and processed wood, marine litter within the Arctic could originate from virtually anywhere in the ocean and, therefore, the whole world should be considered as a potential source for litter in the Arctic. Of course, areas in the immediate vicinity of the Arctic marine areas should be considered as most likely potential source areas, especially the North Atlantic and the North Pacific. In that respect information from coastal areas of the Norwegian Sea and the Gulf of Alaska has been included in the Desktop Study based on the regional circulation patterns. The northeasterly flowing Norwegian current sweeps the western Norwegian coast and transports water deeper into the Barents and Greenland Sea. The southwesterly flowing section of Alaskan Current flows along the southern shore of the Alaskan Peninsula reaching Unimak Pass where an important branch of this current penetrates and conditions the oceanography of the southeastern Bering Sea and slope waters. The input from these areas will be discussed in more detail within Section III.2, "Pathways and Distribution", and is summarized in Figure III.2.

The land-based boundary for the geographic scope of this study is the limit of the Arctic watershed, as marine litter found within the Arctic marine areas could, theoretically, originate from any point within that area (Figure I.1). In this respect, the Arctic watershed is defined as including the watersheds of the rivers flowing into the Arctic marine environment as defined above.

Section II: Applicable Governance Frameworks

II.1 Arctic Council Efforts to address Marine Litter

Since its inception, the Arctic Council has been involved in efforts to address the issue of marine litter, a matter of growing international concern. In 1998, the Arctic Council adopted the Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-Based Activities (RPA).[1] One objective of this RPA is to *"*take action individually and jointly, which will lead to the prevention, reduction, control and elimination of pollution in the Arctic marine environment and the protection of its marine habitat."[2] Subsequently, and shortly after the adoption of the Arctic Marine Strategic Plan in 2004, the Arctic Council Ministers requested PAME to review and update the RPA.[3] PAME amended the RPA and released the updated version on 29 April 2009.

The Arctic Marine Strategic Plan 2015-2025 (AMSP), a framework to guide the Arctic Council's actions to protect Arctic marine and coastal ecosystems, also addresses marine litter through various Strategic Actions. For example, the Strategic Plan calls for improving the understanding of cumulative impacts on marine ecosystems from human activity-induced stressors, including local and long range transported pollution from land and sea-based sources and marine litter (Strategic Action 7.1.3).

The 2017 Fairbanks Declaration of the Arctic Council Ministerial (Fairbanks, Alaska) noted "with concern the increasing accumulation of marine debris in the Arctic, its effects on the environment and its impacts on Arctic communities, and decide[d] to assess the scope of the problem and contribute to its prevention and reduction, and also to continue efforts to address growing concerns relating to the increasing levels of microplastics in the Arctic and potential effects on ecosystems and human health".[4]

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[1] First Ministerial Meeting of the Arctic Council, Iqaluit Declaration, 18 Sept. 1998.

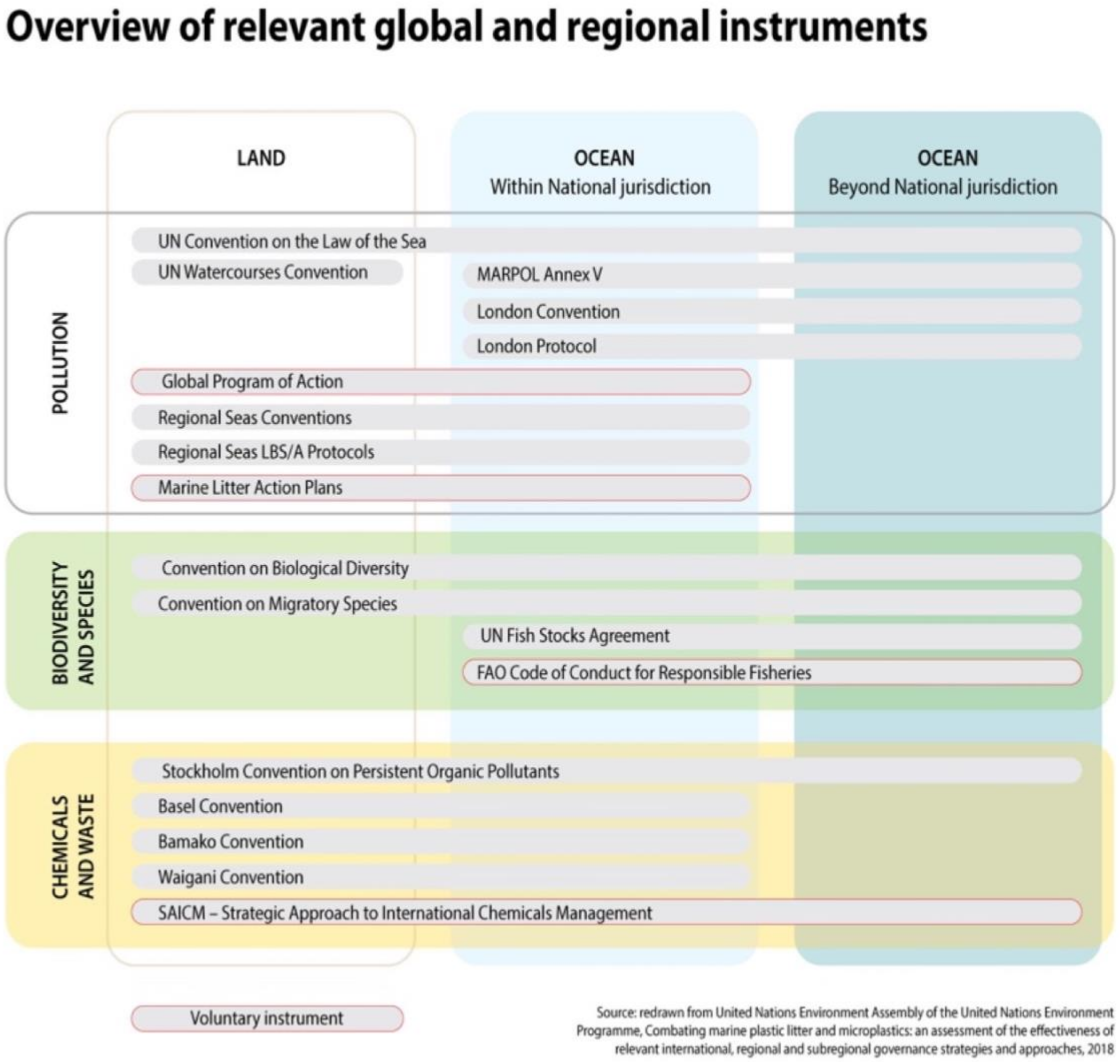
[2] RPA, updated 29 April 2009, at section 2.2 (p. 4).

[3] Fifth Ministerial Meeting of the Arctic Council, Salekhard Declaration, 26 October 2006.

[4] Tenth Ministerial Meeting of the Arctic Council, Fairbanks Declaration, 11 May 2017 at p. 6.

II.2 International Instruments, Strategies, and Programmes

There are a variety of international marine litter-related instruments, including general obligations to protect the marine environment, specific obligations to prevent pollution, and obligations to promote biodiversity. The United Nations Environment Programme (UNEP) has recently examined many of those instruments, summarized in the diagram below.[5]



Source: redrawn from United Nations Environment Assembly of the United Nations Environment Programme, Combating marine plastic litter and microplastics: an assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches, 2018

Figure II.1

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[5] See UNEA, “Combating marine plastic litter and microplasitcs: an assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches,” UNEP/AHEG/2018/1/INF/3 (8 May 2018).

In addition to international instruments, there are a few relevant UN processes that relate to marine litter. In 2017, the UN Environment Assembly (UNEA) called for an Ad Hoc Open-ended Expert Group on Marine Litter and Microplastics[6], which was further extended by UNEA in 2019. In addition, the UN 2030 Agenda on Sustainable Development includes 17 goals, each with specific targets. Goal 14 (Life Below Water) includes a target to, "by 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution." Finally, as far back as 1995, more than 100 countries and the European Union supported the non-binding Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA), which addresses eight source categories of pollution, including marine litter, and encourages the development of regional and national programmes of action.

II.3 Regional Programmes

The UN Environment Regional Seas Programme currently includes efforts of 143 countries participating through 18 Regional Seas Conventions and Action Plans to address the degradation of the world's oceans by engaging neighboring countries to protect their common marine areas.

In general, the plans identify actions such as minimizing inputs from sea-based and land-based sources of marine litter; promoting actions to remove existing litter from the marine environment; supporting education and outreach efforts to increase public awareness, promote better commercial and recreational fishing practices, and promote collaboration among governments, private industry, and non-governmental organizations; and identifying ways to monitor and assess the marine environment and the efficacy of these actions to minimize impacts from marine litter. In addition, some of the plans contain specific actions to be accomplished within set timelines.

Within the European Union, the Marine Strategy Framework Directive and the EU Plastics Strategy provide for a harmonized monitoring framework and the implementation of measures against marine litter at large scale in the waters of its member States.

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[6] UNEA Res. 3/7 (6 Dec. 2017).

Section III: Literature Review

III.1 Sources and Drivers

Marine litter has become ubiquitous in the global ocean (UNEP, 2016). Man-made materials such as plastic, paper, machined wood, textiles, metal, glass, ceramics and rubber are used in pretty much all human activities ranging from activities such as agriculture and fisheries, manufacturing, transportation, trade and commerce and service. The refuse, if mismanaged, or the accidental leakage of any of the above-mentioned man-made materials can reach the natural environment and eventually the marine environment, leading to pollution as marine litter and microplastics.

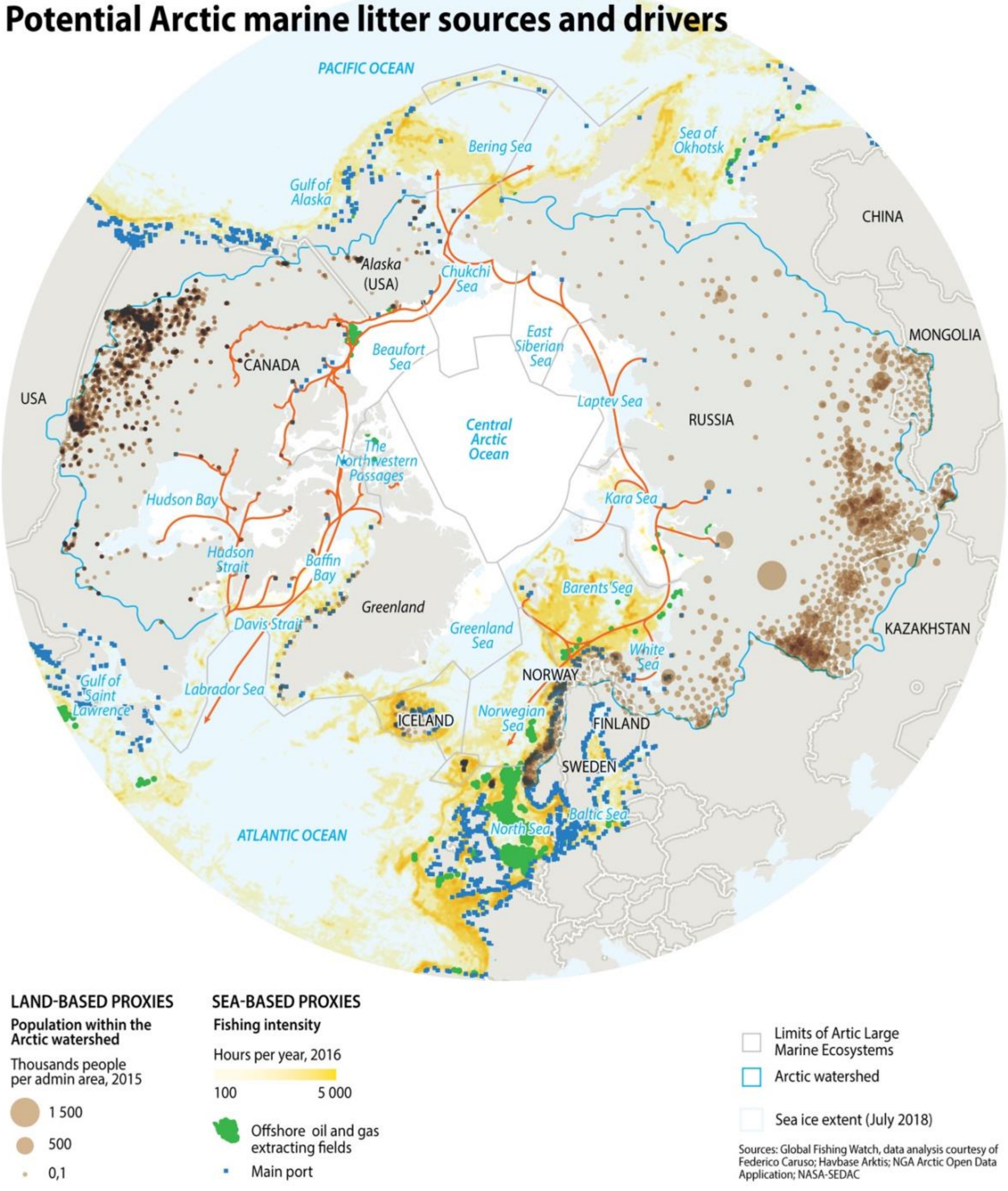
Plastic is of specific interest because of its dominance compositionally and because it is durable (degrades very slowly), light weight (has a density similar to water, allowing it to be transported for long distances), animals interact with it in multiple ways, and it can contain or accumulate toxic substances.

Not every process or activity involving plastic will lead to leakage to the marine environment. Mostly uses in the open environment (outdoors) are the ones that may ultimately lead to pollution if there is a release/leakage mechanism by which plastic raw materials, components, objects and/or their fragments leave the intended lifecycle which consists of production, supply chain, use and waste stream. Additionally, indoor processes may lead to pollution if there is a pathway (e.g. drain pipe or building openings) connecting the indoor space with the open environment. In order to implement measures to combat marine litter effectively, further research is needed to understand not only the reasons why items or their fragments become litter, but also their mode of entry or pathway into the environment (Veiga et al., 2016).

When man-made objects are already within the marine environment at the time that they leave this intended lifecycle, the pathway of entry is very short (i.e., a wave washing over the deck of a boat where objects are not secured or a wind gust taking a plastic bag left behind on a beach) or there is direct leakage (i.e. fishing gear being disposed, lost or worn out in the ocean), and therefore lead to immediate litter. It is therefore logical to organize the analysis of the sources of marine litter as either sea-based (short pathway or direct leakage) or land-based sources (land to sea pathway needed). Within these two groups, the different sources are defined according to economic sector or human activity (OSPAR Commission, 2009; GESAMP, 2015, 2016; UNEP, 2016; UNEP and GRID-Arendal, 2016; OSPAR Commission, 2017).

While research on Arctic marine litter has led to numerous source attributions for debris washed offshore (Merrell, 1980, 1984; Johnson, 1990; Manville, 1990; Bergmann et al., 2017a; Nashoug, 2017; Polasek et al., 2017), there is not, to our knowledge, information available on the total input of litter into the Arctic. Although some of the debris collected during beach surveys can be easily singled out as unequivocally originating from certain sea-based sources (mostly fisheries), this is not the case for other litter that is unidentifiable or that can originate from more than one source either on land or at sea (OSPAR Commission, 2009). This hinders ranking sea-based contributions against land-based contributions or ranking amongst the different sea- or land-based activities. Cózar et al. (2017) used information on size of population living near the coast within the Arctic Circle and on the density of vessels traffic normalized against the surface of the Arctic Ocean as proxies for the likely input of plastic litter from either land or sea. They concluded that, on the basis of the world ratios of vessels per coastal inhabitant, sea-based sources of plastic litter in the Arctic region must be particularly relevant in relation to the land-based sources. Similarly, Tekman et al. (2017) used the number of ships calling at Longyearbyen harbour (Svalbard, Norway) and the number of cruise passengers as a proxy of ship traffic and cruise tourism in the area to assess the potential input of litter.

To complement the information obtained directly from beach surveys, proxies are used in the section below to determine the relative contribution of the different sources of marine litter and to provide information on the size and geographical distribution of the drivers or activities leading to the release of man-made materials into the environment (Figure III.1).



Sources: Global Fishing Watch, data analysis courtesy of Federico Caruso; Havbase Arktis; NGA Arctic Open Data Application; NASA-SEDAC

GRID-Arendal / GEO-GRAPHICS 2018

Figure III.1

Sea-based sources

The major sectors of maritime activity in the Arctic region are fisheries (including commercial, subsistence, and recreational), aquaculture, and shipping, including cruise tourism. One emerging sector of activity that may need consideration is offshore resource exploration and exploitation, including the use and potential discharge of plastic materials contained in offshore chemicals (Moskeland et al., 2018).

Fisheries

Abandoned, lost or otherwise discarded fishing gear (ALDFG) is recognized as a major source of marine litter in the Arctic, more concretely in the Greenland, Norwegian, Barents and Bering Seas and the neighbouring areas of the North Atlantic and North Pacific Oceans (i.e. June, 1990; King, 2009; OSPAR Commission, 2009; Bergmann et al., 2017a; Buhl-Mortensen and Buhl-Mortensen, 2017; Nashoug, 2017; Weslawski and Kotwicki, 2018). Besides ALDFG, the use of fishing gear involves wear and tear that will lead to fragments or pieces of the gear being released in the ocean. For example, bottom fishing nets lose large quantities of attached dolly ropes aimed at protecting the net from abrasive ground contact (e.g. Murray and Cowie, 2011).

Classification of the objects collected during beach surveys in Svalbard established that between 44 and 100% of the mass of litter collected was contributed by fisheries-related items (Bergmann et al., 2017a). Fisheries-related objects are large and relatively dense and therefore their relative mass contribution will always be large in comparison to the number of objects collected. Based on research carried out in Svalbard, fisheries-related objects are either large and dense or relatively small. Examples of smaller parts are net cuttings, strapping band and sheeting. These smaller items make up a significant share of all litter in terms of the number of items. Examples of larger parts are ropes and (sections) of netting. The number of these items are much lower, but due to the large size and heavy weight of ropes and nets, the mass contribution of these two items is highest of all litter items. When survey data include these types of large fisheries objects, the percentage of fisheries items by mass will be correspondingly high and so will be the total litter mass , when estimating these based on these percentages. Most fishing gear that ends up on beaches and can be analyzed is made out of material that floats. This means that material that does not float, such as set nets or crab pots do not end up on beaches and remain in the sea. Almost all fishing gear ending up in beaches on the archipelago of Svalbard originates from bottom trawling (Strietman et al., unpubl. data): netting from cod and shrimp trawls; trawl bobbins and floats, including those that were attached to the nettings, ropes and rope pieces or bundles of packing bands that may have been used on fishing boats to seal cardboard or styrofoam boxes containing seafood or by other sea- and land-based industries. Trawling-related gear tends to predominate in beach Svalbard surveys with 90% of all nets found originating from bottom trawling in the Barents Sea (Strietman et al, unpubl. data). This is likely because of two reasons. First bottom trawling is the main type of fisheries in the Barents Sea and the Svalbard Fisheries Protected Zone (Nashoug, 2017). Second the material used in these type of nettings floats and therefore ends up on beaches. Set nets and other non-floating fishing gear will sink when lost or discarded and not reach the shore (Strietman et al, unpubl. data). Fish crates that might also be used at sea or on land originated from Norway, Denmark, Spain, United Kingdom, Iceland and Faroe Islands providing an indication of the fleets active in the region (and contributing to litter), although crates also tend to circulate among vessels from different countries (Nashoug, 2017). Detailed observations of some of the objects for which origin can be determined (i.e., fishing nets or ropes) may sometimes also allow the identification of the release mechanism (Nashoug, 2017). The analysis of 100 fishing nets collected during clean-ups in Svalbard during the summer of 2017 and 2018 revealed that all of these fishing nets were sections of nets that had been replaced by new parts after they were damaged during fishing operations. Some of the nets pieces exceeded 20 m^2 while most of them were more than 10 m^2. Based on judgement by Norwegian fisheries experts, at least 80-90% of these sections have been deliberately discarded after replacement with new sections of net (Nashoug, 2017; Strietman et al, unpubl. data). It is also worth noting, that at least 60-70% of all ropes collected on Svalbard’s shores are fisheries related but it is not possible to further specify the type of fisheries.

Litter from the fishing industry was also prevalent in the Bering Sea and Subarctic Northern Pacific, around the Aleutian Islands and Alaska Peninsula in the 1970s-80s (Johnson, 1990; June, 1990; Manville, 1990) and is still very present in more recent surveys where, besides the input linked to local fisheries, the influx of debris related to the 2011 tsunami in Japan is also detected (Polasek et al., 2017). Trawl net fragments (ropes, nets, floats, straps, etc.) were the primary type of litter, the number of which kept increasing from year to year, with the highest quantity of 216 fragments/km in Little Tanaga Island (Johnson, 1990). Beach litter studies carried out in Amchitka Island in 1972-74 (before the entry in force of MARPOL 73/78) allowed Merrell (1980) to estimate that a fleet of 1,457 vessels operating in the North Pacific and Bering Sea released 1,665 metric tons of litter into the ocean during 1972, which amounts to more than one metric ton per vessel per year. A correlation between the quantity of litter on AmchitkaIsland and the establishment of fisheries conservation zones and number of vessels in surrounding waters was noted by Merrell (1984) and illustrated how regulations, in this case fishing permits, can lead to a dramatic reduction of fisheries-related items. Countries of origin for litter found on Aleutian shores during the 70s and 80s were Japan, the former USSR, USA, China, Korea, with Japanese fishing nets being positively identified the most often (Merrell, 1980, 1984; Johnson, 1990; Manville, 1990). Identification of the fleet of origin of the fisheries-related items based on the different configurations and combinations of gear allowed conclusions to be drawn on the relationship between the decrease in the presence of litter and the establishment of fisheries area regulations restricting fishing activity of certain fleets.

The central Bering Sea crab fishery was identified as a major contributor to litter washed onto the shores of the Pribilof Islands with items related to this activity accounting up to 70% of the total mass of debris collected and annual accumulation rates of up to several hundreds of kilograms per kilometer (King, 2009).

Comparison of the reports on the literature of the Arctic areas identified as most severely affected by litter related to fisheries with the areas with the highest fishing effort (especially trawling) as depicted in Kroodsma et al. (2018).

Aquaculture

Studies of marine litter in the Arctic do not provide information about the presence of debris associated specifically with aquaculture such as nets, ropes, floats, pipes and packaging material and containers. It is difficult to identify items that are specific to this activity unless they are recovered in close proximity to where aquaculture activities occur or have clear distinguishing markers. Overall, the potential contribution of this sector to marine litter is relatively small in the Arctic compared to the fisheries sector but, on a local scale, it may still contribute significantly. In certain areas of the Norwegian coast aquaculture is estimated to be the source of approximately 30% of the total amount of marine litter detected (OSPAR Commission, 2009).

Aquaculture in the Arctic has grown significantly in the last two decades. It is dominated by Norway (Nordland, Troms and Finnmark counties), which accounts for 93% of the total value of Arctic aquaculture, with a concentration on salmonid production. While Canada is the second largest aquaculture producer amongst the Arctic nations, concentrating also on salmonids and shellfish, this is largely due to production in British Columbia, well south of the Arctic region, and with limited operations in Newfoundland and Quebec. Iceland has an incipient but valuable production of arctic char (Hermansen and Troell, 2012; Troell et al., 2017).

Shipping

This section considers sources connected to all types of shipping activity except fisheries-specific litter, which is considered separately above. This category includes all kinds of materials and goods transporting ships, offshore industry ships and passenger ships including cruise tourism ships.

The potential contribution from shipping to marine litter pollution in the Arctic has been highlighted in several studies (Shaw, 1977; Bergmann and Klages, 2012; Bergmann et al., 2017a; Buhl-Mortensen and Buhl-Mortensen, 2017; Tekman et al., 2017). However, as is the case for aquaculture, it is difficult to ascertain the relative contribution of shipping sources to marine litter based on source identification of the litter, as there is no unequivocal identification of objects or fragments contributed by ships on transit across Arctic waters. Common household items (food, cleaning and personal hygiene products, etc.) are part of the waste generated onboard vessels. When this type of litter is found at sea, it is virtually impossible to determine whether the release occurred in a vessel or on land and it is even more difficult to determine which type of vessel.

