Desktop Study on Marine Litter including Micro-plastics in the Arctic

**1st Draft (11 Mayl 2018)**

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# Glossary

*[Note: to be added]*

# Background

*[Note: to be further developed]*

Marine litter or anthropogenic marine debris, and more concretely the plastic fraction of those, referred to generically as marine plastic pollution, is amongst the most pervasive pollution problems affecting the marine environment globally (UNEP, 2009; UNGA, 2012; UNEP, 2016). The United Nations Environment Programme defined marine litter as ‘any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment’ (UNEP, 2009). Marine plastic pollution therefore consists of plastic items or their fragments deliberately discarded or abandoned in the sea; brought indirectly to the sea by rivers, sewage outfalls, storm water or wind; or accidentally lost, including material lost at sea due to negligent practices or in bad weather. The universal challenge of addressing and managing marine litter is a useful illustration of the global and transboundary nature of many marine environmental problems.

Plastics account for 73 percent of all marine litter (Bergmann et al., 2017o). It is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans (UNEP and GRID-Arendal, 2016), and 4.6-12.7 million tonnes are estimated to be added yearly from land-based sources (Jambeck et al. 2015). The largest share of marine plastic pollution is often attributed to the contribution from land-based sources associated with deficient waste management systems in intensively populated coastal regions. While there is an increasing number of models attempting to gauge the contribution of plastic pollution from land, including the contribution arriving through rivers, (Jambeck et al., 2015, Lebreton et al., 2017) there is no recent estimate of the contribution from activities at sea (i.e. fishing, shipping, aquaculture, etc.) and therefore it is impossible to accurately rank land-based vs. sea-based contributions. In any case regional differences in relative contribution, e.g., 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) already indicate that the input associated with both land-based and sea-based activities deserves more attention.

Arctic Council Ministers adopted the [*Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-based Activities (Arctic RPA)*](https://pame.is/index.php/projects/arctic-marine-shipping/older-projects/rpa-reports) 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 Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA), and as such provides a framework for addressing the main pollution source categories and responding to the global concerns. Marine litter is one of eight contaminant sources of concern to the Arctic marine environment in the GPA and the Arctic RPA.

# Section I: Scope and Objectives

## Scope:

* Conduct a Desktop Study on marine litter and microplastics in the Arctic, and based on the outcomes of the study,
* Explore the possibility of developing an outline for a framework on an Arctic regional action plan on marine litter.

## Objectives:

* To evaluate the scope of