Nashoug (2017) reported that a large amount and variety of household plastics (bottles and containers for beverages, condiments, hygiene and laundry products, etc. of different country of origin were found on the beaches of Northwestern Svalbard. The remoteness of the locations where the products were found, far away from large population centers, makes the release from either fishing, merchant or cruise ships plausible. The presence of large food containers could indicate their release being connected to the galleys of larger vessels.

The analysis of normal activities carried onboard vessels points that in addition to the discard or loss of solid domestic waste or other activity related waste, i.e. packaging or securing materials, the discharge of greywater, sewage and/or sludge could also contribute microplastics from cosmetics or microfibers from textiles– although the exact contribution is yet unknown (UNEP, 2016). Furthermore, the discharge of processed (comminuted) food waste can also potentially lead to leakage of plastic debris and microplastics if waste separation is not adequately carried out.

The data contained in the Arctic Ship Traffic Database allows mapping of shipping routes to reflect the number of voyages and tonnage of the ships transiting the Arctic (Arctic Council, 2009) and provides a proxy for the areas that are potentially exposed to inputs from maritime traffic. The data in the database allow monthly and yearly analyses of shipping intensity, providing for the assessment of seasonal and long-term variability in potential inputs.

Offshore resource exploration and exploitation

Although the availability of information regarding marine litter including microplastics from the oil and gas exploration and extraction activities is limited; its contribution should be considered as part of any future source assessment. Moskeland et al. (2018) identified through their study located on the Norwegian continental shelf that the highest concentration of microplastics were generally found in close proximity to oil and gas installations. The mapping of the distribution of rigs and platforms in the Arctic may provide a proxy for the geographic distribution of potential inputs of marine litter associated with these types of activities.

Land-based sources

Waste and wastewater management

At the global level, a major challenge to minimizing the input of litter and waste from land into the ocean is the lack of adequate waste management in coastal regions with a high and growing population densities (Jambeck et al., 2015). As discussed above, due to overall low population densities in Arctic coastal areas, the localized pressure resulting from land-based inputs should be relatively low overall. Nevertheless, some characteristics unique to the Arctic, such as population concentration along the coastline and river courses; settlements not covered by any waste collection schemes; remoteness, meaning lack of connection with network of large (regional or national) waste management systems; and lack of or deficient local waste management systems, may lead to locally high inputs linked to industrial or domestic waste management.

In small Arctic communities, solid waste collection and disposal is very basic. Recycling and baling facilities are rare and generally limited to larger communities. Collection in very small communities is typically by self-haul while larger communities often use community-haul systems (Warren et al., 2016). In some Arctic communities traditional waste management solutions are uncontrolled waste dumps, sometimes along the shoreline, and simple incinerators with no or limited flue gas treatment (Kirkelund et al., 2017). This has been documented to be the case for example in Greenland (Eisted and Christensen, 2011) and in Iqaluit in the Canadian Arctic (Samuelson, 1998). Inadequate or lacking wastewater treatment further contributes to the waste management problem as wastewater often contains traces of personal care products and many other contaminants originating from both households and industrial facilities (Gunnarsdóttir et al., 2013). Sewage and wastewater treatment differs geographically but are overall deficient in the Arctic, resulting in a continuous discharge of sewage and wastewater from households, institutions (e.g. hospitals), commercial sector and smaller industries directly to the coastal waters (Granberg et al., 2017). Magnusson et al. (2016) found that around 6 million microlitter particles (≥ 100 µm) were released per hour into the sea from the Klettagarđar wastewater treatment plant receiving wastewater from the city of Reykjavik. At this plant only mechanical treatment, consisting only of a coarse grid that retains mainly larger debris, is applied to wastewater. In the same study, effluent water from six Nordic wastewater treatment plants were investigated and the efficiency of different treatment systems compared. Large quantities of microplastic fibers shed from washing synthetic textiles (de Falco et al., 2017), which are frequently worn in the cold polar regions, may reach the marine environment or be captured depending on the type of treatment applied. Sweden, for example, has developed technology to remove medicine via wastewater treatment, and thereby also microplastics are removed. This treatment is somewhat expensive and used in some regions.

There are very few studies looking specifically at the leakage and marine input of plastic debris linked to Arctic waste management systems, but ongoing work to quantify and characterize beach litter (Kirkfeldt, 2016; Strand and et al., in prep.) points towards potential input from inadequate waste management on the western shores of Greenland, where 90% of the

Greenlandic population is concentrated. The composition of the waste accumulated in western Greenland survey sites resembles the composition of surveys carried out in the Skagerrak region, where the influence from higher population density along the coastline is reflected in the litter composition. In contrast, the composition of beach litter surveyed in Eastern Greenland, facing the intensively fished Barents sea and where there are fewer settlements, more closely resembles that of northern Norway and Svalbard where the coastal litter assemblages are characterized by the predominance of fisheries related objects (Strand, 2018).

In addition, a study looking into microplastics in the vicinity of Reykjavik, Iceland (Dippo, 2012), has reported exceptionally high concentrations of small plastic fragments and microplastics from a sandy beach near Reykjavik harbor. Though not specified in this report, the exceptionally high concentration of microplastics, including large amounts of plastic fibers and film, could be linked to this particular location, which is close to the harbor and a waste management facility. Therefore, even in areas of the Arctic with adequate waste collection and management systems, the proximity of waste management facilities to the shoreline should be taken into due consideration.

In order to gain further insight on the potential release of plastics associated with waste management, it could be useful to map the distribution of population density, as well as the location of urban settlements, as this information will provide an indication of potential localized points of release of plastic waste into the environment. This kind of information is readily available at a sufficient resolution. Of course, information on the quality of sewage treatment plants and waste management systems, i.e., coverage of waste and wastewater collection schemes, distribution of waste transfer and management facilities and dumpsites and their standards, would allow further inferences to be drawn on the potential and intensity of release. Jambeck et al. (2015) used national average values from 192 coastal countries for waste mismanagement to estimate the contributions at the national level, but due to the singularities of the Arctic, it would be desirable to use higher-resolution information for the region or local assessments to better gauge the potential contribution from this source.

Transportation and logistics

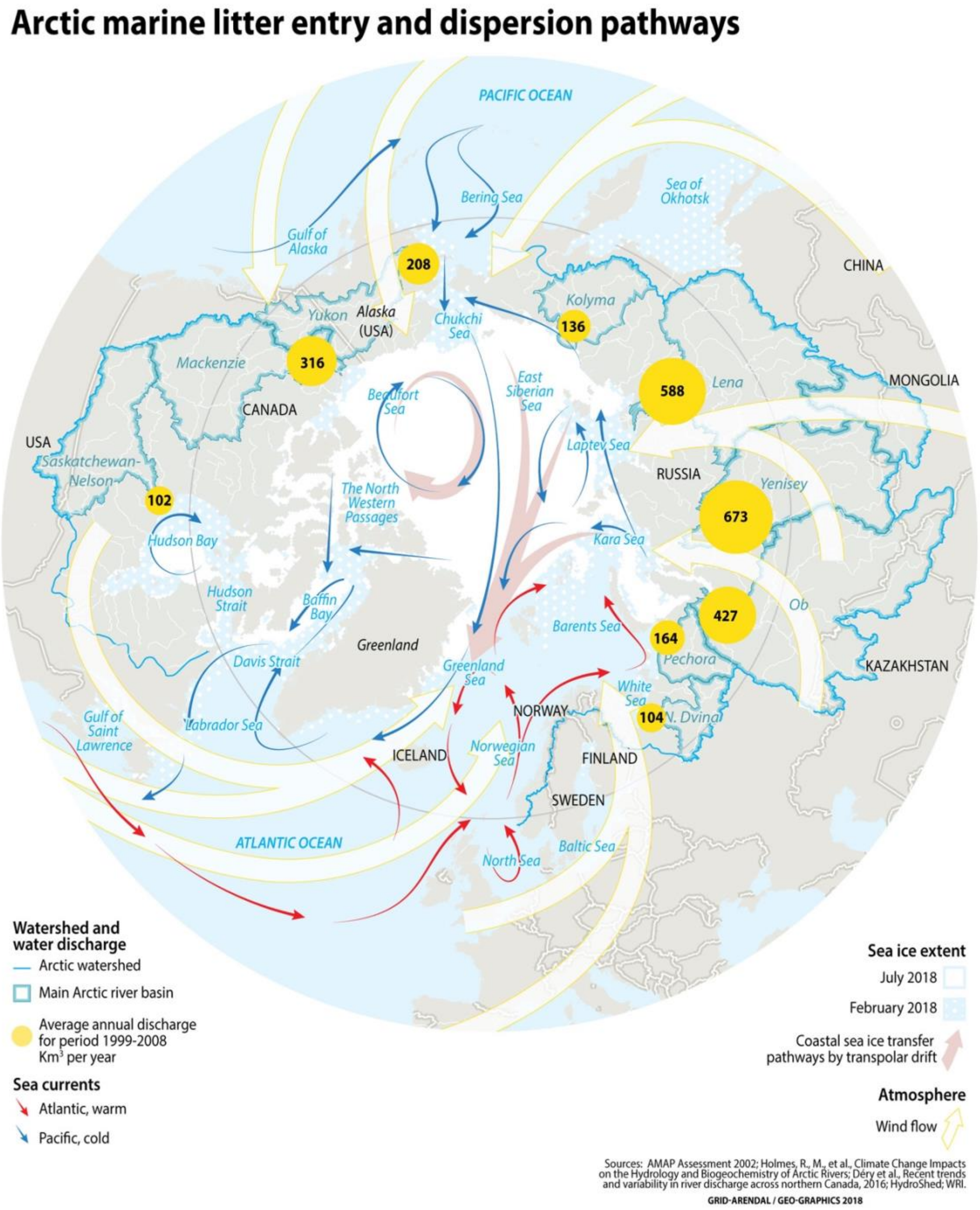
In addition to releases linked to waste transportation, the distribution of goods, including plastic in any of its intermediate forms (pellets, powders etc.) before it is incorporated or turned into a product, can lead to man-made products leaving the intended cycle (UNEP, 2016; UNEP and GRID-Arendal, 2016). Most of the transfer of goods, including waste, will happen alongside the transport infrastructure network. Because of the lack of specific assessments on the release of litter during transportation, a map of the main transportation network, including roads and harbours, could improve the understanding of the areas where potential inputs can occur. Information on the density of the transportation network and the traffic on that network can provide a proxy for the potential intensity for release. The Arctic Ship Traffic Database contains information on ports in the Arctic that could be used to gauge the intensity of port activity to identify which of the port areas could potentially be receiving the largest inputs.

Extractive sector, construction and tourism

Finally, the extractive sector, including agriculture, mining, construction and tourism also run all or part of their operations outdoors in the natural environment and may be a source of litter release into the environment (UNEP, 2016; UNEP and GRID-Arendal, 2016). The distribution and intensity of the activity of these sectors in the Arctic watershed is highly variable and may overall not represent a large contribution, but again, there are no assessments or studies on the contributions from these sectors to litter in the Arctic region. The compilation of proxy indicators for the potential release from these activities - such as geographic distribution, waste and wastewater produced, and how material intensive they are (i.e., plasticulture, amount of plastic, machined wood and other materials used in Arctic construction, single-use plastic in outdoor tourism industry), and indications on the ratio of release into the environment - could allow a better assessment of their potential contribution to marine litter. The increased accessibility of the Arctic to tourism, especially through cruise tourism, may add pressure to the waste management systems in the Arctic.

III.2. Pathways and Distribution

The description and understanding of the pathways of the entry of marine litter into Arctic waters is a crucial element in tracing the litter back to its sources. In addition, the knowledge and understanding of the distribution of marine litter within the Arctic is limited and therefore the consideration of potential pathways and documented (if any) entry or inflow of litter to the Arctic Ocean is a meaningful proxy to its distribution, pointing at likely areas for passage or (temporary) accumulation of debris and particles. Better understanding the fate of litter within the Arctic will also enable its removal to reduce potential impacts caused by its accumulation.


Arctic marine litter entry and dispersion pathways

Sources: AMAP Assessment 2002; Holmes, R., M., et al., Climate Change Impacts on the Hydrology and Biogeochemistry of Arctic Rivers; Déry et al., Recent trends and variability in river discharge across northern Canada, 2016; HydroShed; WRI.

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Figure III.2

Pathways

A complete understanding of the input of litter, including microplastics, into the Arctic marine environment needs consideration of the source sectors and the mechanisms of release as well as the pathways by which the debris reaches the marine environment (Figure III.2). If the release occurs in the terrestrial environment, there has to be a pathway or combination of pathways, connecting the point of release with the point of entry into the marine environment. Rivers and other waterways and wind or atmospheric circulation constitute such pathways.

When considering the presence of debris and microplastics in a part of the global ocean, in this case in the Arctic Ocean, there is a need to consider their transfer into the area considered through the regional circulation pathway and long-range transport.

The understanding of the input through these pathways is crucial in gauging the relative importance of local sea-based or coastal sources versus remote sources within the Arctic watershed or from other parts of the ocean.

Riverine transport

The Arctic watershed is vast and extends well beyond any of the boundaries traditionally used to define the Arctic region. The ten largest rivers in the Artic watershed are the Yenisey, Lena, Ob’, Mackenzie, Yukon, Kolyma, Nelson, Indigirka, Pechora and Dvina (AMAP, 1998). In terms of freshwater discharge, the Yenisey has the largest discharge with 673 km^3/year, followed closely by the Lena with 588 km^3/year (Holmes et al., 2012). The watershed of the Ob’ encompasses the largest population of the ten rivers, with over 28 million people living in it, which is more than three times the population of the second most populated watershed, the Yenisey (8 million people) and more than 25 times the population within the Lena watershed (Holmes et al., 2012). Siberian rivers discharging into the Kara, Laptev and East Siberian Seas have a huge combined drainage area of 9 million km^2 extending far south (Shiklomanov and Skakalsky, 1994) and encompassing many industrial and agricultural regions.

Massive river discharges make terrestrial influences particularly strong in the Arctic Ocean. While it holds less than 1% of the global ocean volume, the Arctic Ocean receives more than 10% of the global river discharge (Holmes et al., 2011). Waters of riverine origin can be traced throughout the Arctic Basin due to large outflows and the extensive ice cover, which minimizes mixing. Arctic rivers have an extreme seasonal pattern with a sudden flow peak during spring thaw, decrease over summer, and minimum flow values just before spring thaw again. This seasonal pattern affects the transfer of any suspended or floating materials, as well as litter, which would peak also during thaw. The transfer of floating litter would normally be hampered during winter when the river surface is frozen.

To date, there is no monitoring of the flux of litter, including microplastics, from rivers into the Arctic. Though riverine discharge pathway has been identified as a possible pathway (Kanhai et al., 2018), its contribution of plastic and other materials in the Arctic is projected to be low due to the fact that these rivers flow through sparsely populated watersheds (Obbard et al., 2014). This assumption would benefit from verification in light of the fact that the population in the Ob', Yenisey and Lena watersheds, which extend beyond Arctic boundaries, is 38 million people, an order of magnitude larger than the population of the entire Arctic region. In addition, the wastewater generated by remote Arctic populations may be characterized by low population equivalents such that their effluents undergo only low, or mostly, no sewage treatment at all, potentially resulting in litter, including microplastics direct leakage into water courses that transfer these to the Arctic Ocean. The leakage may even increase when areas with combined sewage and stormwater sewer systems are not capable of receiving large volumes of wastewater during severe rainfalls or thaw peaks and allow an overflow of untreated sewage and polluted stormwaters into receiving surface waters. During these occasions, even in areas where wastewater is treated to some extent, the overflow may not only contain microplastics, but even meso and macroplastics (Axelsson and van Sebille, 2017) and debris of other materials.

Lebreton et al. (2017) and Schmidt et al. (2017) modelled plastic transfer from major rivers into oceans based on waste management capacity, population density and hydrological information. Unfortunately, data on the watersheds and drainage network for areas north of 60° is not available in the global database used, and therefore this global model does not include plastic input from Arctic rivers. The relative importance of marine litter input through Arctic rivers should be further considered in the light of the facts outlined above.

Atmospheric transport

At the global level, it is assumed that much less litter is transported into the marine environment by wind than by rivers (UNEP and GRID-Arendal, 2016) although, in contrast with rivers, there is currently no global estimate of the input through this pathway. However, wind transport of litter may be significant, particularly in arid and semi-arid areas with reduced surface runoff and dry and windy conditions. Wind may be an important localized pathway for lightweight debris, particularly from waste dumpsites located near or at the coast line, or beside watercourses. During intense storms such as blizzards or hurricanes, wind can mobilize litter that would not normally be available for transport and carry it directly into rivers and the ocean (Lebreton et al., 2012). The Arctic is characterized by dry, windy shorelines with frozen ground for a large part of the year, and multitudes of small coastal communities with open dumpsites near the ocean.

Though atmospheric circulation has been proven elsewhere to provide an efficient pathway for the transportation of microfibers and small plastic particles, such as tire dust, (Cai et al., 2017; Dris et al., 2017), there are to date no published data on microplastics in air in the Arctic region (Halsband and Herzke, 2017). However, microplastics were detected in all of the snow samples taken from drifting sea ice in the Fram Strait and Svalbard, with up to 10,000 microplastic particles per liter snow, indicating atmospheric transport and fallout as a prime pathway (Bergmann et al., 2017c).

Oceanic transport

The movement of particles by ocean currents constitutes an additional pathway and source of marine litter, including microplastics, in the Arctic. The Arctic marine region is well connected to the global ocean through the southern edges of the Norwegian Sea and the Greenland Sea (Denmark Strait), where it meets the North Atlantic Ocean, and through the Bering Strait and the Bering Sea exchanging with the North Pacific Ocean. The influence of the Atlantic is much larger than that of the Pacific, as most of the water in the Arctic Ocean originates from the Atlantic Ocean (79%), while the inflow through the Bering Strait is lower (19%) (AMAP, 1998).

The exchange of water and, with it, any drifting litter, from and to the North Atlantic Ocean has been addressed by the modelling work of van Sebille et al. (2012) that reflected the formation of an accumulation zone on each of the five subtropical basins and one previously unreported patch in the Barents Sea, which they linked to slow surface convergence due to deep-water formation. Recently, Cózar et al. (2017) postulated that both the surface circulation models and the field data reported in their study showed the poleward branch of the Thermohaline Circulation transferring floating debris from the North Atlantic to the Greenland and Barents Seas, where they found a dead end of this plastic conveyor belt. Before these modelling and field work studies provided details on the accumulation of plastics in the Barents and Greenland Seas, Zarfl and Matthies (2010) had already estimated the flux of plastic using surface water flow times the plastic concentration in surface water mass, and toxic substances associated with plastics, concluding that the fluxes associated with plastic drift are 5 to 6 orders of magnitude smaller than those from the same substances dissolved in sea water or transported to the region through the atmosphere. Nevertheless, they pointed out that the significance of various pollutant transport routes does not depend only on absolute mass fluxes but also on bioaccumulation in marine food chains, as will be discussed later.

In addition to the input by drifting oceanic waters, Peeken et al. (2018) postulate through their recent study of microplastics in sea ice cores, that sea ice drift is a pathway for the dispersion and transfer of microplastics from the areas of sea-ice formation in the Amerasian and Eurasian Basins, through the Transpolar Drift and ultimately towards the Fram Strait and the North Atlantic. This transfer mechanism is also shown to provide a dispersion pathway for the waters of the Siberian rivers towards the Barents and Nordic Seas (Pavlov, 2007).

Distribution

Marine litter, including microplastics, has been observed in all environmental compartments across the Arctic marine environment (Figure III.3 below). Even in some locations distant from hubs of human activity, marine litter abundance is within the same order of magnitude to that of populated areas close to urban centers (Hallanger and Gabrielsen, 2018). It is important to note that the geographic distribution of documented observations of marine litter, including microplastics, is heavily dominated by higher accessibility and increased research activity in the Atlantic Arctic (Norwegian, Greenland and Barents Sea), as well as in the Bering Sea and the Gulf of Alaska and their coastal areas. Compositionally speaking, data regarding materials other than plastic is only available for beach and sea-floor surveys, as sea ice, surface waters, water column, and sediment studies have only focused on the concentration of plastic litter and microplastics.

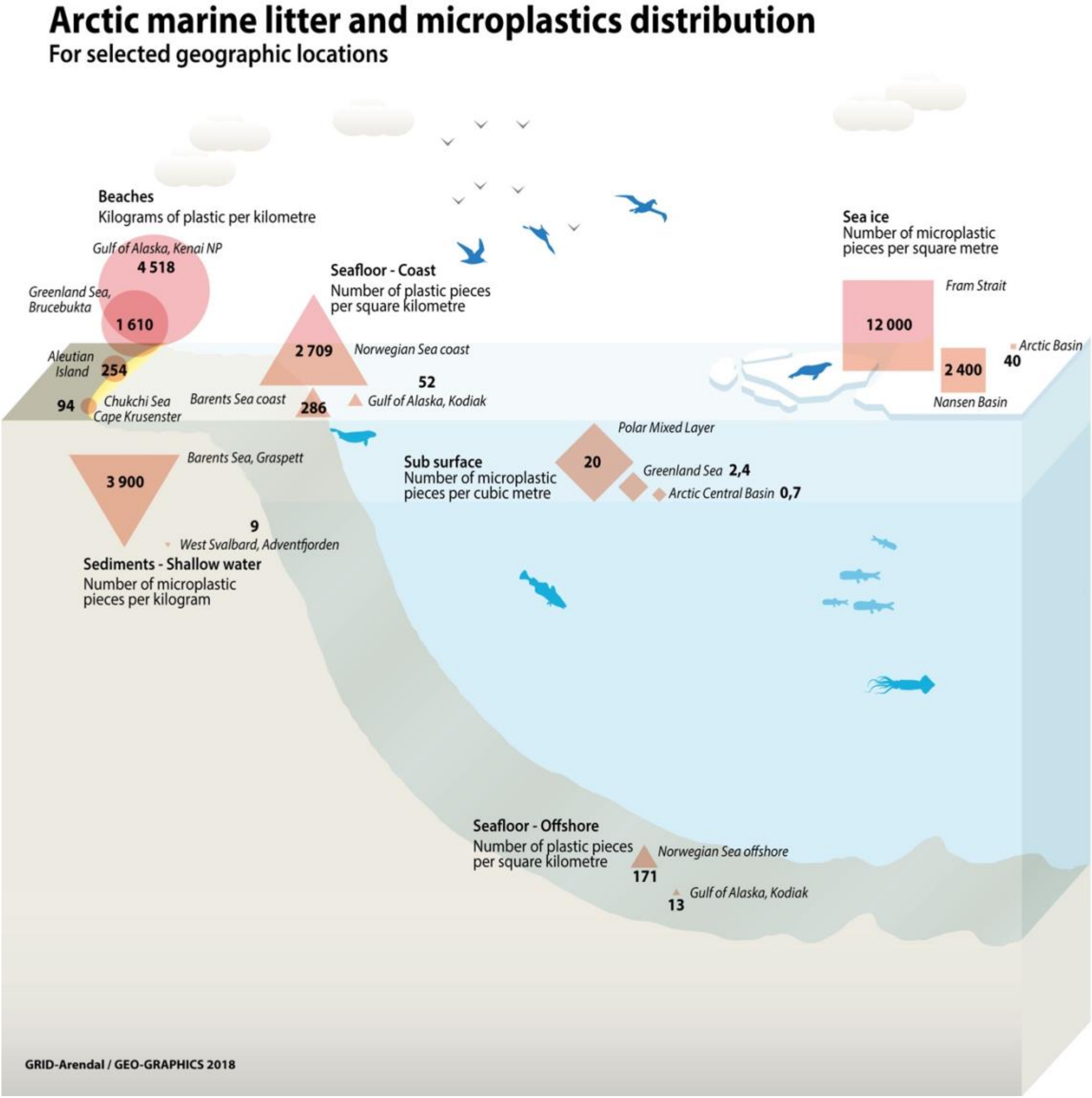


Figure III.3

Beaches and shorelines

Information on litter accumulated on the surface of beaches is mostly limited to objects easily observed by the naked eye when inspecting beaches, and therefore the information on beached plastics corresponds to meso and macrolitter (Annex I, Table 2.1). Information concerning microplastics on beaches is gathered through the collection and analysis of sediment samples (beach sand) and is discussed in the Sediments subsection, below.

A wealth of information was compiled regarding marine litter accumulated on beaches of the Aleutian Islands during pioneering studies in the 1970s and 1980s, notably before the entry into force of international regulations like the International Convention for the Prevention of

Pollution from Ships (MARPOL 73/78), which entered into force in 1982. Hundreds of objects per kilometer were counted on several beaches in Amchitka, Attu, Agattu, Shemya, Buldir, Kiska, Little Kiska, and Adak Islands (i.e. Merrell, 1980; Merrell, 1984; Johnson, 1990; Manville, 1990). This was estimated to correspond to hundreds of kilograms per kilometer with most of it connected to intense fishing activity by Russian, Japanese and U.S. fishing fleets. More than 90% of the litter mass was associated with trawl nets or parts of them. A study recently published by Polasek et al. (2017) documented the presence of litter in three parks in the Gulf of Alaska and two in the Chuckchi Sea north of the Bering Strait. The density of debris in the Gulf of Alaska reached up to 4,196 kg/km but only 63 kg/km on the southeastern shores of Chukchi, lower than previously observed in the southern Bering Sea. While the shores of parks facing the Gulf of Alaska are directly exposed to inputs resulting from intense fishing and shipping activities in the Gulf of Alaska and northeastern Pacific, the shores of the southeastern Chukchi Sea receive fewer inputs due to much lower local fishing and shipping activity and likely to the limited input related to litter drifting from the Bering Sea northwards into the Arctic Ocean through the Bering Strait.

In the OSPAR maritime area of the North-East Atlantic region, beach litter is monitored at 17 sites within the Atlantic Arctic, with 36 surveys conducted in 2017. The amount of beach litter varied from a mean of 1,475 items per 100 m in the spring to 195 items per 100 m in the summer months. Plastic accounted for up to 94% of the material in the spring surveys (OSPAR. Pers. Comm.). The presence of beach litter has been documented on the shores of Svalbard facing the Arctic Ocean and the Fram Strait, with densities from 185 to 1,354 kg/km, with the exception of a site where density reached a maximum value of 7,331 kg/km due to the presence of a heavy fishing net in the area surveyed (Bergmann et al., 2017a). As on the shores of the Bering and Chukchi Seas and the Gulf of Alaska, fisheries-related litter dominated the litter composition on Svalbard’s beaches, accounting for 48 to 100% of the mass. This dominance has also been reported in a study by Weslawski and Kotwicki (2018), carried out on the west coast of Prins Karl Forlandet (westernmost island of Svalbard archipelago).

Figure III.4. Litter items with readable embossed text or labels collected from a beach of the Hinlopen Strait, Svalbard Archipelago (Credit: M. Bergmann, AWI).

A close inspection of litter beached on Svalbard (Figure III.4) showed that the majority of litter items with identifiable imprints originated from Norway and Russia (41%), other European countries (43%), or other sources including Canada, USA, Brazil, Argentina (9%) (Bergmann et al., unpubl. data, Figure III.2). Still, it is important to bear in mind that the identification of the country of production of an object does not mean that the actors involved in the release are also from the same country as the object could have been internationally traded. Similarly, and also very important, the country of production of an object does not indicate where the object has been released, as it could have been transported for long distances before being released in the environment.

Surveys on the northwestern tip of Iceland revealed lower densities of litter, mostly plastic, with an average of 1,040 items/km corresponding to an average of 104 kg/km originating mostly from Icelandic fisheries (Kienitz, 2013). Surveying according to the OSPAR beach protocol has also been recently initiated at several locations on the eastern and western shores of Greenland (Strand and et al., in prep.). Initial results reveal similar median densities for the west coast, with 1,200 items/km, compared to much lower densities of 30 items/km in the East. Analysis of the type of objects collected reveals the dominance of local sources, i.e. mismanaged domestic waste or Barents/Greenland Sea fisheries over long-range transport, especially for west Greenland.

Sea ice

Observations of microplastic particles within sea ice in the Arctic are limited (Table 2.2) but enough to corroborate its presence. Obbard et al. (2014) documented concentrations ranging between 38 and 234 x 10^3 n/m^3 in sea ice cores collected in the central Arctic Ocean and Chuckchi Sea in 2005 and 2010. Recently published results from cores collected in the Fram Strait and the Central Arctic north of Svalbard (Peeken et al., 2018) revealed even higher concentrations of microplastics in sea ice, reaching maximum values of $1.2 \pm 1.4 \times 10^7 n/m^3$ in pack ice in the Fram Strait and minimum values of $1.1 \pm 0.8 \times 10^6 n/m^3$ just north of Svalbard. These concentrations are several orders of magnitude higher than those of Obbard et al. (2014), likely due to different methodologies used, and further confirm that sea ice is an important temporary sink of plastic litter. The second highest concentration was recorded in landfast ice, which was formed locally off east Greenland, highlighting a contamination of east Greenland surface waters at the time of ice formation. However, back-tracking ice drift trajectories from the location where the other ice cores were obtained showed that microplastics were likely incorporated into the ice in the Kara and Laptev Seas and the Central Arctic Ocean and transported to the south with the Transpolar Drift. In addition, the differences in the amounts and composition of microplastic in different depths of the cores point to strong local differences in microplastics present in seawater during the process of ice formation.

Surface and sub-surface waters

Information on floating litter in surface waters is gathered through several methods. For the largest size fractions, visual observations from ships and even low-flying helicopter flights are available for the Barents Sea and Fram Strait (Bergmann et al., 2016) with an average of 0.001 items (all of them plastic) per kilometer. The smaller fractions are studied through the use of surface samplers, water pumps and stomach content analyses of the seabird *Fulmarus glacialis* or northern fulmar (i.e. OSPAR Commission, 2015; van Franeker and Law, 2015). For these size fractions, only plastic is considered in the studies as the other materials either sink (glass, metal and ceramics), disintegrate (cardboard) or are difficult to distinguish from natural particles (machined wood). As for beached litter, information from several pioneering surveys carried out during the 1970's and 1980's in the Bering Sea, Gulf of Alaska and Subarctic North Pacific (Shaw, 1977; Day and Shaw, 1987; Day et al., 1990) revealed that the concentration of plastic in neuston surface waters samples (collected using slightly different net devices with mesh sizes of 0.333 - 0.5 mm and therefore sampling mostly microplastics (<5 mm) and mesoplastics) decreased from the Subarctic North Pacific towards to the Gulf of Alaska and the Bering Sea (Annex II, Table 2.2). However, concentrations in the Bering Sea have increased from the mid 1970's from tens of particles to thousands of particles per square kilometer (Annex II, Table 2.2 and references therein). Still, concentrations in the Bering Sea in 2006 (0.017±0.010 - 0.072±0.041 n/m^3, Doyle et al. (2011)) were one order of magnitude lower than concentrations in the Atlantic Arctic in 2014 (0.34±0.31 n/m^3, Lusher et al., 2016). Cózar et al. (2017) recorded surface concentration of plastics in parts of the Norwegian and Barents Sea to have a median value of 0.063 n/m^2 in 2013. These concentrations are similar to median concentrations for subtropical accumulation zones associated with the subtropical oceanic gyres (0.044 n/m^2) and one order of magnitude above the medians for non-accumulation open waters (0.0019 n/m^2) (Cózar et al., 2017). Therefore, plastic abundance in certain areas of the Atlantic Arctic is comparable to the abundance in the subtropical oceanic gyres, although maximum values for subtropical oceanic gyres (1.3 n/m^2) are one order of magnitude above maximum values recorded in the Barents Sea (0.32 n/m^2; Cózar et al., 2017).

Studies of ingestion of surface plastic particles by northern fulmars show that levels of floating litter in the Atlantic Arctic and in the Gulf of Alaska are significantly lower than those in the North Sea and the Eastern North Pacific (Provencher et al., 2017). Despite this northwards decreasing trend, floating plastic is certainly present at high latitudes and much higher in the Atlantic sector of the Arctic than, for example in the Canadian Arctic, with almost 90% of the individuals with ingested plastic in the Svalbard region compared to 40% in the Canadian Arctic (Trevail et al., 2015a; Provencher et al., 2017).

Scattered information from subsurface water samples (Lusher et al., 2015; Sundet et al., 2017) could not provide any insight on the vertical distribution of microplastics near the surface. The increase of plastic litter over time in the Bering Sea may be related to transportation of litter from other areas where concentration has been increasing due to increasing input (Day and Shaw, 1987). According to the data modelled by van Sebille et al. (2012) and measured by Cózar et al. (2017) plastics are likely concentrated in the Norwegian and Barents Seas surface waters as a result of the flow of water loaded with particles from the North Atlantic and the subsequent sinking and deep water formation in the Barents Sea. The recent study by Peeken et al. (2018) points to further pathways, i.e. southwards drift of particles from the Central Arctic to the Fram Strait with the Transpolar drift. High quantities of litter and microplastic in the Fram Strait are therefore potentially linked to (1) increasing local sources, (2) transport N->S (Transpolar Drift, engaging also pollutants from the Pacific and rivers) and (3) transport S->N (thermohaline circulation). Van Sebille et al. (2012) and Cózar et al. (2017) did not fully consider the transpolar drifts in their models and regarded the ice as a barrier more than a source.

The present and potential future increase of human activities in a warmer Arctic with longer ice-free seasons may favor the dispersion and increased concentration of plastic particles in Arctic surface waters (Cózar et al., 2017). Peeken et al. (2018) also highlight that the presence of microplastics in Arctic waters may increase with increased human activity and as a result of increased sea ice melt.

Water column

Data on the concentration of plastic within deeper parts of the water column that provide insight on the three-dimensional distribution of plastics in the Arctic, or even other parts of the world’s oceans, is scarce (Table 2.2). Amelineau et al. (2016) gathered data on the concentration of microplastics across the top 50 meters of the water column near the eastern coast of Greenland and found concentrations within the same range and order of magnitude as those recorded in subsurface water samples in the Greenland and Norwegian Sea between Norway and Svalbard (Lusher et al., 2016). Morgana et al. (2018) reported values for the Northeastern Greenland Sea very similar to the values reported by the previous two studies in nearby regions confirming the ubiquitous presence in the Greenland Sea and Fram Strait.

Kanhai et al. (2018) showed the ranges for microplastic abundance (n/m^3) across the different water masses in the Arctic Central Basin to be as follows: Polar Mixed Layer (0–375) > Deep and bottom waters (0–104) > Atlantic water (0–95) > Halocline waters i.e. Atlantic or Pacific (0–83). These values confirm that microplastics are present throughout the whole water column in the central Arctic Ocean, that they are being transported downwards out of the surface waters and that the water column constitutes one of the reservoirs of microplastics in the region. Using large volume pumps and Fourier-transform infrared spectroscopy imaging techniques, Tekman et al. (in prep.) detected higher mean microplastic concentrations at the sea surface (510 n/m^3) and at 300 - 2500 m water depths (190 n/m^3) in the eastern Fram Strait, indicating that higher abundance of microplastics and presence throughout the water column in this region of the Arctic marine environment. Due to the fact that the density of most plastic polymers is close to the density of seawater (GESAMP, 2015), particle aggregate formation and ballasting processes (Kanhai et al., 2018) contributes to the efficient dispersal of microplastics through the water column. When particles aggregate, they bind to each other and particles lighter than seawater may end up sinking due to the fact that the aggregate may reach a density higher than seawater because of the contribution of other particles with a much higher density (ballasting).

Seafloor

Information on the presence of litter on the Arctic seafloor has been obtained in several studies through trawls or underwater photo and video transects (Table 2.3). As with surface water data, seafloor data is mostly restricted to the Atlantic Arctic, the Bering Sea and surrounding coastal areas. While surveys during the 1980s and 1990s in the Bering Sea and the Gulf of Alaska recorded concentrations of up to tens of objects per square kilometer, recent surveys in the Barents, Norwegian and Greenland Sea recorded concentrations of hundreds and up to thousands of items of litter per square kilometer.

Photo transects of litter on the seafloor of the Greenland Sea at the deep-sea observatory HAUSGARTEN (Bergmann and Klages, 2012; Tekman et al., 2017) have revealed a surprising increase in marine litter concentrations between 2002 and 2014, and especially at the northern station of the observatory, where concentrations of marine litter increased 23-fold from 346 objects per km^2 in 2004 to 8,082 objects per km^2 in 2014. Plastic was the dominant litter type, accounting for 47%, followed by glass (26%), rope (11%), metal (7%), fabric (6%), with paper/cardboard, pottery and timber making up the remaining 4%. Addition of more recent surveys revealed a 29-fold increase over time (2016: 10,358 ± 2,117 objects per km^2) (Parga-Martinez et al. in prep.). Buhl-Mortensen and Buhl-Mortensen (2017) carried out an extensive study of marine litter on the seafloor of the Barents and Norwegian seas and reported background density values of 202 and 279 items/km^2, respectively. Fishing gear, largely dominated in coastal and offshore areas of the Norwegian and Barents Sea followed by other plastic items, rubber, ceramics and glass. The much higher values reported for HAUSGARTEN, a more remote location than most of the sites covered in the study by Buhl-Mortensen and Buhl-Mortensen (2017), could be related to the different methodological approach used but also to temporal differences. Alternatively, in addition to Atlantic inputs, HAUSGARTEN may receive litter transported from the Central Arctic to the south via the transpolar drift. The study carried out by Grøsvik et al. (2018) included data from bottom trawls and provided weight of litter by seafloor area, averaging 26 kg per km^2 with 66% of this corresponding to processed wood while plastic litter (2.9 kg per km^2) accounted for more than 11% of the total mass but dominating the number of observations.

Through trawl sampling, and in some instances through photo/video transects, it is often possible to recognize objects or fragments of objects that allow tracing them to the potential sources. Except at HAUSGARTEN, all of the surveys above that targeted seafloor litter in the Arctic or nearby locations documented debris linked to fishing and/or shipping activities. At HAUSGARTEN, most of the items were plastic film fragments, which could not be clearly attributed to any particular source.

Due to the scarcity of information and lack of consistent monitoring programs across the Arctic, it is difficult to assess trends over time, but Bergmann and Klages (2012) and Tekman et al. (2017) indicate that the abundance of plastic in the Arctic seafloor is increasing, as is the proportion of smaller items.

Sediments

Marine litter sediment studies focus on plastic because of the reasons mentioned in the Background section. In addition, for fine grained sediments, glass, metal, ceramic, and wood treated in a manner as to be persistent, may be difficult to distinguish from the wider environment, while plastic is identified more easily due to their different density and chemical nature. The presence of plastics in marine sediments within the Arctic has only been documented in studies published during the last 5 years focusing on beaches, shallow-water and deep sea environments. Information is limited to Iceland, Svalbard/Greenland Sea and the Bering Sea and Gulf of Alaska (Annex I, Table 2.4). Information in this section is devoted to plastic concentration in beach and bottom sediments which is considered a different compartment than the surface of the beach or the surface of the seafloor.

Large plastic particles and microplastics were found in almost half of the beach sediments sampled near Reykjavik (Dippo, 2012) with no clear relationship to the distance from town detected. Therefore, it cannot be concluded that dispersion from point sources by ocean currents play a major role in the distribution of microplastics in Iceland. The sample with the highest particle load (> 150 n/l) could reflect the influence of the harbor and Reykjavik's waste collection and treatment facility. For sites not influenced by these very local sources, the distribution, the presence of fisheries-related debris and the type of particles collected suggest that offshore fisheries and local meteorological and hydrographic conditions (winds and currents) are driving factors.

Plastic particles have also been identified in some of the beach sediment samples collected in several locations in Svalbard (Sundet et al., 2016; 2017). The sample containing the largest number of particles (111 n/l) was taken at the high-water mark or wrack line where plastic particles may be washed off shore during largest waves or the last high tide and accumulate temporarily. On the other side of the Arctic, another recent study (Whitmire and Van Bloem, 2017) identified between 40 and 130 pieces of plastic per kg of dry sediment collected at 6 different national park beaches bordering the eastern shores of the Bering Sea and the Gulf of Alaska.

Information on seafloor sediments is available for the Fram Strait including the western and north western shores of Svalbard (Woodall et al., 2014; Bergmann et al., 2017b) and the Barents Sea (Moskeland et al., 2018). Available information from these studies (Woodall et al., 2014; Sundet et al., 2016; Bergmann et al., 2017b; Sundet et al., 2017; Moskeland et al., 2018) suggests an increase in the concentration of microplastics with depth reaching several thousands of particles per litter or kilogram of sediment. This emerging trend would need to be confirmed through studies using a targeted approach and homogenous methodology. Both Woodall et al. (2014) and Bergmann et al. (2017b) postulate that the deep sea could be an area for preferential accumulation of small plastic particles constituting a large sink of the plastic that has accumulated in the ocean during the last decades. Bergmann et al. (2017b) also explores the linkages between the presence of the sea ice margin, including the role of the formation of algal aggregates during ice margin production blooms, and the highest concentration of plastics (6595 n / kg sediment) of all the studied sites. This possibility is further emphasized by the potential role of the transport of microplastics by sea ice drifting along the Transpolar Drift and reaching the Fram Strait, where it would melt releasing its pollution load (Peeken et al., 2018).

In 2018 and 2019, surveys were carried out to monitor the presence of microplastic in bottom surface sediments from the northern Bering and Chukchi Seas (Jingli et al., 2018). Microplastics concentrations ranged from non-detectable to 68.78 items/kg dry weight of sediment. The highest concentrations were detected in the Chukchi Sea with negative correlation between microplastic abundance and water depth was observed. Polypropylene (PP) accounted for the largest proportion (51.5%) of the identified microplastic particles, followed by polyethylene terephthalate (PET) (35.2%) and rayon (13.3%). Fibers constituted the most common shape of plastic particles. The range of polymer types, physical shapes and spatial distribution characteristics of the microplastics suggest that water masses from the Pacific and local coastal inputs are possible sources for the microplastics found in the study area.

III.3. Interactions with biota and impacts

The impacts of marine litter, including microplastic, in the Arctic are, as in other areas, multiple and complex. Litter in the environment impacts biota, habitats and ecosystems. When marine litter is found in the same areas where human activities are carried out, it can also cause direct socio-economic and cultural impacts. In addition, impacts to the natural environment may also lead to further socio-economic and cultural impacts. The severity of the resulting socio-economic impacts will depend on which ecosystem service is affected and how fundamental the processes disrupted by the presence of litter and microplastics are for the functioning of the ecosystems. Some studies are already focusing on the impacts to the natural environment in the Arctic, while the resulting socio-economic impacts have, at most, been discussed qualitatively.

Interactions with biota, biological and ecological impacts

Documentation of interactions between marine organisms and plastic marine litter has increased drastically over the past years (Kühn et al., 2015; Lusher, 2015; Ryan, 2015a; Rochman et al., 2016; Werner et al., 2016; Provencher et al., 2017), covering impacts at the suborganism, organism, population, assemblage, habitat and ecosystem levels. Though impacts have often been demonstrated at the suborganismal levels, impacts from and beyond the population level are considered the most ecologically relevant. For example, for some marine mammals and seabirds it has been proven that the addition of debris to their habitats causes contamination via ingestion or harm through entanglement, but there is little evidence for this contamination having an impact on their population (Rochman et al., 2016; Galloway et al., 2017). An extensive study on the impacts of marine litter (Werner et al., 2018) concludes that there are harmful effects of marine litter on individual organisms of many species and there is evidence that marine litter negatively affects populations of some species. Yet, the monitoring of impacts on biota is challenging and linking evidence of the substantial numbers of individuals affected by marine litter and microplastics to negative effects on populations is difficult and not possible to date for most affected species. Similarly, within the Arctic region there are, so far, no studies demonstrating the interaction and impact beyond the organismal level. It is important to note that most studies on plastic ingestion in biota have occurred to date outside of the Arctic (Provencher et al. 2018), and similar to how we consider the effects of other contaminants, much of what we know about effects is derived from understanding developed in other regions. Small scale studies have nevertheless shown that plastic pollution can modify marine assemblages (Green et al., 2016), and there is growing evidence that marine litter, in combination with other anthropogenic stressors, represents a substantial challenge to marine biodiversity, ecosystems and its services (UNEP, 2016; Villarrubia-Gómez et al., 2017). As with many other anthropogenic stressors, quantifying the ecological effects (i.e. at population level or higher) of marine litter in isolation is challenging but that that does not mean that there are no impacts.

The synthesis below is organized following the different kinds of direct interaction that plastic debris and microplastics have with organisms in the Arctic, i.e., ingestion, entanglement and rafting. In addition, it also considers the implications of the interactions in terms of constituting additional pathways for input and/or redistribution and providing for one last reservoir or matrix in which plastic litter accumulates in the Arctic marine environment besides those covered under “Pathways and Distribution”. A schematic synthesis of the different modes of interaction with biota is provided in Figure III.5.

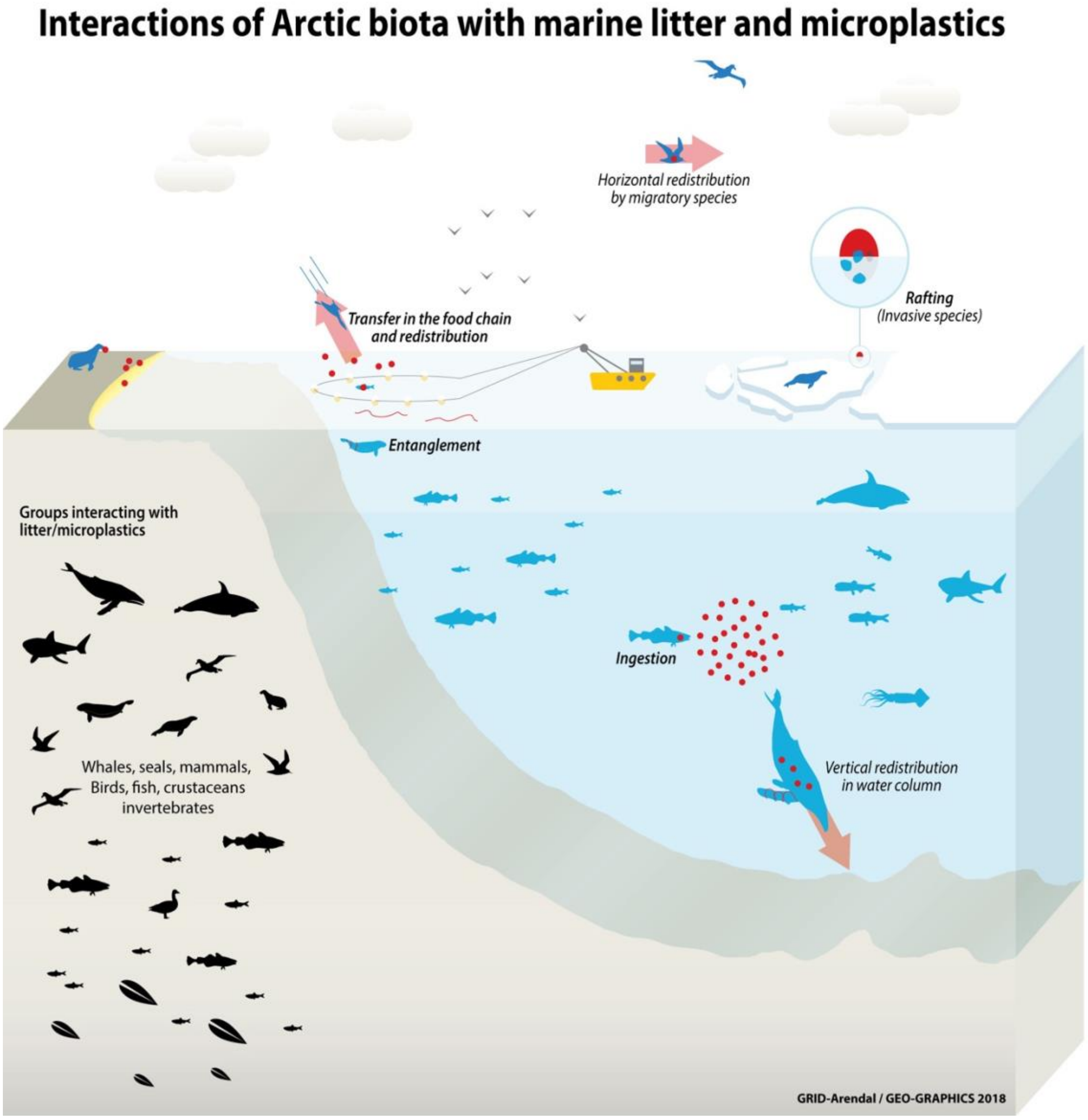


Figure III.5

Ingestion

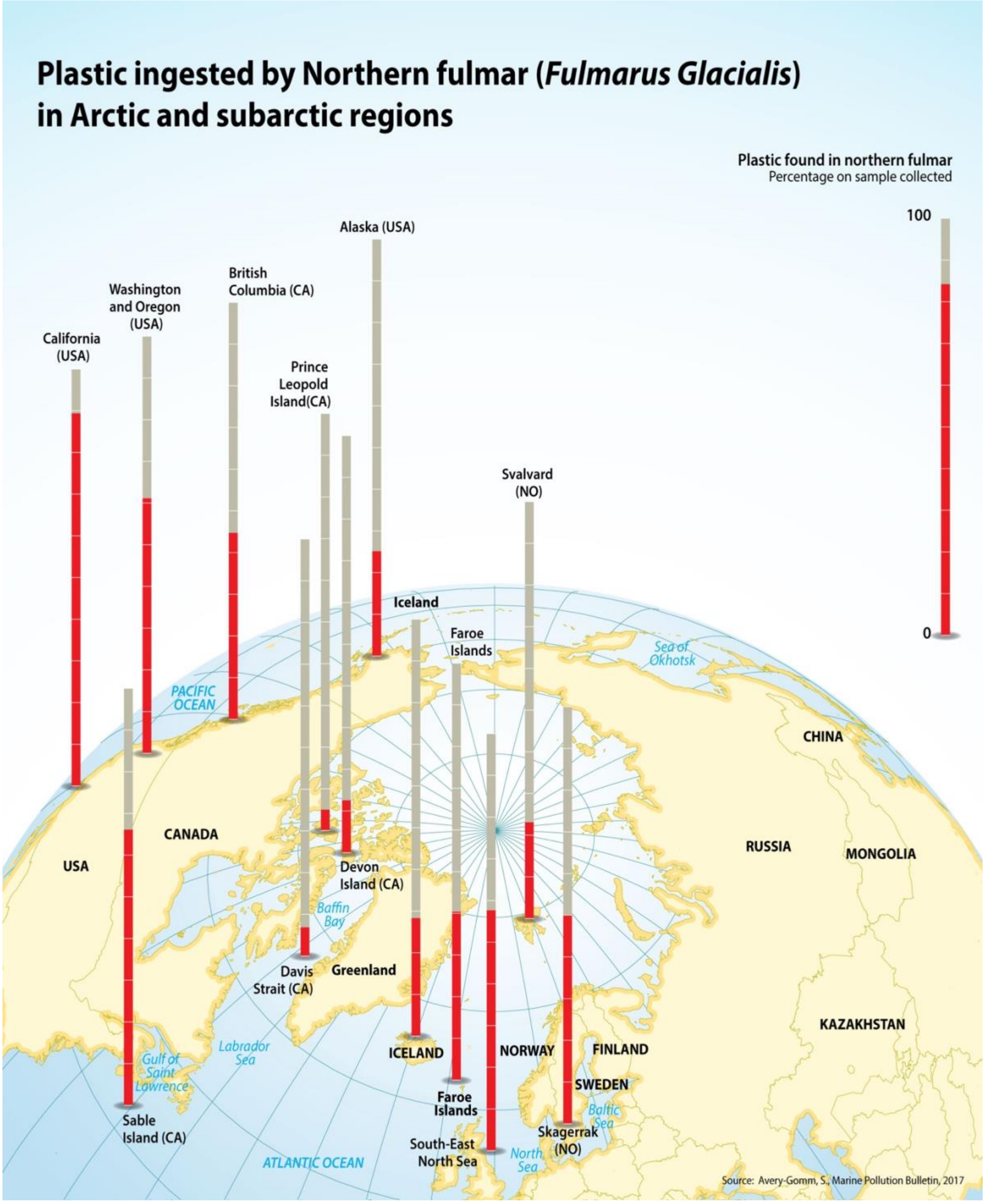
Studies on the ingestion of marine litter have, so far, almost exclusively documented the ingestion of plastic debris and microplastics. Plastic ingestion has been documented in a multitude of studies across the Arctic and its vicinity since the 1970s (see Annex I, Table 3.1). Plastic has been found in the digestive system of seabirds (on which most studies are focused), marine mammals including cetaceans and seals, sharks, fishes and invertebrates.

Seabirds

Literature on the presence of plastic in seabirds is extensive for several regions of the Arctic and its vicinity. Observations have been collected in the Barents, Norwegian and Greenland

Seas; Labrador Sea, Davis Strait, Baffin Bay and the Northwest Passage; the subarctic North Atlantic; the Gulf of Alaska and the Bering Sea; and the subarctic North Pacific (Annex I, Table 3.1). Research on seabirds, in particular northern fulmars (*Fulmarus glacialis*), prevails amongst other groups of organisms due to their widespread recognition as biological indicators of levels of pollution, distribution across the northern Hemisphere, allowing for standardized comparisons to be made (Trevail et al., 2015a; van Franeker and Law, 2015, Provencher et al., 2017), and their high vulnerability to plastic ingestion due to their feeding habits (van Franeker et al., 2011). According to some studies the residence time of plastic in the gastro-intestinal tract of northern fulmars is short, with 75% of the plastic ingested being passed from the stomach to the gut within a month (van Franeker and Law, 2015). If this is so, plastic in the stomach contents of northern fulmars is a relatively robust indicator of local pollution levels. If sampling is carried out shortly after migration, the amount of plastic in the stomach contents may be an indicator of plastic pollution in their foraging areas along their migratory pathway, but this will not mask the trends in multiyear datasets of geographically distinct regions (van Franeker et al., 2011; Trevail et al., 2015b). Some caution should still be used when interpreting plastic ingestion data, as the inference of environmental conditions based on plastic stomach contents has been a subject of discussion, and accurate measures of ingested plastic retention times are needed to better understand temporal and spatial patterns in ingested plastic loads within marine organisms (Ryan, 2015b). In addition, O'Hanlon et al., 2017 conclude in their review of the incidence of marine plastic debris in seabirds of the northeastern Atlantic that opportunistic sampling with limited or no coordination precludes the identification of temporal and spatial trends and therefore, the apparent trends derived from our review should be considered cautiously.

The stomach contents of northern fulmars have been the focus of a special project for the monitoring and assessment of plastic particles in the North Atlantic developed within the OSPAR Ecological Quality Objectives (EcoQOs) (OSPAR Commission, 2008; van Franeker and The SNS Fulmar Study Group, 2013; OSPAR Commission, 2015) and have also been established as an OSPAR Common Indicator. The methodology initially developed for monitoring the incidence of plastic pollution in the North Sea is now being used for the areas of the eastern North Atlantic, the western North Atlantic and of the North Pacific where northern fulmar is found. This includes observations within the Arctic region, thus allowing relevant comparisons within and across the Arctic. Some of the most recent examples of such extensive comparisons, including data from within and outside the Arctic region, are included in the works of Trevail et al., 2015a; van Franeker and Law, 2015; Avery-Gomm et al., 2017; Provencher et al., 2017; and van Franeker, 2017.



Source: Avery-Gomm, S., Marine Pollution Bulletin, 2017

Figure III.6

The latest comparison of standardized plastic content in northern fulmars (Avery-Gomm et al., 2017) (Figure III.6), which added data from the Labrador Sea to the existing dataset, further corroborates the northwards decreasing trend in plastic contents in the Eastern North Atlantic, Western North Atlantic and Eastern North Pacific (Kuhn and van Franeker, 2012). Therefore, northern fulmars foraging in the Arctic contain less plastic in comparison with those which breed and forage closer to highly developed and populated areas further south (e.g., comparative studies of Day et al., 1985; Provencher et al., 2014; Trevail et al., 2014; Amelineau et al., 2016; Avery-Gomm et al., 2017). Out of the three regions, the Arctic areas north of the Eastern North Atlantic (Barents and Greenland Seas) are characterized by much higher levels of plastic presence in northern fulmars than in areas at the same latitude or further south in the Eastern North Pacific (Gulf of Alaska) and the Eastern North Atlantic (Northwest Passage). Increased sea-based human activities (Kuhn and van Franeker, 2012), good connectivity through ocean circulation to areas further south in the Atlantic Ocean (Trevail et al., 2014; Trevail et al., 2015a; Cózar et al., 2017), release from melting sea ice (Obbard et al., 2014; Peeken et al., 2018) and overwintering in the North Atlantic during the non-breading season (van Franeker et al., 2011) have been suggested as reasons for high levels of plastics in marine birds of the Atlantic Arctic as compared to other areas of the Arctic.

In addition, these standardized research efforts have allowed the assessment of temporal trends in the abundance of plastics in the surface of the North Atlantic over the last 30 years (Provencher et al., 2017). Despite a complex pattern with strong variability in the abundance and mass of total plastics, dominated by user plastics (fragments of plastics of multiple origins), a clear 75% reduction of industrial plastic particles (pre-production pellets) in the stomach content of northern fulmars in the North Sea has been recorded. This reduction has also been detected in floating particles in the North Atlantic gyre over time, proving that measures implemented to reduce the leakage of pellets to the ocean can lead to a reduction of plastic particles present in the marine environment (van Franeker and Law, 2015) and available for interaction with organisms. The reduction of industrial plastics has also been detected through similar studies of short-tailed shearwaters (*Adrenna tenuirostris*) in the Bering Sea (Vlietstra and Parga, 2002) pointing to the global nature of the reduction of industrial plastics in surface waters and therefore applicable to the whole of the Arctic. However, the most recent assessment of plastic particles in fulmar stomachs, conducted in

2017 as part of OSPAR’s Intermediate Assessment, indicates that levels of plastic ingestion by northern fulmars in the North Sea appear to have stabilized since the early 2000’s (OSPAR, 2017).

Recent literature reviews and studies of plastic and microplastic in the Atlantic sector of the Arctic (Provencher et al., 2014; Trevail et al., 2015a; Poon et al., 2017; Hallanger and Gabrielsen, 2018) collected information on the ingestion of plastic by three other seabird species, Brunnich’s guillemot or thick-billed murre (*Uria lomvia*), little auk or dovekie (*Alle alle*) and black-legged kittiwake (*Rissa tridactyla*) (Annex I, Table 3.1). Records for the common eider (*Somateria mollissima*) and the king eider (*S. spectabilis*) did not show eiders to be ingesting plastic (Annex I, Table 3.1). The systematic review of literature dating back to the 1980s and 1990s (i.e. Day et al., 1985; Robards et al., 1995), and devoted to seabirds elsewhere in the Arctic, including the Russian and Canadian High Arctic, the Bering Sea and Alaska (Annex I, Table 3.1), provide records of plastic ingestion to varying degrees for the common eider and fifteen other species. Trevail et al. (2015b) also compiled records of plastic ingestion in seven sub-Arctic species, most of them included in table 3.1, indicating the widespread incidence of plastic ingestion in certain species. The vulnerability to plastic ingestion for the different Arctic seabird species will differ accordingly to their foraging habitats, behaviours and diets.

Review of records of plastic ingestion by seabirds (Annex I, Table 3.1) seems to indicate that since studies started documenting it, the frequency of occurrence of plastics in Arctic seabirds has stayed relatively stable, while the number of plastic items ingested per individual, as well the total weight, seem to be increasing over time. This is coherent with the single genus (*Uria spp*.) study carried out by Bond et al. (2013) that showed no significant trend over time in the frequency of plastic ingestion by common and thick-billed murres, while the number of pieces and mass by individual fluctuated from highest in the 1980s, lowest in the late 1990s, and intermediate in contemporary samples.

The occurrence of plastics in surface-feeding seabird species is two times higher than in pursuit-diving birds (Annex I, Table 3.2), with the exception of values reported by Day et al. (1985), where frequency of plastic occurrence in pursuit-diving birds was 26% and 16% for surface-seizing birds, though this exception might be due to the sample size for these categories. However, the distribution of plastics among the surface feeders also differs.

Northern fulmars, for instance, have a greater frequency of occurrence of plastics than kittiwakes (Annex I, Table 3.2). As suggested by Avery-Gomm et al. (2013) and Poon et al. (2017) this might be explained by the breeding strategies of the two species: northern fulmars feed in areas further from their breeding ground and almost twice as large as feeding areas for kittiwakes, which allows them to reach areas with higher plastic concentration. Plastics tend to concentrate in areas of fronts and eddies, which are also areas where procellarids like northern fulmars tend to feed (van Franeker and Law, 2015), particularly in offshore and shelf edge habitats (review in Mallory et al. 2012). Provencher et al. (2014) also highlighted the influence of the foraging strategies (surface seizing vs. pursuit diving) in plastic ingestion. In addition, fulmars are more omnivorous than kittiwakes, with the former consuming more large zooplankton, larval fish, and invertebrates (Mallory et al. 2012), while the latter consume primarily fish (Hatch et al., 2009). Procellariids, including northern fulmars, do not regurgitate indigestible items like other seabirds do and so are vulnerable to the accumulation of debris (Mallory, 2006).

Studies of seabird diets have also helped document the transportation of plastics in the food chain. Hammer et al. (2016) examined plastic pellets found in great skuas and showed the higher prevalence of plastic pellets amongst the ingested remains of northern fulmars, indicating that plastics were transported from sea surface-feeders to predators.

The impacts associated with plastic ingestion by seabirds and other groups of organisms are potentially twofold: physical (e.g., internal injuries, ulceration and lodging in the digestive system causing obstructions, malfunctioning of the stomach and satiety feelings), and toxic due to the absorption of chemicals in instances when they are added to plastic during manufacturing and/or absorbed by it during its use and movement in the environment (Ask et al., 2016). The potential physical effects of plastic ingestion in Arctic seabirds have been discussed and inferred by analogy to demonstrated effects in seabirds from other latitudes since the 1980’s (Day et al., 1985, Spear et al., 1995), but few Arctic studies have addressed sublethal (e.g., body mass loss, reduced growth) and lethal effects. This is likely linked to the fact that it is often difficult to determine whether the plastic in dead stranded individuals (the large majority for northern fulmar studies) was actually the cause of death (Rochman et al., 2016). Vliestra and Parga (2002) found no relationship between plastic incidence and body mass in short-tailed shearwaters in the Bering Sea (collected as bycatch or shot) and concluded that body condition is little, if at all, compromised by plastic ingestion at least at the levels found during the study. However, Spear et al. (1995) documented a negative relationship between body weight of tropical Pacific seabirds and number of ingested plastic particles. While there is a lack of research directly connecting plastic ingestion to negative physical effects, some studies indicate that plastic may contribute to health degradation and, potentially, mortality. During a mass mortality of northern fulmars in the North Sea in 2004, several indicators suggested a background hormonal disturbance, potentially related to persistent high levels of chemicals, some of which may have derived from plastics, circulating in their bodies during a period of prolonged food shortage (van Franeker and The SNS Fulmar Study Group, 2011). While the North Sea population of northern fulmar has been growing for the last two centuries this trend has stopped or reversed since the 1990's and reproductive success is at present poor (van Franeker and The SNS Fulmar Study Group, 2011, Werner et al., 2016). These authors point out that many factors are involved in population trends, but reduced adult survival and reduced reproductive output as a consequence of plastic ingestion are population effects that could play a role.

Further research on the interactions between plastics ingestion and impacts on seabird reproduction and population trends could help in discerning the cause relationship between the two. The studies by Trevail et al. (2014), Ask et al. (2016) and Herzke et al. (2016) specifically targeted the relationship between toxic substances and the abundance of plastic in northern fulmars from the Faroe Islands and Norway. After studying plastic in stomach contents and toxic chemicals (PCBs, PBDEs, PFAs, DDTs and other pesticides and OPFRs) in liver and muscle tissue from northern fulmars, they concluded that ingested plastic does not appear to be a significant route of exposure to the contaminants analysed therein. The dynamic bioaccumulation model included in the study by Herzke et al. (2016) suggested that plastics found in the stomachs of northern fulmars are likely to act as a passive sampler of the persistent organic pollutants (POPs) that the northern fulmars receive through their diet, i.e. absorbing these substances while in the environment and providing information on environmental concentrations of these substances potentially present in the food ingested. However, previous reports indicated that some PBDE and PCB congeners predominantly associated with plastic due to adsorption compared to overall diet could be transferred to seabird tissues (Yamashita et al., 2011; Tanaka et al., 2013). Except for DDTs and other pesticides, all of these substances are added to plastics during their manufacture. They are also present in the environment and absorbed onto plastic surfaces. Their association with plastic, however, does not seem to constitute a substantial addition to the chemical burden that northern fulmars experience through overall diet where these pollutants bioaccumulate (Ask et al., 2016).

Marine mammals

Data relative to the ingestion of plastic debris by marine mammals is mostly derived from dietary studies and anecdotal records of the presence of plastic in beached or stranded individuals (Annex I, Table 3.3). Some records also mentioned the presence of wood but not specified if this was natural or machined wood.

Regarding cetaceans, ingested plastic debris have been recorded in individual sperm whales (*Physeter microcephalus*) and fin whales (*Balaenoptera physalus*), all of them caught in whaling operations off the eastern coast of Iceland. Martin and Clarke (1986) reported that less than 10% of the 221 sperm whales caught between 1977 and 1981 had non-food items (rocks, plastic and/or wood debris less than 0.2 m in length) in their stomachs. As for larger debris, five discarded fishing nets were recorded as part of the guts content in the examined individuals, the largest weighing 63 kg. This net was firmly stuck between the second and third stomach, causing a potentially lethal obstruction through starvation. The authors postulated that the smaller items could easily be expelled with the bones and squid beaks at periodic regurgitations. In 1982, a plastic bucket was found in the intestines of a sperm whale caught close to the Icelandic shore. This sperm whale was in poor condition, and the authors argue that the bucket could have contributed to its condition and a caused a lethal intestinal obstruction (Lambertsen and Kohn, 1987). Further, six out of 82 fin whales caught in summer 1985, also in Iceland; had plastic material (plastic bags and small pieces of plastic sheeting) in their guts (Sadove and Morreale, 1990).

Anecdotal occurrences of plastic debris in the stomachs of bowhead whales (*Balaena mysticetus*) from Baffin Bay and the Beaufort Sea were also recorded in the 90’s (Lowry, 1993; Philo et al., 1993; also in Finley, 2001).

In recent years, the media has often linked incidence of lethal impacts to ingestion of marine debris by cetaceans, such as the sperm whale (*Physeter macrocephalus*) stranded on the Norwegian west coast near Bergen in February 2017. However, most of these incidents have not been the subject of published research studies, with some exceptions, was the case for the stranding of two other individuals of the same species on the coast of northern California (Jacobsen et al., 2010). In one whale, the emaciated body condition of the animal suggested starvation following gastric blockage, while for the other, gastric rupture following impaction with debris was presumed to be the cause of death.

Fish

There are very few studies that have documented the ingestion of plastic by fish in the Arctic. Plastic debris (fishing gear or line) has been found in stomach analyses of Greenland sharks (*Somniosus microcephalus*) from south Greenland with a frequency of 8.3% (Nielsen et al., 2013), and 3% from Svalbard (Leclerc et al., 2012). Low incidence (2.8% non-fibrous particles) was recently reported in juvenile polar cod (*Boreogadus saida*) caught in open coastal waters east of Svalbard and under the ice in the northern Svalbard shelf area, documenting for the first-time plastic ingestion by this ecologically important species in the Central Arctic Ocean (Kühn et al., 2018). Similarly, there was no evidence of plastic ingestion in the following three fish species, Atlantic cod, Atlantic salmon and capelin, that are common commercial and sustenance food fish off the Newfoundland coast of Canada (Liboiron et al. 2018). A recent study by Morgana et al. (2018) investigated the presence of microplastics in two mid-trophic level Arctic fishes collected off Northeast Greenland, the pelagic polar cod (*B. saida*) and the demersal bigeye sculpin (*Triglops nybelini*). The study found different proportions of ingestion among the species, 18% for *B. saida* (n = 85), substantially higher incidence than for the juvenile individuals sampled in Svalbard by Kühn et al. (2018), and 34% for *T. nybelini* (n = 71). The significant difference in the occurrence of microplastics between the two species is likely a consequence of their feeding behavior and habitat, reflecting the ingestion of sinking microplastics by the demersal bigeye sculpin. The study of Atlantic cod (*Gadus morhua*) from the Norwegian coast by Bråte et al. (2016) confirms the low or no incidence of plastic ingestion in two more Arctic locations (Lofoten Islands in the Norwegian Sea and Varangerfjorden in the Barents Sea). Additionally, Koelmans et al. (2014) conclude that in the case of plastic ingestion by Atlantic cod, this does not constitute a significant pathway for exposure to known contaminants associated to plastic like nonylphenol and bisphenol.

Despite the lack of other records of plastic ingestion in the Arctic, several of the species documented to ingest plastic in the North Sea have geographic distribution ranges that extend well within the Arctic. For example, Bråte et al. (2017) compiled information from studies of the presence of micro- and macroplastics in marine species from Nordic waters identifying up to 14 fish species known to ingest plastic in this region, which includes the Norwegian Sea, Greenland Sea and the western Barents Sea. It should be borne in mind, however, that results from stomach content analyses only represent a snapshot in time, the organism's last meal unless objects cannot be excreted.

There are currently no studies in the Arctic documenting ingestion of microplastics by fish age classes that predominantly occupy the mesopelagic layer. Mesopelagic fish inhabit the disphotic zone of the pelagic realm (200-1,000 m depth) from the Arctic to the Antarctic, with many species undergoing diurnal vertical migrations in the water column by residing at depth during the day before migrating to the surface at night to feed (Gjøsaeter and Kawaguchi, 1980). Smaller mesopelagic species feed on zooplankton, while the larger ones feed on decapods and fish, and can thus be exposed to microplastic and plastic ingestion through direct consumption or by feeding on zooplankton or other organisms that had already consumed plastics (Wieczorek et al., 2018). Wieczorek et al. (2018) investigated microplastic incidence in mesopelagic fish of the Northwest Atlantic and documented presence of microplastics in the gut of 73% of all fish, with *Gonostoma denudatum* having the highest ingestion rate (100%) followed by *Serrivomer beanii* (93%) and *Lampanyctus macdonaldi* (75%), amongst the highest reported for gut contents of fish and much larger than in a similar study in the North East Atlantic (11%) (Lusher et al., 2016) and North Pacific Subtropical Gyre (9.2%) (Davison and Asch, 2011). Wieczorek et al. (2018) attributed the high values to methodological differences with previous studies but also to the fact that the study was carried out in a hot spot for microplastics and mesopelagic fish alike. The study further concluded that colour, size, shape and composition similarities in microplastics found in mesopelagic fishes and those collected in surface waters of the same zone are attributable to surface water feeding by mesopelagic fishes. Wieczorek et al. (2018) also highlighted the key role mesopelagic fishes play by constituting a substantial share of the biomass in the pelagic realm, providing an important food source for organisms high in the trophic chain, including commercially harvestable species and seabirds, being responsible for a significant amount of carbon and nutrient cycling, and enhancing deep transfer of natural particles and potentially microplastics (Lusher et al., 2016).

Invertebrates

The only known reports of debris ingested by invertebrates in the Arctic shows microplastic ingestion by blue mussels (*Mytilus edulis*) from Svalbard with 90% occurrence and an average of 9.5 items per individual (Sundet et al., 2016), and by snow crabs (*Chionoecetes opilio*) with a 20% incidence also in Svalbard (Sundet, 2014).

Little is currently known about the impacts of litter on seafloor biota, though 67% of the litter items observed on the seafloor of the HAUSGARTEN observatory were in some way interacting with epibenthic megafauna (Bergmann and Klages, 2012). Microplastics were also detected in deep-sea starfish *Hymenaster pellucidus* from the Rockall Trough (Courtene-Jones et al., 2017), which also inhabit HAUSGARTEN.

A recent study by Fang et al. (2018) reported for the first time the ingestion of microplastics by benthic organisms in the Arctic and sub-Arctic regions, representing 11 different species inhabiting the shelf of the Bering and Chukchi Seas. Mean uptake ranged from 0.02 to 0.46 items g^{-1} wet weight (ww), or 0.04-1.67 items $individual^{-1}$, which is lower than uptake in other regions worldwide. Interestingly, the highest value appeared at the northernmost site in the Chukchi Sea, implying that the sea ice and the cold current represent possible transport mediums for microplastics ingested by benthic fauna and pointing to transfer mechanisms similar to those implied by the research carried out in the Fram Strait by Peeken et al. (2018).

Although microplastic ingestion by zooplankton has not been documented in the Arctic, several studies have shown this can occur in natural conditions, for example in the Northwest Pacific and the coastal waters of Southeast Alaska and British Columbia (Desforges et al., 2015), and in laboratory experiments (Cole et al., 2013). Microplastic ingestion by zooplankton may have far-reaching implications (Galloway et al., 2017; Villarrubia-Gómez et al., 2017) due to the role of this group, together with phytoplankton, as the base of most marine food webs. As for other larger organisms, microplastic ingestion by zooplankton may have negative effects, as demonstrated in laboratory conditions, such as gut-blockage, increasing gut-retention times leading to reduced feeding function (Cole et al., 2013), and reduced fecundity linked to the physical disturbance caused by the presence of plastic in the digestive tract (Cole et al., 2015). The degree of transfer and bioaccumulation of plastic-associated toxic substances, such as persistent organic pollutants (POPs), to zooplankton and fishes is being researched, but evidence is currently limited (Lohmann, 2017). The review by

Lohman (2017) did highlight that microplastics are potentially an important transfer vector for other plastic additives, like flame retardants, into marine organisms.

Entanglement

This section covers entanglements which can occur from abandoned, lost or discarded fishing gear (ALDFC). It does not cover by-catch as that happens with gear that is actively being used and therefore not litter or debris.

Entanglements of various species, mostly marine mammals, have been documented in studies; however, most are anecdotal (e.g. Beach et al., 1976; Baba et al., 1990; June, 1990; Sadove and Morreale, 1990; Kapel, 1985 in Finley, 2001 and summary in Hallanger and Gabrielsen, 2018). The only systematic monitoring was conducted in 1960s-80s for the Pacific juvenile male northern fur seals (Merrell, 1980; Fowler, 1985, 1987; Kuzin, 1990). Other comparative studies were conducted on Pacific female northern fur seals in 1991-1999 (Kiyota and Baba, 2001) and Pacific humpback whales on 2003-2004 (Neilson et al., 2009) (Annex I, Table 3.4).

Pinnipeds

Most studies focusing on pinniped entanglement correspond to studies on entanglement of northern fur seals (*Callorhinus ursinus*) in Northern Pacific Ocean and Bering Sea (Merrell, 1980; Scordino, 1985; Fowler, 1987; Fowler et al., 1990; Kuzin, 1990; Fowler et al., 1993; Kiyota and Baba, 2001). The main source of comprehensive data on entanglements during the eighties was the commercial harvest of fur seals from the United States' Pribilof Islands' rookeries (Fowler et al., 1990) and Russian Commander Islands (Kuzin, 1990). Systematic monitoring ended with the application of bans on commercial seal hunting.

Rates of entanglement in the Bering Sea increased over time, reaching maximum levels of recorded entanglements in 1975 and 1976 (Fowler et al., 1990; Kuzin, 1990). Interestingly, the abundance of beached fisheries debris and number of entangled fur seals from the region are slightly correlated (Merrell, 1980; Fowler, 1987; Johnson, 1990). Fowler (1987) linked increasing entanglement of juvenile male seals with the wider introduction of synthetic fishing gear and packing bands, with trawl net fragments being the predominant (more than 2/3) entanglement debris (Fowler, 1987; Baba et al., 1990; Fowler et al., 1990). Baba et al. (1990) noted that marine debris were concentrated along the continental slope, the area targeted by trawl-fisheries and also the feeding ground for seals. Chances of entanglement were subject to change with the season and location, with the breeding season (May-October) in Pribilof Islands being the riskiest showing higher risks of entanglement (Ribic and Swartzman, 1990). Juvenile male fur seals are potentially more susceptible to interact with plastic debris than female fur seals, as male fur seals return to the breeding grounds earlier than females, and young seals are curious and tend to interact with floating objects (Kiyota and Baba, 2001).

Entanglement in plastic debris causes strangulation and injuries, leading to movement restriction, lower swimming speed and shortened activity pattern (Feldkamp et al., 1989; Yoshida et al., 1990b, a; Fowler, 2002), which in turn reduces foraging ability. For the female fur seals, it also impairs maternity care by shortening the length of feeding trips leading to pups gaining weight at a lower rate (DeLong 1988 in Fowler, 2002). The secondary effects are: vulnerability to predation, susceptibility to infections for wounded seals, retardation of growth of young seals (Scordino, 1985; Fowler, 2002) and mortality caused by drowning and starvation (Fowler, 2002; Kühn et al., 2015).

The chance of survival for entangled northern fur seal is less than 39%, and chances for death increase along with the size of entangling debris (Fowler et al., 1990). Even if the levels of fatal entanglement of northern fur seals were studied, entanglement-related mortality remains uncertain (Merrell, 1980). Dead entangled seals were observed, most of them far from the rookeries (Fowler, 1987; Baba et al., 1990), and it is believed that many seals died as a result of interaction with ALDFG (Trites, 1992). According to Fowler (1987) and Fowler et al. (1990), entanglement added an extra 15% to the yearly mortality rate of the northern fur seals population in Pribilof Islands, though population decline was also attributed to the parallel reduction of prey resources (Trites, 1992). However, Fowler (2002) noted in a synthesis paper on the northern fur seal that, although the decline in the 1970's may not have occurred without the effect of entanglement caused mortality, the influence of other factors such as overfishing, contaminants and global climate change cannot be ignored specially at times of low entanglement rates.

Entanglement has also been observed in Svalbard for other pinniped species, such as harbour seals (*Phoca vitulina*), bearded seals (*Erignathus barbatus*) (Bergmann et al., 2017a) and ringed seals (*Phoca hispida*) (pers. Comm. Governor of Svalbard). Additionally, it is estimated that the population of eastern Aleutian northern (Steller's) sea lions declined by half between

1957 and 1988 and entanglement was suggested as a possible contributing factor to this decline (Manville, 1990).

Cetaceans

Signs of entanglement of cetaceans such as impressions, lacerations, incisions, abrasions and scars have also been observed in Arctic waters, though the number of studies is limited to a few anectodal reports and a study on non-lethal entanglement in Alaska. Sadove and Morreale (1990) reported that five out of 95 fin whales harvested in Iceland showed signs of previous entanglement. Philo et al. (1992) compiled the signs of entanglement on several bowhead whales (*Balaena mysticetus*) in the 1980´s and 1990´s in Alaska and argued that despite the fact that entanglement could lead to mortality, especially for smaller individuals, there were no signs that this had an effect on whale populations. In a more recent study looking at non-lethal entanglement of humpback whales (*Megaptera novaeangliae*), Neilson et al. (2009) concluded that the large majority of humpback whales in northern South East Alaska had been entangled but that most whales apparently shed the gear on their own. The lack of cetacean entanglement studies in the Arctic was recently highlighted by Stelfox et al. (2016).

Crustaceans and fish

The shift since 1940 from fishing gear made from natural to synthetically manufactured materials has resulted in the increase of “ghost fishing,” which is the process by which ALDFG continues to catch fish while drifting in the ocean or lying on the seafloor. It has been estimated that each year, upwards of 640,000 tons of gear is lost globally, meaning that ALDFG accounts for over 10% of the total marine debris floating in our oceans (Macfadyen et al., 2009). The incidence of ghost fishing in the Arctic is also very limited, and only a limited number of studies have looked into these impacts. Stevens et al. (2000) documented ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots in Alaska and reported an incidence of ghost fishing of the target species in 16% of the ghost pots recovered reaching a total of 227 individuals in 24 pots. Still, they concluded that the data on abundance of pots and number of crabs captured did not allow them to draw conclusions on impacts without knowing more about ingress, egress and mortality. Sunflower sea stars (Pycnopodia helianthoides) were the most frequent (42%) occupant and second most abundant (189 in 62 pots).

Humborstad et al. (2003) documented ghost fishing of Greenland halibut *(Reinhardtius hippoglossoides)* on the continental slope in the southern Norwegian Sea with catches of tens of kilograms per day per gill net fleet (825 m long), indicating that gillnets continue to fish for years and adding to concern regarding the impacts of ghost fishing on this stock. They concluded that in order to ascertain the impact on the stock, annual losses of nets need to be estimated.

Terrestrial species

Entanglements of terrestrial species have also been documented in the Arctic. Formal records exist for entanglement in fishing nets of barren ground caribou (*Rangifer tarandus granti*) in the Aleutian Islands (Beach et al., 1976). Instances of entanglement in fishing nets has also been documented for the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and polar bears (*Ursus maritimus*) (Bergmann et al., 2017a). While entanglement has been document through the recording of trapped alive individuals or corpses and carcasses with obvious signs of entanglement, ingestion in terrestrial species has so far not been documented.

Ingestion and entanglement impact at the population level

The review above indicates that plastic ingestion and entanglement in the Arctic have been studied and documented at the individual level for a limited number of species and even less with regards to microplastic interaction. The potential consequences of ingestion and entanglement have been poorly studied and documented, with only a few studies establishing a link between the interaction with plastic and lethal or sublethal effects. The population consequences are largely unknown at present, and very few examples provide any notion of substantial effects at the population level. Only two studies have suggested population level effects for the northern fulmar *Fulmarus glacialis* (van Franeker and The SNS Fulmar Study Group, 2011) and the commercially important crustacean Norway lobster (*Nephrops norvegicus*) (Murray and Cowie 2011). The Norway lobster study was carried out in Scotland, but this species range extends to the Faroes, Iceland and northern Norway (Bell, 2015).

Biota mediated transport and redistribution

Organisms may influence the transport and distribution of marine litter in the Arctic. Organisms can actively or passively transport plastic debris and particles in, out and within the marine environment, contributing to their redistribution and geographical accumulation or dispersion. An example of active transport is the incorporation of plastic debris, especially dolly rope thread, into nests of seabirds. O'Hanlon et al. (2017) reported three studies from the northeastern Atlantic on nest incorporation by the northern gannet (*Morus bassanus*) and black-legged kittiwake (*Rissa tridactyla*). Both species are present and nest within the Arctic region. The risk and effects of entanglement by nest incorporation is addressed in the previous section, but it is likely birds can contribute to the export of floating plastic and its accumulation in localized coastal areas (Votier et al., 2011).

Other marine organisms also have the potential for redistributing plastic particles through ingestion and defecation. The influence of this process in the distribution of plastic in the ocean will certainly depend on the amount ingested, as well as population size, but will be especially relevant when the ingestion and defecation and/or regurgitation happen in different compartments, i.e., feeding at sea and defecating on land leading to microplastics being detected in guano (Provencher et al., 2018) or different locations within the same compartment (feeding in surface waters and defecating at depth). Similarly Hammer et al. (2016) have documented how seabirds transport marine plastics to terrestrial environments. The ingestion of plastic particles by zooplankton (Cole et al., 2016) and mesopelagic fish (Wieczorek et al., 2018) would be such an example, as both are known to migrate tens to hundreds of meters within the water column to feed at the surface during the night and avoid predation at depth during the day. Diel migration of large populations of plankton and mesopelagic fish is known to influence carbon cycling in the ocean by exporting carbon from surface to deeper waters through this mechanism (also known as a biological pump), and an analogous process could affect plastic particle distribution in the water column. Further when plastic is released at depth, it would be packaged in fecal pellets that could behave differently from the individual particle in the water column.

While this is likely a relatively small input into the Arctic as compared with the other transport routes as described in the Pathways subsection, how migratory biota may be bringing plastic litter to the Arctic and potentially concentrating it in specific regions may be of interest when designing monitoring programs. For example, a monitoring program could study whether there are higher concentrations of microplastics in the environment around seabird colonies as compared to other areas where this input via guano is not occurring.

Rafting of non-native species

Marine litter functions like natural floating debris, providing a means of travel for non-native – and potentially invasive – species and pathogens (Barnes and Milner, 2005; Gregory, 2009; Mouat et al., 2010; CIESM, 2014), and is therefore increasingly recognized as a possible vector for invasive alien species (Watkins et al., 2015), including in Arctic waters (Barnes, 2002; Barnes and Milner, 2005). Increasing marine litter abundance therefore contributes to increasing the potential risk of invasions by non-indigenous species. Marine plastic debris can act as a new pelagic habitat for microorganisms and invertebrates like bryozoans, barnacles, tube worms, foraminifera, coralline algae, hydroids and bivalve molluscs. The number of species reported rafting on debris has increased markedly since the 1970s (UN CBD, 1992). For example, marine litter is estimated to have doubled the opportunities for marine organisms to travel at tropical latitudes and more than tripled it at high (>50°) latitudes (Barnes, 2002). The only Arctic-specific study looking at the northward dispersal of species by rafting on marine litter was carried out on the western coast of Svalbard and documented large objects (fishing boxes, containers) colonized by barnacles (*Semibalanus sp.*), gooseneck barnacles (*Lepas sp.*), blue shells (*Mytilus sp.*), bryozoans and marine macro-algae (Weslawski and Kotwicki, 2018). The authors concluded that the rafting of groups of adult organisms favors their better biological dispersal compared to larval transport, and is regarded here as the main reason for reappearance of the genus Mytilus on Svalbard.

The low temperature of the Arctic is the most important barrier to invasion by marine-borne alien organisms. However, with a warming 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).

Socioeconomic impacts

Werner et al., (2016) and Bråte et al. (2017) described the societal and economic impacts associated with marine litter in European and Nordic waters, which are mostly analogous to impacts in the Arctic. These impacts are mainly linked to the economic sectors using the Arctic marine ecosystems, namely the fishing and aquaculture, shipping, and tourism and recreation sectors, which are also highlighted as the main impacted sectors in a global study by Newman et al. (2015). To date, there is no economic assessment to estimate the costs of plastic litter to these sectors, which besides bearing the costs are at the same time potential sources.

Fishing and aquaculture can be impacted through different mechanisms. These include reduced quality, the perception of reduced quality, or uncertainty on the quality of fish products that may lead to a shift of consumer habits away from seafood (GESAMP, 2016). Also, an associated impact could be the reduced quantity of fish products due to changes in the stocks of commercial species as a result of direct impacts from ingestion or entanglement on populations of these species or the species upon which they rely. These associated economic impacts can only be determined when enough information of the ecological impacts at the population, assemblage or ecosystem level, are investigated and determined. Additionally, there could be impacts associated to reduced landings of seafood due to direct physical interaction with marine litter. Lost or abandoned fishing gear, parts of it and other debris, can get caught in fishing nets, decreasing catch capacity or its quality.

Many Indigenous peoples in the Arctic harvest fish and marine mammals for food, and for economic and cultural wellbeing. A number of indigenous communities practice and rely on traditional sealing (including harp seals, ringed seals, and northern fur seals). Sealing constitutes a source of food, cultural and economic activities. The potential decrease in population of these species, as well as relocation of rookeries can have a negative impact on both cultural and economic parts of lives of indigenous communities and individuals. Though most seal products (such as pelt, meat, oil) are produced and delivered to the market by commercial undertakings, some are harvested by indigenous seal hunters for local consumption, cultural use, sale and/or securing food supply.

Marine litter has additional effects on the cultural practices and the harvest of food of communities living in the Arctic. Examples of this are commercial fishing line entanglement on harvested marine mammals and the presence of plastic debris on culturally used areas. Communities identify sanitation and waste systems (such as landfills) as contributing to food insecurity because they impact the marine environment integrity and its biota (Inuit Circumpolar Council – Alaska, 2015). The Nunavut Wildlife Management Board, for example, has identified the effects of marine plastics and litter in the Arctic marine environment as one of its research priorities based on potential impact considerations.

Potential impacts for sectors relying on marine transportation (fishing, shipping, energy and tourism) include fouling/blockages of propellers, cooling systems or other systems relying on seawater pumped into the vessel, leading to mechanical problems, navigational hazards, and costs associated with repairs and down time. The extent of this impact needs special consideration in the Arctic because damage to vessels in harsh and hazardous conditions, coupled with the difficulty of assistance and rescue operations, may present an additional hazard to human lives.

Plastic litter can have direct and indirect effects on the mental health of those living and/or visiting coastal areas (Wyles et al., 2016). Some of these effects are linked to the aesthetic value of coastal and marine ecosystems such that visitors may be discouraged from frequenting unsightly locations where plastics litter the shorelines (GESAMP, 2016). This may be especially true for the Arctic, where one of the main appeals for visitors is the pristine character of the environment. Additionally, visitors to the Arctic expect the possibility of observing emblematic fauna linked to Arctic biodiversity, and, in particular, large fauna like cetaceans, seals, polar bears and birds. Witnessing the suffering caused by marine litter on individual animals or media attention on the matter can have detrimental effects on the perception of the Arctic region as an undisturbed destination. The incipient and growing Arctic tourism and recreation sector may be affected if people are discouraged from visiting impacted areas.

An economic cost that is already occurring is that of cleaning up Arctic shores, something which is normally borne by the public sector, civil society and individual citizens. Information on clean-up programs will be provided in the next sub-section, but data on the economic costs of beach clean-ups is unfortunately not available for the Arctic.

The ongoing MARine Plastic pollution in the Arctic (MARP) project (www.marp.no) will deliver management relevant research on marine waste using Svalbard and the Barents Sea as a case study regarding the status and sources and socio-economic costs of marine waste. In addition, it will look at how regulations and incentives are affecting how waste in general, and ship-waste in particular is handled. The project is presently addressing the assessment of socio-economic costs of marine litter in the Arctic and should produce some results by 2020.

III.4. Monitoring and Response

Monitoring

Monitoring can be used for a variety of purposes, such as understanding the movement of marine litter within the Arctic, the water profile, the contributions of different sources, the contribution from different geographic regions (e.g., outside the Arctic), the impacts on species, etc. One example of a monitoring programme is under the framework of OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic). Under OSPAR, an extensive monitoring program has been implemented for waters of the Arctic region in the area covered under the convention encompassing the Norwegian and Greenland Seas and the western part of the Barents Sea. OSPAR currently assesses beach litter (OSPAR, 2017a), seabed litter (OSPAR, 2017b) and plastic particles in northern fulmars' stomachs (OSPAR Commission, 2015). Those are Common Indicators as part of its monitoring and assessment programme. These allow the determination of the abundance, trends and composition of marine litter in the OSPAR Maritime Area for different marine compartments (coast, seafloor and floating). OSPAR is also pioneering the development of a new indicator on microplastics in sediments. Currently, there is a total of 17 beaches monitored in Greenland, six in Iceland, one in Faroe Islands, three in mainland Norway and two in Svalbard. This extensive monitoring scheme is producing a wealth of valuable information on types and composition of litter items. However, as most Arctic beaches have only been recently added to the monitoring network, the datasets are not long enough for the calculation of statistically significant temporal trends in the amounts of overall litter or its composition. The monitoring of plastic particles in northern fulmars has been carried out more exhaustively in the North Sea, where the method was originally developed and where multiyear temporal series are available, although data for certain periods is available for the Faroe Islands, Iceland and Svalbard. This monitoring methodology has also been applied to monitor northern fulmars in the Northwest Atlantic and the Northwest Pacific, allowing comparison within and across different regions of the Arctic (Avery-Gomm et al., 2017). Seabed litter data collected according to the OSPAR protocol is currently not available for its Arctic Region covering the Norwegian, Barents and Greenland Seas (OSPAR, 2017b).

Beach litter surveys are an important foundation for management decisions as they can contribute to knowledge about the magnitude of the problem, monitor its development over time, identify the main sources and management target levels of litter presence along the coastline. It is important to bear in mind that monitoring approaches, such as the methodology applied by OSPAR on its own does not provide knowledge for targeted management purposes. For example, in OSPAR, all types of fishing nets are categorized as fishing nets smaller or larger than 50cm, making it challenging to use this data to pinpoint the origin, the type of fisheries involved or possible reasons why these items may have ended up in the sea.

In order to provide information on key litter categories at the level necessary for taking informed management decisions, the “deep dive” methodology has been developed within the MARP and Arctic Marine Litter Project. This methodology has been developed to provide detailed insight into the origin, sources and underlying behavior, processes and policy framework(s) that may have contributed to litter ending up in the marine environment, as well as identifying potential solutions. The idea behind the beach litter “deep dive” tool is that with the help of sector experts, detailed management relevant information can be collected. Engaging stakeholders in the collection of data and its analysis facilitates the establishment of a management oriented dialogue with these actors that contribute and often also receive the impacts of marine litter.

Besides the OSPAR monitoring program there are to date only limited monitoring programs targeting marine litter, including microplastics, in the Arctic. In the United States, the National Park Service led a project to assess microplastics in sediments on beaches, including several locations in the Arctic, but in a limited extent temporally and spatially. Based on the experience of the Clean Up Svalbard initiative, Bergmann et al. (2017a) suggest that there is an opportunity to use regular visits by tourists to gather data on marine litter from remote, poorly sampled areas. In order to capitalize on this opportunity, some compromises on the level of detail and time required for monitoring would need to be made so the experience does not drastically affect the recreational value of the voyage. Another initiative that could be adapted to gather data in Arctic shores is the NOAA Marine Debris Monitoring and Assessment Project which is the NOAA Marine Debris Program flagship shoreline monitoring and citizen science initiative that engages partner organizations and trained volunteers across the nation in completing shoreline marine debris surveys on macro-debris (greater than 2.5cm). This protocol has also been utilized at multiple locations in the Arctic and Alaska by

NOAA and U.S. Fish and Wildlife Service staff, integrating Alaska-specific adaptations in data collection and reporting. While citizen science is a viable option for gathering information on marine litter in coastal areas when focusing on large debris (as in the example mentioned above), attempting to sample and gather information on microplastics requires specifically designed and implemented research programs, as the methodology for sample gathering and analysis is much more complex. This places greater emphasis on training requirements for all individuals supporting microplastic monitoring, as multiple projects have utilized trained volunteers for water and shoreline sample collection.

A similar opportunity would be to use traditional ecological knowledge to supplement and/or complement monitoring schemes. As an example, in the United States, the National Park Service has done work to integrate traditional ecological knowledge (TEK) to nearshore modeling of ocean current patterns as they relate to oil spill dispersion and debris deposition and sources (Weingartner et al., 2017). Currently there is work in Canada using local Indigenous Knowledge to assess how microplastics may be concentrated around seabird colonies. The synthesis of Indigenous Knowledge regarding where plastic is most likely to be found is a potential area for further study (Provencher, pers. comm). Similar traditional and local knowledge may be available and useful to gather and integrate from other communities in the Arctic. Inuit Hunters, for example, are monitoring litter and have increased concerns on impacts to subsistence species, such as plastic in marine mammals and birds (ICC, pers. Comm).

In summary, most of the monitoring efforts thus far have been focused on acquiring coastal, mostly beach, data. Only monitoring of plastic content in the stomach of northern fulmars has developed to an extent that allows temporal and geographic comparison.

Ongoing Efforts to Address Marine Litter in the Arctic

In 2016, under the framework of the MARP Project, experts and fishermen from Norway, Russia and the United Kingdom studied some of the litter collected through the Clean Up Svalbard initiative in order to discern the sources and mode of entry of the dominant types of debris. They reported on the dominance of fisheries-related waste and waste from other marine activities, alongside with household related waste that could originate from land or sea as a result of inadequate waste management (Nashoug, 2017). This led to enhanced awareness among the fisherman operating in the Barents Sea. The Norwegian Fishermen's

Association, the Fishing Industry Union of the North, the Association of coastal Fishermen and Fish Farmers in Murmansk, and Fisheries Iceland produced a joint statement condemning the disposal of nets and other fishing equipment from any member vessel.

The awareness created by this kind of research project focused on understanding the drivers, release mechanisms and impacts to fisheries, has led to specific actions to address marine litter in the Arctic. A relevant example is the "Fishing for Litter" program that started in Norway in 2016, following the OSPAR approach used in other countries of the northeast Atlantic and the North Sea for 15 years. The program expanded from three to eight harbors in 2017, with three of them – Ålesund, Trømso and Båtsfjord – located within the Arctic region. "Fishing for Litter" is a program under which fishing vessels deliver marine litter caught during regular fishing activity free-of-charge to assigned marinas, and it is targeted to address the challenges connected with fisheries-related waste and ghost fishing gear. From 2016-2017, a total of 92 deliveries totaling more than 118 metric tons were made in the harbours of Tromsø and Ålesund, more than 60% of which was fisheries-related waste (SALT Lofoten AS, 2017).

In 2017, the Arctic Marine Litter project (www.wur.eu/arcticmarinelitter) was initiated, a collaboration between Wageningen Economic Research, SALT Lofoten AS and local partners in Svalbard. The aim of the Arctic Marine Litter project is to work on prevention by understanding the sources of marine litter and working on solutions. The project is a collaborative, multidisciplinary project with direct stakeholder engagement and is expanding by involving more and more partners throughout the Arctic. The Arctic Marine Litter Project will develop a more comprehensive understanding of the relevant stakeholders, underlying processes and clean-ups related to key litter categories, including solutions and management options to prevent the most common litter items from ending up in Arctic waters. The project consists of three parts. The first part is to examine the exact sources, clean-ups and underlying processes that have resulted in key litter items ending up on the shores of the European Arctic (the current focus is Svalbard and Jan Mayen). The second part is to engage with stakeholders to define practical solutions and management options to prevent litter from ending up in the European Arctic. Based on the knowledge developed in the first two parts, the third part is to identify what additional information should be collected through beach litter monitoring programmes in order to evaluate the impact of actions taken by the stakeholders involved in relation to the key litter categories. The Arctic Marine Litter project is designed to work as a catalyst for change by directly engaging stakeholders and providing input for Arctic policy initiatives on marine litter.

Recently, at the Arctic Council Working Group level, PAME Working Group recognized the importance of improved waste management in Arctic ports and developed a Regional Reception Facilities Plan (RRFP), based on the International Maritime Organization (IMO) Guidelines in response to the IMO's Polar Code amendments to MARPOL Annexes which came into force on 1st of January 2017 concerning ship generated waste. Based on this, PAME developed a proposal for IMO to consider the concept of regional agreements for waste management and reception in the Arctic, allowing States with ports in the Arctic Region to enter into regional arrangements for port reception facilities (PRF). In addition, the Conservation of Arctic Flora and Fauna Working Group (CAFF) Arctic Migratory Bird Initiative (AMBI) identified two key actions needed to mitigate habitat degradation of Arctic seabird species. One component of these actions is focused on the need to better understand the effects of plastic pollution in the ocean on Arctic seabirds and seaducks, and in response, preparation is now underway to organize a project. Finally, the Arctic Monitoring and Assessment Program (AMAP) has included a marine litter monitoring project for its 2019-2021 Work Plan, which may help fill in some of the knowledge gaps from this literature study.

Another major course of action towards mitigating the effects of marine litter is in the form of coastal clean-ups organized at different scales, frequency and capacity across the Artic.

Since 2006, the NOAA Marine Debris Program has worked with partners to remove over 900 metric tons of marine debris from Alaskan shorelines through Community Based Removal Grants, while the Gulf of Alaska Keeper (www.goak.org) has cleaned more than 2400 kilometers of coastline, collecting more than 1350 metric tons of debris, primarily in the Northern Gulf of Alaska region in Prince William Sound and the Kenai Peninsula. In addition, the Marine Conservation Alliance Foundation has been conducting coastal clean-ups in Alaska and the Aleutian Islands and removed more than 275 metric tons of debris between 2003 and 2007 from shorelines across the state (King, 2009).

In Canada, the Great Canadian Shoreline Cleanup has been active since 1994, running volunteer clean-ups. In 2014, for example, 4.5 metric tonnes of waste were picked up along a tiny portion (ca. 50 km) of the tens of thousands of kilometers of Arctic shoreline of the Newfoundland and Labrador and Nunavut provinces (Pettipas et al., 2016).

Bláí herinn (The Blue Army) is a non-profit organization in Iceland that was founded in 1998 and has been involved in various environmental projects in Iceland, especially regarding beach/coastal and marine cleanups. The Blue Army has recycled over 1100 tons of garbage from Icelandic shorelines, harbors and open areas. Underwater cleanup projects have resulted in recycling of over 100 tons of garbage.

The project "Hreinsum Ísland" is a coastal cleanup project that is managed by Landvernd, the Icelandic Environment Association, in association with the Blue Army. The objective with the project is to draw attention to issues associated with marine litter and to get individuals, groups and enterprises involved by signing up for voluntary beach cleanups at hreinsumisland.is.

In Norway, Hold Norge Rent coordinates thousands of beach clean-ups annually. The 'Clean Up Svalbard' campaign (a collaboration among tourists, Spitsbergen Travel and the Governor of Svalbard) engages visiting tourists and tourist cruise/sailing vessel crew members in yearly beach clean-ups (Governor of Svalbard, 2009). Beach clean-up campaigns like these may help to lessen the impacts and collect the data from remote sites, as well as educate people and create the sense of responsibility (Bergmann et al., 2017a; Nashoug, 2017). In fact, all of the organizations in charge of the coastal cleanup campaigns mentioned above conduct considerable efforts to raise public awareness of marine plastic pollution.

Representatives of the Saami Council proposed a new project, Clean-up of the Saami territory in the Murmansk Region, for consideration by the Arctic Contaminants Action Programme (ACAP). The project, which is expected to begin following conclusion of the formal ACAP project approval process, will involve both the inventory and eventual collection and proper disposal of land-based waste in this part of the Saami territory.

Both coastal clean-ups and "Fishing for litter" are mitigating actions that address reducing the amount and effects of pollution once the leakage of plastic debris has already occurred.

Section IV: Knowledge Gaps

The information on marine litter compiled in the previous subsections helps improve our understanding of the status and impacts of marine litter, and in particular, plastic litter and microplastics, in the Arctic region, but is by no means comprehensive. This kind of compilation has not been formalized previously for the whole Arctic region, but some efforts have compiled information for parts of the Arctic (Trevail et al., 2015b; Hallanger and Gabrielsen, 2018) or for larger regions, like the Nordic region including part of the Arctic (Strand et al., 2015). This literature review identifies numerous knowledge gaps that research could fill. In particular, this review focused on the available literature on marine litter and microplastics in the Arctic. The existing literature is heavily dominated by plastic due to its larger contribution to the total amount of litter and the greater representation in the literature. This makes difficult to ascertain the sources, pathways, input, distribution, interactions with biota and impacts linked to other litter materials. Additional knowledge could have significant implications for next steps regarding marine litter including microparticles in the Arctic.

Regarding **drivers**, there is, to our knowledge, no specific socioeconomic assessment looking at indicators such as population and waste generation, recycling and management for the region considered in this review, i.e. the Arctic watershed. As discussed within section III.1, the compilation of information relative to the drivers of marine litter could constitute excellent proxies to identify the relative contribution and geographic distribution of different possible **sources** as there is, yet, no direct comprehensive assessment of the litter and microplastics leaked to the Arctic. In stark contrast to the rest of the world, the assessment of human-driven input of marine litter in the Arctic from sea-based sources is less challenging than that of land-based sources. This is due to the limited and geographically-constrained nature of maritime activities in the Arctic Ocean compared to the vast and relatively poorly surveyed watershed that constitutes the catchment area for input from land-based sources.

There is no assessment of the input of marine litter by fishing, aquaculture, resource exploration and exploitation, and shipping activities based on information reported by the operators within the sector. This information is useful to understand the relative importance of local sourced pollution versus pollution brought to the Arctic by currents.

Similarly, there is no compilation of data on population density and distribution of population centers in conjunction with the capacity of waste and wastewater management systems at the regional and local level, nor is there compiled data on transportation and logistics, such as road and port network and traffic intensity.

As for **pathways,** there is no observational data regarding riverine input of marine litter from the Arctic watershed into the Arctic Ocean. There is a considerable wealth of information on the discharge of water and chemical substances (i.e. nutrients, pollutants), but there is no observational data regarding riverine input of marine litter and microplastics from the Arctic watershed into the Arctic Ocean. The work of Lebreton et al. (2017) to model the input of plastics from rivers was hindered in Arctic due to the lack of data on population density, mismanaged plastic waste production per inhabitant, per country monthly catchment runoff and the presence of artificial barriers. Similarly to riverine input, there is no data on the influx of marine litter into the Arctic marine environment through wind or atmospheric circulation or precipitation (Halsband and Herzke, 2017).

The magnitude of the input through oceanic circulation, mostly through the northern arm of the North Atlantic circulation, has been discussed and researched by Zarfl and Matthies (2010) and Cózar et al. (2017). Similarly, the flow of marine litter and microplastics from the North Pacific and the Gulf of Alaska into the Bering Sea and further into the Arctic Ocean through the Bering Strait is unknown.

The information already available on the **distribution** and trends of marine litter provides valuable understanding of the ubiquitous presence of marine litter throughout the marine environment, but this is far from comprehensive. Beach litter data is restricted to the regions and sectors of the coastline that are: densely populated, have had opportunistic data collection, or have been identified as hotspots for accumulation and are being targeted for mitigation actions. Information on concentration in sea ice is limited to two studies while data on the concentration of marine litter on surface waters and in the water column is also constrained to certain areas of the Arctic where research has been focused. There is no data for the Kara, Laptev, East Siberian, Chukchi Seas and the Beaufort or Northwestern Passages. Further, data on presence of marine litter on the seafloor is limited to certain areas of the Arctic Ocean.

The full understanding of marine litter **interactions with biota** and the derived ecological and socio-economic impacts in the Arctic is extremely challenging, as for any other region of the ocean, due to the complexity of ecosystems and biodiversity. The available information on interactions with biota only covers certain groups of organisms that are known to interact with plastic litter and some additional information due to anecdotical records. Information on ingestion is well developed for seabirds, as they are known to interact and be impacted at the individual level. Knowledge on ingestion by seabirds has led to the identification of knowledge gaps regarding the residence time of plastic in the digestive tract (Avery-Gomm et al., 2017), the transfer of toxic substances associated to plastic to seabirds tissues and the effects that this may cause. Despite the wealth of information compiled on northern fulmars and some other species like black-legged kittiwakes, it is still largely unknown to what degree other species do ingest plastic and the level of effect. Bråte et al. (2017) reviewed the gaps regarding Nordic marine biota, which are extensive in the Arctic and highlight the lack of broad understanding of plastic and microplastic ingestion and effects on fish, as well as organisms lower on the trophic chain, such as zooplankton.

With regards to entanglement, knowledge was abundant on pinnipeds during the 1980’s and 1990’s in the Bering Sea and Gulf of Alaska, but monitoring efforts have since been reduced. In the rest of the Arctic, knowledge is fragmented and covers only some groups or species, such as whales. Studies on interactions between biota and marine litter in the Arctic have mostly focused on the interaction and effects at the individual level, and information on the effects at the population level are lacking, even for the better-studied species.

Plastic additives or adsorbed environmental contaminants can be potentially toxic to marine organisms, but as of today, it is not possible to determine a level for safe environmental concentrations for microplastics (OSPAR Commission, 2017). Current evidence indicates that the risk to human health appears to be no more significant than via other exposure routes, but an understanding of exposure, bioaccumulation and impacts at different food web levels is still lacking (UNEP, 2016).

Finally, the understanding of the final fate of marine litter in the Arctic is also limited and constitutes a gap in the understanding of systemic impacts. Further, there are no studies of the socio-economic impacts of marine litter in the Arctic. When considering addressing the knowledge and knowledge gaps highlighted in this report, it is important to keep in mind the logistical and practical challenges of conducting research in the Arctic.

Section V: Main Findings and Next Steps

This literature review provides an opportunity to identify potential next steps to further examine and address marine litter, including microplastics, in the Arctic Ocean and inform future work under the Arctic Council.

The presence of marine litter, including microplastics, in the Arctic Ocean is connected to human activities occurring within and outside the Arctic region. Despite the lack of estimates of marine litter input linked to different human activities occurring in the Arctic region, the analysis of existing coastal and seafloor litter data identifies fisheries-related activities as a major source in the Arctic. Other sea-based activities like aquaculture, passenger and goods shipping, and oil and gas exploration activities constitute additional sea-based sources. As for land-based sources, coastal litter data points to deficient waste and wastewater management systems in some coastal Arctic communities as an important localized source of marine litter. While there is a lack of data from each of the sectors of activity on leakage of litter or microplastics, an understanding of the geographical distribution of the different human activities in the Arctic can be used to determine the areas of the Arctic that may be more exposed to the risk of input from these activities. For example, the wealth of information gathered in this study on fishing effort could be mapped at high resolution to ascertain the areas with highest likelihood for input of marine litter associated with the fisheries sector. The detailed mapping of the areas where aquaculture is occurring would also provide an indication of where the highest potential pressure associated with this activity may occur as it would the mapping of the distribution of shipping intensity.

The proportion of marine litter, including microplastics, arriving from distant sources is difficult to gauge against the local sources, but connectivity of Arctic marine areas with surrounding marine areas and with Arctic watersheds provides potential for input from distant sources. Existing research on the input of marine litter and microplastics from other oceanic areas could provide better estimates of the total input through further measurements of the concentration in surface waters and in the water column at better spatial and temporal resolution.

Marine litter, including microplastics, generated and released to the environment outside of Arctic marine areas can use several pathways to get to the ocean. The Arctic watershed is very large with several large rivers that deliver substantial amounts of freshwater to the Arctic Ocean. Marine litter, including microplastics, originating inland in areas more densely populated than the coastal areas could potentially contribute to the total input, but there are no studies measuring the outflow of marine litter, including microplastics, from Arctic rivers. Similarly, the input of light weight litter (i.e. plastic and microplastics) via atmospheric flows in the Arctic has not been investigated either. Two other pathways that have been researched and shown to potentially influence the arrival and distribution of marine litter, including microplastics, in the Arctic are regional circulation and currents and the drift of sea ice along the Transpolar Drift. These two pathways are postulated as responsible for accumulation of microplastics in waters and sediments of specific areas like the Barents Sea and the Fram Strait and potentially other marginal ice zones like in the Chuckchi Sea

The knowledge on distribution of marine litter, including microplastics, in the Arctic is geographically skewed due to information being mostly available for the Barents and Norwegian Sea and for the Bering Sea. Few data are available for the Central Arctic Ocean and the coastal areas around it in Siberia, Arctic Alaska, mainland Canada, and the Canadian Arctic Archipelago. Marine litter, including microplastics, has been found across the Arctic marine environment including along the shoreline, sea ice, sea surface and subsurface waters, water column, seafloor and sediments. An assessment is not available either to discern which areas may hold the most litter, but the coastline and the seafloor accumulate the largest items, and the shoreline in particular accumulates items at high density in specific locations, resulting in marine litter hotspots. The seafloor, and especially areas with high accumulation rates, have been identified as sinks for litter, including microplastics.

The many different methods and variables chosen to measure and report abundance of marine litter in each Arctic marine environment area makes geographic comparison challenging. The only exception are reports of abundance of small plastic fragments in surface waters obtained through investigating the plastic content of northern fulmars (*Fulmarus glacialis*), which describe an apparent South to North decreasing trend when compared to high-latitudes in both the North Pacific and the North Atlantic. Within the Arctic the abundance is highest in the Barents Sea followed by the Bering Sea and lowest in the Canadian Arctic.

Regarding interactions with, and impacts on, biota, the Arctic is no different than other marine areas. Organisms in the Arctic have been documented to ingest, get entangled in, and raft on marine litter, including microplastics. In addition, through ingestion and entanglement, organisms contribute to the redistribution of litter within and across the different areas of the Arctic marine environment. Based on current information, seabirds compose the group with a higher proportion of individuals having ingested plastic particles. Cetaceans, as well as some species of fish and invertebrates, have also been documented to ingest plastic litter, including microplastics. Entanglement has been documented to affect pinnipeds, cetaceans, crustaceans and fish and even some terrestrial species. Despite a growing number of studies, plastic ingestion and entanglement in the Arctic have been studied and documented at the individual level for only a limited number of species and even less with regards to microplastic interaction. The potential consequences of ingestion and entanglement have been poorly studied and documented and only a few studies have established a link between the interaction with plastic and lethal or sublethal effects. The population consequences are largely unknown at present, with only very few examples in which we have a notion of substantial effects at the population level.

The existing and potential socioeconomic impacts of marine litter, including microplastics, in the Arctic are linked to impacts in the fisheries and aquaculture sectors, tourism, cultural and aesthetic values and practices and associated to the costs of shoreline cleanups.

The focus placed so far on the study of marine litter, including microplastics, has not led to the establishment of formal consistent monitoring programs that cover all the sources, pathways, compartments and impacts of this environmental challenge. However, there is a need for a more comprehensive knowledge on Arctic-specific marine litter sources and pathways and its effects on the Arctic marine environment. Thus, developing a Regional Action Plan (RAP) on marine litter in the Arctic is timely, recognizing that a RAP can be modified over time as more knowledge is accumulated.

Developing a monitoring program as part of, or parallel to, the development of a regional action plan is of great importance in gaining further knowledge on litter distribution and composition, as well as informing decision-making. In addition, a monitoring program will allow the building of a baseline for the assessment of the effectiveness of any measures included in the RAP.

Annex I: Literature review tables

Table 2.1. Abundance of macroplastics observed on beaches

Sea	Location	Year	Abundance (kg/km) if not defined differently	Abundance of fisheries waste (kg/km) if not defined differently	Method	Total length (km)	Beaches (no.)	Reference
Bering Sea and Subarctic North Pacific *(Aleutian Islands)*	Amchitka Island	1972	Total 121.64 *(or 193.2 n/km)*	119.835 *(or 128 n/km)* (trawls 108.57 kg/km)	Visual observation **(hereinafter - VO)**	10	10	(Merrell, 1980)
		1973	Total 156.42 *(or 283.9 n/km)*	154.607 *(or 176.6 n/km)* (trawls 132.24 kg/km)				
		1974	Total 345.42 *(or 499.3 n/km)*	339.445 *(or 278.6 n/km)* (trawls 290 kg/km)				
		1982	Total 254.14 *(or 588.9 n/km)*	247.955 *(or 198 n/km)* (trawls 190.82 kg/km)				(Merrell, 1984)
		1987	∽290 n/km	∽230 (litter from trawls)	VO	10	10	(Johnson, 1990)
	Attu, Agattu, Shemya, Buldir, Kiska, Little Kiska and Adak	1988	852 n/km	595,95 n/km 89,19 n/km (netting)	VO. Sea level to high storm tide level	3.7	25	(Manville, 1990)
Chukchi Sea	Cape Krusenstern National Monument	2015	94.36 *(∽85% of total debris)* 0.5± 0.31 kg/km h^{-1} *(plastic, rope/netting, foam)*	0.16+-0.18 kg/km h^{-1} (rope/netting)	VO. Approximate vegetation line; wrack line	22.23	3	(Polasek et al., 2017)
	Bering Land Bridge National Preserve		33.13 *(∽92% of total debris)*		VO. Approximate vegetation line	15.49	2	
Subarctic North Pacific *(Gulf of Alaska)*	Kenai Fjords National Park		4518.25 *(∽90% of total debris)* 44.68± 51.74 kg/km h^{-1}	5.96 ± 14.5 kg/km h^{-1} (rope/netting)	VO. Approx. vegetation line, Wet-dry line, Berm line, Wrack line, Beach	14.84	13	

						center line			
	Wrangell-St. Elias National Park		1924.91 *(~76% of total debris)*			VO. Vegetation line, Berm line	4.45	2	
	Katmai National Park and Preserve		1623.19 *(~95.1% of total debris)*			VO. Beach center line	28.68	8	
North Atlantic Ocean	Western Iceland	2011	3,625 g/m2 *[Total 59 items =261 g]*		n.a.	VO	72 m^2 [36 quadrates (2x2m)]	12	(Dippo, 2012)
Greenland	West Greenland	2016-2017	120 (7–934) n/100 m		n.a.	NS	NS	13	(Strand and et al., in prep.)
	East Greenland		3 (0–272) n/100 m		n.a.	NS	NS		
Mid-Atlantic Ridge	Hornvík, Hornstrandir nature reserve, Westfjord, Iceland	2012	850 n/km or 60 kg/km	Estimated for all 7 beaches: 506 n/km Or 67 kg/km	55-65% of total		Transect: 100x40 100x10 100x10 2000x2	7	(Kienitz, 2013)
	Rekavík bak Höfn, Hornstrandir nature reserve, Westfjord, Iceland	2012	6650 n/km or 575 kg/km				Transect: 10x10 10x10		
	Hlöðuvík, Hornstrandir nature reserve, Westfjord, Iceland	2012	1692 n/km or 146 kg/km				Transect: 100x10 100x10 20x20 20x20 20x20		
	Hesteyrarfjörður, Hornstrandir nature reserve, Westfjord, Iceland	2012	35 n/km or 2 kg/km				Transect: 100x10 100x10 100x10 100x10		
	Aðalvík, Hornstrandir nature	2012	443 n/km or 55 kg/km				Transect: 100x10		

	reserve, Westfjord, Iceland						100x10 100x20		
	Rekavík, Hornstrandir nature reserve, Westfjord, Iceland	2012	373 n/km or 131 kg/km				Transect: 100x10 100x10 100x10 100x10		
	Fljótavík, Hornstrandir nature reserve, Westfjord, Iceland	2012	113 n/km or 34 kg/km				Transect: 100x50 100x10 100x10 100x10		
Greenland Sea	Brucebukta	2016	1610.1 kg/km	9- 524 $g\ m^{-2}$ (82-100% of overall litter mass)	999.9	VO. 20m to water	1800 m^2	1 (area of 90x20 m)	(Bergmann et al., 2017a)
Arctic Ocean *(Northern and North-western Svalbard)*	Reinstrandodden		62841.6 kg/km		62732.4	VO. 0.2 m to water	1680 m^2	1 (area of 120x14)	
	Sørvika		19.36 $g\ m^{-2}$		13,13 $g\ m^{-2}$	VO. 0.5m to water	2048 m^2	1	
	Isflakbukta		1134.9 kg/km		547.2	VO. 0.5m to water	1800 m^2	1 (area of 90x20 m)	
	Crozierpynten		794.7 kg/km		440.1	VO. 0.5-2m to water	1845 m^2	1 (area of 90x20,5 m)	
	Alpiniøya		1280.9 kg/km		1065.4	VO. 5.7-7m to water	2559 m^2	1 (area of 100x52 m)	

Table 2.2. Abundance of plastic observed in sea ice and seawater

Depth Range	Location	Year	Density	Size fraction	Sampling method	Reference
Sea ice	Arctic basin *(88∘03.333'N, 58∘44.9'E)*	2005	∽11 n/l	microplastics	Ice cores (sample depths: 252 and 347 cm) *samples volumes examined were typically 50–100 cm3* [FTIR microscopy]	(Obbard et al., 2014)
	Arctic basin *(84∘18.772'N, 149∘03.533'W)*	2005	∽100 n/l	microplastics	Ice cores (sample depth 135 cm) [FTIR microscopy]	
	Arctic basin *(78∘17.493'N, 176∘40.739'W)*	2005	∽28 n/l	microplastics	Ice cores (sample depths: 83 and 107 cm) [FTIR microscopy]	
	Arctic basin *(68∘18.19'N, 166∘58.86'W)*	2010	∽40 n/l	microplastics	Ice cores (sample depths: 95, 105, and 115 cm) [FTIR microscopy]	
	Greenland Sea *(Fram Strait)*	n.a.	2 x 1000000 n/m^3	microplastics	Pack ice cores	(Bergmann et al., 2017b)
		n.a.	6 x 10000 n/m^3	microplastics	Land-locked ice cores	
	Fram Strait (78,27N 14,71W)	2014	$4.1\pm 2.0\times 10^{6}$ n m^{-3}	microplastics	Land-fast ice [Imaging FTIR]	(Peeken et al., 2018)
	Fram Strait (79,75N 4,30E)	2014	$1.2\pm 1.4\times 10^{7}$ n m^{-3}	microplastics	Pack ice [Imaging FTIR]	
	North of Svalbard (81,94 13,57E)	2015	$2.9 \pm 2.4\times 10^{6}$ n m^{-3}	microplastics	Pack ice [Imaging FTIR]	
	North of Svalbard (81,24N 19,43E)	2015	$1.1\pm 0.8\times 10^{6}$ n m^{-3}	microplastics	Pack ice [Imaging FTIR]	
	Nansen Basin (85,09N 42,61E)	2015	$2.4\pm 1.0\times 10^{6}$ n m^{-3}	microplastics	Pack ice [Imaging FTIR]	
Surface	Norwegian Sea *(Transect from Tromsø up to SW Svalbard (78.07°)*	2014	0 – 1.31 (0.34±0.31 SD) or 0,028 n/m^2	microplastics	Manta net (top 10–16 cm of the water column)	(Lusher et al., 2015)

Depth Range	Location	Year	Density	Size fraction	Sampling method	Reference
	Barents Sea and Greenland Sea *(Fram Strait)*	2012	0 - 0.216 n /km^1	macroplastics	Visual observation from helicopter and vessel	(Bergmann et al., 2016)
	Barents Sea and Greenland Sea	2013	0.063 n/m^2	microplastics	Manta net	(Cózar et al., 2017)
	Barents Sea	2010-2016	NS (plastic= 34.6±22.3% of all marine litter)	macroplastics	VO from vessel	(Grøsvik et al., 2018)
	Bering Sea	1985	0,23±0,19 n/km^{-2}	macroplastics >2.5 cm	VO from vessel	(Day and Shaw, 1987)
		1974-75	68 n/km^{-2}	micro- and mesoplastics (0.363mm-0.4 m)	Surface sampler	(Shaw, 1977)
		1985	80±190 n/km^{-2}	micro- and mesoplastics (0.33mm-1.3 m)	Surface sampler	(Day and Shaw, 1987)
		1985-88	100 n/km^2 (600 SD)	micro- and mesoplastics (0.5mm- 0.5 m)	Surface sampler	(Day et al., 1990)
		2006	0.017 (±0.010) n/m^3 **or** 0.040 (±0.034) mg/m^3	microplastics	Neuston nets (0.505 mm mesh, mouth opening of 30x50cm)	(Doyle et al., 2011)
		2006	0.072 (±0.041) n/m^3 **or** 0.080 (±0.033) mg/m^3	microplastics		
	Subarctic North Pacific	1984	0,15 n/km^{-2}	macroplastics	Visual observation from vessel	(Dahlberg and Day, 1985 in Day and Shaw, 1987)
		1985	0,94±1,22 n/km^{-2}	macroplastics > 2.5 cm	Visual observation from vessel	(Day and Shaw, 1987)
		1976	0	micro- and mesoplastics (0.33mm-0.4 m)	Surface sampler	(Shaw and Mapes, 1979)
		1985	3370±2380 n/km^{-2}	micro- and mesoplastics (0.33mm-1.3 m)	Surface sampler	(Day and Shaw, 1987)
		1985-88	12,800 n/km^2 (22 300SD)	micro- and mesoplastics (0.5mm- 0.5 m)	Surface sampler	(Day et al., 1990)
	Gulf of Alaska	1974-75	132 n/km^{-2}	micro- and mesoplastics (0.363mm-0.4 m)	Surface sampler	(Shaw, 1977)

Depth Range	**Location**	**Year**	**Density**	**Size fraction**	**Sampling method**	**Reference**
Sub surface	Norwegian Sea *(Transect from Tromsø up to SW Svalbard (78.07°)*	2014	0 – 11.5 n m^{-3} [average 2.68 (±2.95 SD) n m^{-3}]	microplastics	On-board seawater pump, depth 6 m	(Lusher et al., 2015)
	Greenland Sea	2005	0.15 – 2.64 n m^{-3} (0.99±0.62)	microplastics	WP-2; opening 0.25 m2 mesh 500µm, 50m to surface	(Amelineau et al., 2016)
		2014	0.81 – 4.52 n m^{-3} (2.38±1.11)	microplastics		
	Greenland Sea	2015	1-3 n m^{-3} (2.4 ±0.8)	microplastics	On-board seawater pump, depth 6 m	(Morgana et al., 2018)
	Arctic Central Basin	2016	0-7.5 (median 0.7) n m^{-3}	microplastics	On-board seawater pump, depth 8.5 m	(Kanhai et al., 2018)
	Polar Mixed Layer	2016	0-375 (median 20.8) n m^{-3}	microplastics	CTD rosette sampler, depths 8–4369 m	
	Including abundance in various layers:					
	Polar Mixed Layer (depth 8-51 m)		0-375 n m^{-3}		15 depths sampled	
	Halocline (Atlantic or Pacific) (depth 56-166 m)		0-83 n m^{-3}		7 depths sampled	
	Atlantic water (depth 251-850 m)		0-95 n m^{-3}		10 depths sampled	
	Deep and bottom waters (depth 1001-4369 m)		0-104 n m^{-3}		16 depths sampled	
	Kongsfjorden, Svalbard	2016	0	microplastics	On-board seawater pump, depth 2 m	(Sundet et al., 2017)
	Adventfhorden, Svalbard	2016	0	microplastics		
	Isfjorden, Svalbard	2016	1-2 n m^{-3}	microplastics		
	Breibogen, Svalbard	2016	1-2 n m^{-3}	microplastics		
	Barents Sea	2010-2016	0.011 mg m^{-3}	macroplastics	pelagic trawl haul (<60 m), mouth opening 20x20m; 2265 trawls	(Grøsvik et al., 2018)

Table 2.3. Abundance of litter observed on seafloor

Sea	Location	Year	Density (n/km^2)	Mean depth (m)	Method (area sampled (km^2))	Composition	Main Sources	Reference
Greenland Sea	HAUSGARTEN N3 and HG IV	2002 (only HG IV)	3523 ± 1354	2500	Photo (1.926)	59% of total plastic; 66.6% of total medium size	n.a.	(Bergmann and Klages, 2012; Tekman et al., 2017)
		2004	660 ± 337		Photo (5.032)		n.a.	
		2007	873 ± 376		Photo (6.316)		n.a.	
		2011	5061 ± 2130		Photo (2.622)		correlation with increase of shipping (including tourism) in Svalbard	
		2012	4891 ± 1141		Photo (6.298)	47% of total were plastic; 57% of total had small size	n.a.	
		2013 (only N3)	4731 ± 1642		Photo (2.020)	n.a.	drift sea ice as a transport vehicle	
		2014	6566 ± 1422		Photo (3.948)	n.a.	n.a.	
Barents Sea	Barents Sea Ecosystem Survey	2010-2016	26 (2.9 plastic) kg km^{-2}	230	Bottom trawl haul; 1860 trawls	86% of trawls contained plastic 18.4 ± 20.4 % of the debris made of plastics	Fisheries and other maritime activities	(Grøsvik et al., 2018)
	Coast (119 locations)	2006-2017	286	<100-500	Video (249.9)	Fishing gear is prevalent, followed by unspecified	Fisheries	(Buhl-Mortensen and Buhl-

Sea	**Location**	**Year**	**Density (n/km^2)**	**Mean depth (m)**	**Method (area sampled (km^2))**	**Composition**	**Main Sources**	**Reference**
	Offshore (1013 locations)		209	<100-2700	Video (2,127.3)	and plastic litter		Mortensen, 2017)
Norwegian Sea	Coast (16 locations)	2009-2015	2706	<100-500	Video (33.6)			
	Offshore (630 locations)		171	<100-2700	Video (1,325.1)			
Bering Sea	South Eastern Bering Sea	1975	7.5% of total hauls contained debris	n.a.	Trawl (12.2m x ~3.25km)	7.5% of total trawls had plastic	Fisheries	(Feder et al., 1978)
		1976	41% of total hauls contained debris	n.a.		6.6% of total trawls had plastic		
	Eastern Bering Sea	1988	7.52	n.a.	Trawl (26.6)	51% plastic; 27% metal	40% Galley wastes, 24% fisheries, 23% engineering and processing	(June, 1990)
	Norton Sound		1.94	n.a.	Trawl (4.2)	49% metal, 12% plastic	38% engineering and processing, 36% galley waste, 26% personal use items	
Gulf of Alaska	Kodiak Island Inlets	1994	58.475	n.a.	Trawl (2.36)	plastic 26.3 n/km2; metal 23.7 n/km2	fisheries 25 n/km2;	(Hess et al., 1999)
		1995	62.397	n.a.	Trawl (2.42)	plastic 31.5 n/km2; metal 21.1 n/km2	fisheries 24.4 n/km2;	

Sea	Location	Year	Density (n/km^2)	Mean depth (m)	Method (area sampled (km^2))	Composition	Main Sources	Reference
		1996	52.209	n.a.	Trawl (2.49)	plastic 22.1 n/km2; metal 22.1 n/km2	fisheries 20.1 n/km2;	
	Kodiak Island Open sea	1994	10.417	n.a.	Trawl (1.92)	plastic 7.8 n/km2; metal 2.1 n/km2	fisheries 6.8 n/km2;	
		1995	21.256	n.a.	Trawl (2.07)	plastic 18.8 n/km2; metal 1.4 n/km2	fisheries 11.1 n/km2;	
		1996	13.004	n.a.	Trawl (2.23)	plastic 8.5 n/km2; metal 2.7 n/km2	fisheries 4.5 n/km2;	
Greenland Sea (Continental slope)	Hausgarten	1999-2011	13.6+-7.9 n/ha^{-1}	2450	ROV; Towed camera system (72.2 ha)	60% Plastic	Fisheries; transported land-based waste	(Pham et al., 2014)
Norwegian Sea (Continental slope)	North Faroe-Shetland Channel	2006	0.3+-0.2 n/ha^{-1}	657	Towed camera system (2.3 ha)	100% Fishing gear		
	North-East Faroe Shetland Channel	2006	1.9+-1.0 n/ha^{-1}	501	Towed camera system (1.2 ha)	100% Fishing gear		
Norwegian Sea (Continental shelf)	Norwegian Margin	2007	9.7+-3.8 n/ha^{-1}	304	Manned submersible (0.6 ha)	80% Fishing gear; 20% Plastic	Fisheries; transported land-based waste	
North-Eastern Atlantic (Ocean Ridges)	Wyville-Thomson Ridge	2006	10.9+-4.3 n/ha^{-1}	670	Towed camera system (1.2 ha)	85.7% Fishing gear; 14.3% Metal	Fisheries	
	North Charlie Gibbs Fracture Zone	-	0.4+-0.3 n/ha^{-1}	2300	ROV (2.4 ha)	100% Metal		

Sea	**Location**	**Year**	**Density (n/km^2)**	**Mean depth (m)**	**Method (area sampled (km^2))**	**Composition**	**Main Sources**	**Reference**
	South Charlie Gibbs Fracture Zone	-	2.9+-1.4 n/ha^{-1}	2600	ROV (2.4 ha)	28.6% Plastic; 28.6% Glass; 28.6% Metal		
North-Eastern Atlantic (Seamounts, banks and mounds)	Anton Dohm Seamount	2005-2009	1.9+-1.0 n/ha^{-1}	992	Towed camera system (2.2 ha)	100% Metal	Fisheries	
	Darwin Mounds	2011	9.7+-2.9 n/ha^{-1}	1007	ROV (1.8 ha)	60% Plastic; 15% Metal; 10% Fishing gear		
	Hatton Bank	2005-2011	1.9+-0.8 n/ha^{-1}	706	ROV; Towed camera system (4 ha)	87.5% Fishing gear; 12.5% Metal		
	Rockhall Bank	2005-2011	0.7+-0.5 n/ha^{-1}	702	ROV; Towed camera system (2.4 ha)	33.3% Fishing gear; 66.7% Metal		
	Rosemary Bank	2006	3.3+-2.3 n/ha^{-1}	577	Towed camera system (1.1 ha)	66.7% Fishing gear; 33.3% Metal		

Table 2.4 Abundance of microplastics observed in sediments

Sampling site	Sea	Location	Year	Density (n/kg or n/l)	Width/ Depth (m)	Sampling method	Sample/ total leght	Replicates (n)	Reference
Shore line	North Atlantic Ocean	Western Iceland	2011	4.84 n/l (1307 items in total)	NS	Shovel (counted microplastics size5-1 mm)	2x2m, top 2cm = 7.5 l	36 (3 quadrates on 12 sites)	(Dippo, 2012)
		Sisimiut areas (impacted by urban and boat activities)	NS	4600-15000 n/kg dw	NS	NS	NS	8	(Strand and et al., in prep.)
		Sisimiut area		90-860 n/kg dw	NS	NS	NS		
	Greenland Sea	W Svalbard, Adventdalen	2015	0 – 6.3 n/kg	Not given	Shovel	~1 l	3	(Sundet et al., 2016)
		N Svalbard, Breibogen	2016	111 n/l sediment	Above high tide mark	Shovel	~2 l	2	(Sundet et al., 2017)
				5-8 n/l sediment	Below high tide mark	Shovel	~2 l	2	
	Bering Sea	Bering Land Bridge National Preserve	2016	95 n/kg of dry sand (22.5 SE)	low tide along a 50-meter transect parallel with the shore between the high and low tide lines	Shovel	equivalent volume approx. 736 cm3	10	(Whitmire and Van Bloem, 2017)
		Cape Krusenstern National Monument	2015	123.8 n/kg of dry sand (24.6 SE)					
	Gulf of Alaska	Aniakchak National Monument & Preserve	2016	51.3 n/kg of dry sand (10.5 SE)					
		Katmai National Park & Preserve	2015	128.8 n/kg of dry sand (36.,1 SE)					
		Kenai Fjords National Park	2015	43.8 n/kg of dry sand (5.2 SE)					
		Lake Clark National Park & Preserve	2016	40 n/kg of dry sand (40 SE)					
		Wrangell St. Elias National Park & Preserve	2015	97.5 n/kg of dry sand (25.3 SE)					

Sampling site	**Sea**	**Location**	**Year**	**Density (n/kg or n/l)**	**Width/ Depth (m)**	**Sampling method**	**Sample/ total leght**	**Replicates (n)**	**Reference**
Shallow water	Greenland Sea	W Svalbard, Adventfjorden	2015	9.2 n/kg sediment	40-70	Van Veen grab	~1 l	3	(Sundet et al., 2016)
		N Svalbard, Breibogen	2016	2-10 n/l sediment	40-60	Van Veen grab	0.50 l	6	(Sundet et al., 2017)
Deep sea	Barents Sea	Stangnestind	2017	2700 n/kg	251	Van Veen grab	Ø 0.15 m2 top 0-1 cm; 0,006 g	1	(Moskeland et al., 2018)
		Korpfjell	2017	1400 n/kg	242	Van Veen grab	Ø 0.15 m2 top 0-1 cm; 0,0046 g	1	
		Scarecrow3	2017	3200 n/kg	461	Van Veen grab	Ø 0.15 m2 top 0-1 cm; 0,0075 g	1	
		Kråketind	2017	830 n/kg	440	Van Veen grab	Ø 0.15 m2 top 0-1 cm; 0,0036 g	1	
		Gråspett	2017	3900 n/kg	508	Van Veen grab	Ø 0.15 m2 top 0-1 cm; 0,0086 g	1	
	Norwegian Sea	SW Svalbard	2010	200 n/l sediment	1000	Megacorer / boxcorer	Ø=10 cm, top 1 cm	Not given	(Woodall et al., 2014)
			2010	300 n/l sediment	2000				
	Greenland Sea *(Fram Starit)*	Hausgarten	2015	44 - 3464 n/l sediment	2300-5600	Multicorer	Ø=10 cm, top 5 cm	3 – 6 (depending on station)	(Bergmann et al., 2017c)

Table 3.1. Plastic ingested by seabirds in the Arctic

Species	Region	Location	Year of study	Sample size	Frequency of occurrence	Average mass per individual (±SD)	Average item per individual (±SD)	References
Seabirds								
Northern fulmar (*Fulmarus glacialis)*	Svalbard and Jan Mayen	Svalbard	1980	22	82.0%			Camphuysen & Franeker 1997 in (O'Hanlon et al., 2017)
		Svalbard	1980 (regurgitates)	13	8.0%			Camphuysen & Franeker 1997 in (O'Hanlon et al., 2017)
		Svalbard	1982	14	36.0%			(Mehlum and Giertz, 1984)
		Bjørnøya, Svalbard	1983	22	82.0%		4.5	(van Franeker, 1985)
		Jan Mayen	1983	29	76.0%		4.7	(van Franeker, 1985)
		Eastern sea, Svalbard	1984	8	50.0%			(Gjertz et al., 1985)
		Hornsund, Svalbard	1984	20	15.0%			(Lydersen et al., 1989)
		Isfjord, Svalbard	2013	40	87.5%	0.08±0.02 g	15.32 ± 5.51	(Trevail et al., 2014; Trevail et al., 2015)
	Norway	Northern Norway, Barents Sea	2012-2013	72	81.0%	0.136 ± 0.176 g	17.4 ± 26.8	(Ask et al., 2016; Herzke et al., 2016)
	Russia	Frans Josef Land	1994	5	20.0%		0.02	(Weslawski et al., 1994)
	Alaska	Subarctic North Pacific	1969-1977	38	58.0%		2.79±4.53	(Day, 1980)
		Subarctic North Pacific	1988-1990	19	84.2%			(Robards et al., 1995)
		Central North Pacific	1990-1991	42	88.0%			(Robards et al., 1997)
	Canada	Canadian Arcitc	1978-1979	214	40.0%			M. S. V. Bradstreet unpub. in (Day et al., 1985)
		Davis Strait, Nunavut	2002	42	36.0%	0.02–0.31 g	1.3 ± 2.3	(Mallory et al., 2006)
		Cape Vera, Northern Devon Island, Nunavut	2003-2004	102	31.0%		7.4 ± 2.1SE (of affected)	(Mallory, 2008)
		Prince Leopold Island, Nunavut	2008	10	80.0%	0.050 g (SD 0.099)	2.5±3.5	(Provencher et al., 2009)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
		Cape Searle, Eastern Baffin Island, Nunavut	2008	15	87.0%	0.124 g (SD 0.162)	7.6 ±6.6	(Provencher et al., 2009)
		Prince Leopold Island, Nunavut	2013	9	89.0%	0.025+-0.025	3.4±3.1	(Poon et al., 2017)
		Labrador Sea	2014	39	64.0%	114+-0.202 g	5.9+-10.8	(Avery-Gomm et al., 2017)
			2015	31	97.0%	0.198+-0.311	18.7+-28.9	(Avery-Gomm et al., 2017)
	Greenland	West Greenland	2000	NS	54.2% (EcoQO 4.2%)	NS	NS	(Strand and et al., in prep.)
			2016	NS	85.7% (EcoQO 34.9%)	NS	NS	
	Iceland	Westfjord, Iceland	2011	58	79.0%	0.13+-0.04	6.0+-0.99	(Kuhn and van Franeker, 2012)
	Faroe Islands	Faroe Islands	1997	35	51.0%			Durinck unpub. in (Provencher et al., 2014a)
		Faroe Islands	2002-2006 (fulmars with >0.1 g plastic)	NS	43.0%	0.09g		(OSPAR Commission, 2009)
		Faroe Islands	2007-2010	699	91.0%	0.15 ± 0.01 g	11.3 ± 0.6	(van Franeker and The SNS Fulmar Study Group, 2013)
		Faroe Islands	2011	27	33.3%	0.23 ± 0.35 g	13.9 ± 29.9	Trevail 2014; van Franeker et al. 2013 in (Ask et al., 2016)
Brünnich’s guillemot/ Thick-billed murre (*Uria lomvia)*	Svalbard	Svalbard	1982	1	0.0%	-	-	(Mehlum and Giertz, 1984)
		Eastern sea, Svalbard	1984	3	0.0%	-	-	(Gjertz et al., 1985)
		Hornsund, Svalbard	1984	21	24.0%			(Lydersen et al., 1989)
	Alaska	Alaska	1969-1977	138	1.4%			(Day et al., 1985)
		Alaska	1988-1990	92	0.0%	-	-	(Robards et al., 1995)
		Central North Pacific	1990-1991	1	100.0%			(Robards et al., 1997)
	Canada	Canadian Arcitc	1978-1979	283	1.0%		7	M. S. V. Bradstreet unpub. in (Day et al., 1985)

Species	Region	Location	Year of study	Sample size	Frequency of occurrence	Average mass per individual (±SD)	Average item per individual (±SD)	References
		Northeast Newfoundland	1985-1986	1249	7.7%	0.005+-0.041 g	0.14+-0.70	Elliot et al. 1990 unpub, Heneman 1988 in (Bond et al., 2013)
		Northeast Newfoundland	1996-1997	310	4.8%			Rowe et al. 2000 in (Bond et al., 2013)
		Harbour Breton, Newfoundland	2005	7	0.0%	-	-	Muzzafar unpub. in (Provencher et al., 2014a)
		St. Mary's Bay, Newfoundland	2005	4	0.0%	-	-	Muzzafar unpub. in (Provencher et al., 2014a)
		Gannet Islands, Newfoundland	2006	15	0.0%	-	-	Muzzafar 2000 in (Provencher et al., 2014a)
		Coats Island, Nunavut	2006	16	0.0%	-	-	Muzzafar 2000 in (Provencher et al., 2014a)
		Coats Island, Eastern Canadian Arctic	2007	25	4.0%	0.0032 g	0.04 (SD 0.20)	(Provencher et al., 2010)
		The Minarets, Eastern Canadian Arctic	2007-2008	50	6.0%	0.0003g	0.06 (SD0.26)	(Provencher et al., 2010)
		Akpatok Island, Eastern Canadian Arctic	2008	31	23.0%	0.0025 g	0.29 (SD 0.64)	(Provencher et al., 2010)
		Digges Sound, Eastern Canadian Arctic	2008	30	12.0%	0.0015 g	0.27 (SD 0.69)	(Provencher et al., 2010)
		Prince Leopold Island, Eastern Canadian Arctic	2008	50	8.0%	0.0017g	0.30 (SD 1.39)	(Provencher et al., 2010)
		Twillingate, St. Mary's Bay, Conception Bay, Newfoundland, Canada	2011-2012	32	14.3%	0.0203 ± 0.0162 g (with one common murre)	0.091 ± 0.291 (with one common murre)	(Bond et al., 2013)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
		Prince Leopold Is. East Arctic Canada.	2013	10	0.0%	-	-	(Poon et al., 2017)
	Greenland	Southwest Greenland	1988-1999	202	6.0%		0.09, 0 (0-3)	(Falk and Durinck, 1993)
		Haklyut Island	1997	40	0.0%	-	-	Falk unpub in (Provencher et al., 2014a)
		Nuuk	2006	15	0.0%	-	-	Muzzafar 2000 in (Provencher et al., 2014a)
Common murre/guillemot *(Uria aalge)*	Alaska	Alaska	1969-1977	191	0.0%	-	-	Day 1980
		Alaska	1988-1990	134	0.8%			(Robards et al., 1995)
	Canada	Northeast Newfoundland	1996-1997	60	1.7%		0.02 ± 0.02	Rowe et al. 2000 in (Bond et al., 2013)
		St. Mary's Bay, Newfoundland	2006	15	0.0%	-	-	Muzaffar unpub data in (Provencher et al., 2014a)
		Gannet Islands, Newfoundland	2006	15	0.0%	-	-	Muzzafar (2000) in (Provencher et al., 2014a)
		Renews, Newfoundland	2006	13	0.0%	-	-	Muzzafar (2000) in (Provencher et al., 2014a)
		Twillingate, St. Mary's Bay, Conception Bay, Newfoundland, Canada	2011-2012	32	9.1%		0.09 ± 0.09	(Bond et al., 2013)
Little auk/dovekie (*Alle alle)*	Svalbard	Svalbard	1982-1984	29	0.0%	-	-	(Mehlum and Giertz, 1984; Gjertz et al., 1985)
		Eastern sea, Svalbard	1984	3	0.0%	-	-	(Gjertz et al., 1985)
		Hornsund, Svalbard	1984	11	45.0%			(Lydersen et al., 1989)
	Canada	Canadian Arcitc	1978-1979	303	"present"			(Day, 1980)
		Cape Shore, Newfoundland	2003	73	1.4%			Robertson et al. 2006 unpub. In (Avery-Gomm et al., 2016)
		Placentia Bay, NL	2011	21	0.0%	-	-	(Rosing-Asvid et al., 2013)
		White Bay, Newfoundland	2013	65	13.8%	0.0183±0.0205 g	0.1538+-0.4043	(Fife et al., 2015)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
		Holyrood, NL	2013	171	30.4%	0.0049+-0.0280 g	0.8070+-3.910	(Avery-Gomm et al., 2016)
	Greenland	Nuuk	1988-1989	19	0.0%	-	-	Falk and Durinck unpub. in (Provencher et al., 2014a)
		Hakluyt Island	1997-1998	104	8.7%			(Pedersen and Falk, 2001)
		Eastern Greenland	2005 (Gular pouches)	26	Fragments – 50%; filaments – 100%		9.99	(Amelineau et al., 2016)
		Cape Farewell	2010-2011	90	0.0%	-	-	(Rosing-Asvid et al., 2013)
		Nuuk	2010-2011	94	0.0%	-	-	(Rosing-Asvid et al., 2013)
		Eastern Greenland	2014 (Gular pouches)	18	Fragments – 50%; filaments – 100%		8.99	(Amelineau et al., 2016)
Black-legged kittiwake (*Rissa tridactyla*)	Svalbard	Svalbard	1982	27	0.0%			(Mehlum and Giertz, 1984)
		Eastern sea, Svalbard	1984	18	0.0%			(Gjertz et al., 1985)
		Hornsund, Svalbard	1984	20	5.0%			(Lydersen et al., 1989)
	Alaska	Alaska	1969-1977	188	4.8%		0.1	(Day, 1980)
			1988-1990	256	7.8%			(Robards et al., 1995)
		Central North Pacific	1990-1991	5	0.0%			(Robards et al., 1997)
	Canada	Canadian Arcitc	1978-1979	50	12.0%			M. S. V. Bradstreet unpub. in (Day et al., 1985)
		Prince Leopold Is. East Arctic Canada.	2013	11	9.0%	0.003+-0.009	0.18±0.6	(Poon et al., 2017)
Red-legged kittiwake (*Rissa brevirostris*)	Alaska	Alaska	1969-1977	46	13.0%		0.2	(Day, 1980)
			1988-1990	15	26.7%			(Robards et al., 1995)
Short-tailed shearwater (*Ardenna tenuirostris*)	Alaska	Alaska	1969-1977	200	83.5%		5.4	(Day, 1980)
			1988-1990	5	80.0%			(Robards et al., 1995)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual (±SD)**	**Average item per individual (±SD)**	**References**
		Central North Pacific	1990-1991	200	88.0%			(Robards et al., 1997)
		Southeastern Bering Sea; Aleutian Islands	1997-1999, 2001	330	83.9%	114±7.8 mg	5.8±0.4	(Vlietstra and Parga, 2002)
		North Pacific Ocean, Bering Sea	2003	87	NS	0.218 (SD 0.187)	13.4 (SD 9.6)	(Yamashita et al., 2011)
			2005	12	NS	0.289 (SD 0.163)	21.7 (SD 25.6)	(Yamashita et al., 2011)
Sooty shearwater *(Ardenna grisea)*	Canada	Placentia Bay, NL	1978	5	0.2%			Brown et al. 1981 in (Bond et al., 2014)
	Alaska	Alaska	1969-1977	76	43.0%		1.1	(Day, 1980)
	Alaska	Central North Pacific	1990-1991	543	85.0%			(Robards et al., 1997)
Leach's stormptrel *(Oceanodroma leucorhoa)*	Alaska	Pacific Alaska	1969-1977	4	25.0%		3	(Day, 1980)
		Pacific Alaska	1988-1990	64	48.4%			(Robards et al., 1995)
		Central North Pacific	1990-1991	3	67.0%			(Robards et al., 1997)
	Canada	Eastern Newfoundland	1987-1988	749	5.0%			Hedd et al. 2009 in (Provencher et al., 2014a)
		Eastern Newfoundland	2002-2006	224	6.0%			Hedd and Montevecchi 2006 in (Provencher et al., 2014a)
		Gull Island, Newfoundland	2012	63	48.0%	3.1±2.5 mg	1.9±3.4	(Bond and Lavers, 2013)
Fork-tailed storm petrel *(Oceanodroma furcata)*	Alaska	Alaska	1969-1977	8	100.0%		6.2	(Day, 1980)
			1988-1990	21	85.7%			(Robards et al., 1995)
			1990-1991	12	100.0%			(Robards et al., 1997)
Common eider (*Somateria mollissima)*	Svalbard	Svalbard	1982	1	0.0%	-	-	(Mehlum and Giertz, 1984)
		Hornsund	1984	20	0.0%	-	-	(Lydersen et al., 1989)
	Russia	Frans Josef Land	1994	5	0.0%	-	-	(Weslawski et al., 1994)
	Greenland	Nuuk	1999-2002	241	0.0%	-	-	Jamieson at al. 2006 in (Provencher et al., 2014a)
		Nuuk	2012	135	0.0%	-	-	Merkel unpub. in (Provencher et al., 2014a)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
	Canada	Belcher Is, Nunavut	1998-2003	388	0.0%	-	-	Jamieson unpubl. in (Provencher et al., 2014a)
		Cape Dorset, Nunavut	2000-2002	108	0.0%	-	-	Jamieson unpub. in (Provencher et al., 2014a)
		Cape Dorset, Nunavut	2011	100	1.0%			Provencher et al. 2013 in (Provencher et al., 2014a)
		Little Fogo Islands, Newfoundland, Canada	n.a.	40	2.5%		0.02 ± 0.16	(Holland et al., 2016)
Atlantic Puffin (*Fratercula arctica*)	Norway	Hordaland, Norway	1970	9	22.0%			Berland 1971 in (O'Hanlon et al., 2017)
	Svalbard	Hornsund, Svalbard	1984	14	0.0%	-	-	(Lydersen et al., 1989)
	Faroe Islands	Faroe Islands/Norwegian Sea	1987-1988	36	0.0%	-	-	Falk et al. (1992) in (Provencher et al., 2014a)
	Canada	Gull Island, Witless Bay, Newfoundland	1999	2	0.0%	-	-	Muzaffar unpub. in (Provencher et al., 2014a)
		Bay of Exploits, Newfoundland	2004	14	7.0%			Muzaffar unpub. in (Provencher et al., 2014a)
Tufted Puffin *(Fratercula cirrhata)*	Alaska	Gulf of Alaska	1969-1977	190	10.5%		0.2±0.8	(Day, 1980)
		Aleutian Islands	1969-1977	122	20.5%		0.7±2.1	(Day, 1980)
		Bering and Chukchi Seas	1969-1977	35	14.3%		0.6±2.9	(Day, 1980)
		Alaska	1988-1990	489	24.5%			(Robards et al., 1995)
		Central North Pacific	1990-1991	8	88.0%			(Robards et al., 1997)
Horned Puffin (*Fratercula corniculata)*	Alaska	Gulf of Alaska	1969-1977	41	26.8%		0.8±1.7	(Day, 1980)
		Aleutian Islands	1969-1977	74	50.0%		1.0±1.5	(Day, 1980)
		Bering and Chukchi Seas	1969-1977	50	30.0%		0.6±1.7	(Day, 1980)
		Alaska	1988-1990	120	36.7%			(Robards et al., 1995)
		Central North Pacific	1990-1991	28	57.0%			(Robards et al., 1997)
Parakeet auklet	Alaska	Gulf of Alaska	1969-1977	13	84.6%		21.1±22.6	(Day, 1980)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
(*Aethia psittacula*)		Aleutian Islands	1969-1977	55	90.9%		21.3±22.8	(Day, 1980)
		Bering and Chukchi Seas	1969-1977	45	53.3%		2.6±4.0	(Day, 1980)
		Pacific Alaska	1988-1990	208	93.8%		17.1	(Robards et al., 1995)
		Central North Pacific	1988-1990	3	33.3%			(Robards et al., 1997)
Least auklet *(Aethia pusilla)*	Alaska	Alaska	1969-1977	89	1.1%			(Day, 1980)
			1988-1990	13	0.0%	-	-	(Robards et al., 1995)
Crested auklet (*Aethia cristatella*)	Alaska	Alaska	1969-1977	85	0.0%	-	-	(Day, 1980)
			1988-1990	40	2.5%			(Robards et al., 1995)
Cassin's auklet *(Ptychoramphus aleuticus)*	Alaska	Alaska	1969-1977	10	40.0%		3.8	(Day, 1980)
			1988-1990	35	11.4%			(Robards et al., 1995)
Rinoceros auklet *(Cerorhinca monocerata)*	Alaska	Alaska	1969-1977	20	0.0%			(Day, 1980)
		Alaska	1988-1990	1	0.0%	-	-	(Robards et al., 1995)
		Central North Pacific	1990-1991	9	44.0%			(Robards et al., 1997)
Pigeon guillemot *(Cepphus columba)*	Alaska	Alaska	1969-1977	18	0.0%	-	-	(Day, 1980)
			1988-1990	43	2.6%			(Robards et al., 1995)
Mew gull *(Larus canus*)	Norway	Hardangervidda	1980-1982 (pellets)	259	1.0%			Byrkjedal et al. 1986 in (O'Hanlon et al., 2017)
	Alaska	Pacific Alaska	1969-1977	10	0.0%	-	-	(Day, 1980)
			1988-1990	4	25.0%			(Robards et al., 1995)
Glaucous gull (*Larus hyperboreus*)	Alaska	Alaska	1969-1977	33	3.0%	-	0,03±0,17	(Day, 1980)
	Russia	Frans Josef Land	1994	5	0.0%	-	-	(Weslawski et al., 1994)
	Svalbard	Svalbard	1982	2	0.0%	-	-	(Mehlum and Giertz, 1984)
		Hornsund, Svalbard	1984	18	0.0%	-	-	(Lydersen et al., 1989)
Great skua *(Stercorarius skua)*	Norway	Bjørnøya, Norway	2008-2009	350	2.0% (in pellets)			Knutsen 2010 in (O'Hanlon et al., 2017)
	Faroe Islands	Skúvoy breeding colony	2013	165	6.0% (in pellets)	0.0066 g (SD 0.00597)		(Hammer et al., 2016)
Pelagic cormorant	Alaska	Alaska	1969-1977	3	0.0%	-	-	(Day, 1980)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
(Phalacrocorax pelagicus)	Alaska	Alaska	1988-1990	10	20.0%			(Robards et al., 1995)
Red-necked phalarope *(Phalaropus lobatus)*	Alaska	Alaska	1969-1977	3	66.7%	0.01 g ±0.02 SD	1±1 SD	(Day, 1980)
Long-tailed jaeger/skua (*Stercorarius longicaudus*)	Svalbard	Svalbard	1982	1	0.0%	-	-	(Mehlum and Giertz, 1984)
	Alaska	Central North Pacific	1990-1991	2	0.0%	-	-	(Robards et al., 1997)
Pomarine jaeger/skua (*Stercorarius pomarinus*)	Svalbard	Svalbard	1984	3	0.0%	-	-	(Gjertz et al., 1985)
	Alaska	Central North Pacific	1990-1991	1	0.0%	-	-	(Robards et al., 1997)
Parasitic jager/ Arctic skua *(Stercorarius parasiticus)*	Alaska	Alaska	1969-1977	1	0.0%	-	-	(Day, 1980)
Ivory gull (*Pagophila eburnea*)	Alaska	Alaska	1969-1977	1	0.0%	-	-	(Day, 1980)
	Svalbard	Svalbard	1982	6	0.0%	-	-	(Mehlum and Giertz, 1984)
		Eastern sea, Svalbard	1984	4	0.0%	-	-	(Gjertz et al., 1985)
Glaucous-winged gull *(Larus glaucescens)*	Alaska	Alaska	1969-1977	63	0.0%	-	-	(Day, 1980)
		Alaska	1988-1990	21	0.0%	-	-	(Robards et al., 1995)
Bonaparte's gull *(Chroicocephalus philadelphia)*	Alaska	Alaska	1969-1977	4	0.0%	-	-	(Day, 1980)
Arctic tern (*Sterna paradisaea*)	Alaska	Alaska	1969-1977	21	0.0%	-	-	(Day, 1980)
	Russia	Frans Josef Land	1994	5	0.0%	-	-	(Weslawski et al., 1994)
	Canada	Nasaruvaalik Island, Nunavut	2007	41	0.0%	-	-	(Provencher et al., 2014a)
Aleutian tern *(Onychoprion aleuticus)*	Alaska	Alaska	1969-1977	8	0.0%	-	-	(Day, 1980)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
Double crested cormorant *(Phalacrocorax auritus)*	Alaska	Alaska	1969-1977	4	0.0%	-	-	(Day, 1980)
Red faced cormorant *(Phalacrocorax urile)*	Alaska	Alaska	1969-1977	2	0.0%	-	-	(Day, 1980)
	Alaska	Alaska	1988-1990	16	0.0%	-	-	(Robards et al., 1995)
Marbled murrelet *(Brachyramphus marmoratus)*	Alaska	Alaska	1969-1977	61	0.0%	-	-	(Day, 1980)
		Alaska	1988-1990	96	0.0%	-	-	(Robards et al., 1995)
Kittlitz's murrelet *(Brachyramphus brevirostris)*	Alaska	Alaska	1969-1977	5	0.0%	-	-	(Day, 1980)
		Alaska	1988-1990	17	0.0%	-	-	(Robards et al., 1995)
Ancient murrelet *(Synthliboramphus antiquus)*	Alaska	Alaska	1969-1977	16	0.0%	-	-	(Day, 1980)
		Alaska	1988-1990	68	0.0%	-	-	(Robards et al., 1995)
Whiskered auklet *(Aethia pygmaea)*	Alaska	Alaska	1969-1977	5	0.0%	-	-	(Day, 1980)
		Alaska	1988-1990	22	0.0%	-	-	(Robards et al., 1995)
Black guillemot (*Cepphus grylle*)	Svalbard	Svalbard	1982	8	0.0%	-	-	(Mehlum and Giertz, 1984)
		Eastern sea, Svalbard	1984	2	0.0%	-	-	(Gjertz et al., 1985)
		Hornsund, Svalbard	1984	20	0.0%	-	-	(Lydersen et al., 1989)
	Russia	Frans Josef Land	1994	5	0.0%	-	-	(Weslawski et al., 1994)
	Canada	Prince Leopold Island	2013	3	0.0%	-	-	(Poon et al., 2017)
King eider *(Somateria spectabilis)*	Greenland	Nuuk	2000-2002	41	0.0%	-	-	Jamieson unpub. in (Provencher et al., 2014a)
	Canada	Cape Dorset, Nunavut	2001	3	0.0%	-	-	Jamieson unpub. in (Provencher et al., 2014a)
			2011	10	0.0%	-	-	Provencher et al. 2013 in (Provencher et al., 2014b)
Long-tailed duck *(Clangula hyemalis)*	Canada	Belcher Is, Nunavut	1998-1999	27	0.0%	-	-	Jamieson et al. 2001 in (Provencher et al., 2014a)

Species	**Region**	**Location**	**Year of study**	**Sample size**	**Frequency of occurrence**	**Average mass per individual** (±SD)	**Average item per individual** (±SD)	**References**
Razorbill *(Alca torda)*	Canada	Bay of Exploits, Newfoundland	2004	2	0.0%	-	-	Muzaffar unpub. in (Provencher et al., 2014a)
		Notre Dame Bay, Newfoundland	2011-2012	8	0.0%	-	-	Bond unpub. in (Provencher et al., 2014a)
Surf scoter (*Melanitta perspicillata*)	Canada	Nain, Newfoundland	2006	38	0.0%	-	-	Muzaffar unpub. in (Provencher et al., 2014a)

Table 3.2. Average plastic ingestion by seabirds in the Arctic (species and foraging strategies)

Primary feeding mode / Species	**Number of studies**	**Years of studies**	**Number of samples**	**Frequency of occurrence**
Surface foragers	**61**	-	**3850**	**24.2%**
Northern fulmar (Fulmarus glacialis)	26	1969-**2016**	1625	63.7%
Mew gull (Larus canus)	2	1969-1990	273	8.7%
Glaucous gull (Larus hyperboreus)	4	1969-1994	58	0.8%
Red-necked phalarope (Phalaropus lobatus)	1	1969-1977	3	67.0%
Glaucous-winged gull (Larus glaucescens)	2	1969-1990	84	0.0%
Bonaparte's gull (Chroicocephalus philadelphia)	1	1969-1977	4	0.0%
Black-legged kittiwake (Rissa tridactyla)	8	1969-**2013**	575	4.8%
Red-legged kittiwake (Rissa brevirostris)	2	1969-1990	61	19.9%
Leach's storm petrel (Oceanodroma leucorhoa)	6	1969-**2012**	1107	33.2%
Fork-tailed storm petrel (Oceanodroma furcata)	3	1969-1991	41	95.2%
Ivory gull (Pagophila eburnea)	3	1969-1984	11	0.0%
Aleutian tern (Onychoprion aleuticus)	1	1969-1977	8	0.0%
Plunging	**3**	-	**67**	**0.0%**
Arctic tern (Sterna paradisaea)	3	1969-2007	67	0.0%
Pursuit-diving	**118**	-	**9019**	**13.1%**
Brünnich's guillemot/ Thick-billed murre (Uria lomvia)	23	1969-**2013**	2625	9.2%
Common murre/guillemot (Uria aalge)	7	1969-**2012**	460	1.7%
Little auk/dovekie (Alle alle)	14	1978-**2014**	1027	14.0%
Short-tailed shearwater (Ardenna tenuirostris)	6	1969-2005	834	83.9%
Sooty shearwater (Ardenna grisea)	3	1969-1991	624	42.7%
Common eider (Somateria mollissima)	9	1982-**2012**	1038	0.4%
Atlantic Puffin (Fratercula arctica)	5	1970-2004	75	5.8%
Tufted Puffin (Fratercula cirrhata) 8	5	1969-1991	844	31.6%
Horned Puffin (Fratercula corniculata)	5	1969-1991	313	40.1%
Parakeet auklet (Aethia psittacula)	5	1969-1990	324	71.1%
Least auklet (Aethia pusilla)	2	1969-1990	102	0.6%
Crested auklet (Aethia cristatella)	2	1969-1990	125	1.3%
Cassin's auklet (Ptychoramphus aleuticus)	2	1969-1990	45	25.7%
Rinoceros auklet (Cerorhinca monocerata)	3	1969-1991	30	14.7%
Pigeon guillemot (Cepphus columba)	2	1969-1990	61	1.3%
Pelagic cormorant (Phalacrocorax pelagicus)	2	1969-1990	13	10.0%
Double crested cormorant (Phalacrocorax auritus)	1	1969-1977	4	0.0%
Red-faced cormorant (Phalacrocorax urile)	2	1969-1990	18	0.0%
Marbled murrelet (Brachyramphus marmoratus)	2	1969-1990	157	0.0%
Kittlitz's murrelet (Brachyramphus brevirostris)	2	1969-1990	22	0.0%
Ancient murrelet (Synthliboramphus antiquus)	2	1969-1990	84	0.0%

Primary feeding mode / Species	**Number of studies**	**Years of studies**	**Number of samples**	**Frequency of occurrence**
Whiskered auklet (Aethia pygmaea)	2	1969-1990	27	0.0%
Black guillemot (Cepphus grylle)	5	1982-**2013**	38	0.0%
King eider (Somateria spectabilis)	3	2000-**2011**	54	0.0%
Long-tailed duck (Clangula hyemalis)	1	1998-1999	27	0.0%
Razorbill (Alca torda)	2	2004-**2012**	10	0.0%
Surf scoter (Melanitta perspicillata)	1	2006	38	0.0%
Piracy/Carnivore	**7**	-	**523**	**1.0%**
Great skua (Stercorarius skua)	2	2008-**2013**	515	4.0%
Long-tailed jaeger/skua (Stercorarius longicaudus)	2	1982-1991	3	0.0%
Pomarine jaeger/skua (Stercorarius pomarinus)	2	1984-1991	4	0.0%
Parasitic jager/ Arctic skua (Stercorarius parasiticus)	1	1969-1977	1	0.0%

Annex II: List of References

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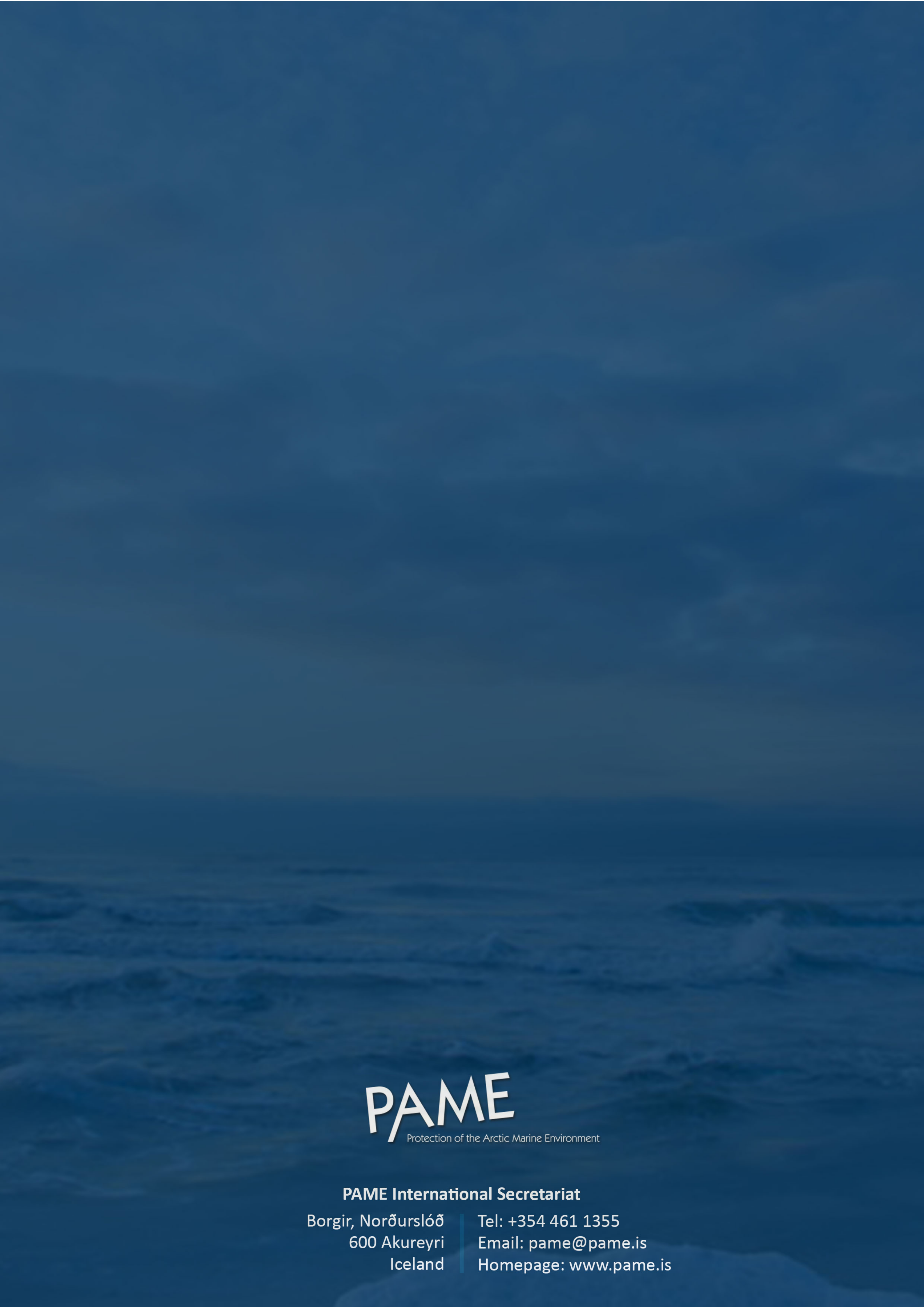

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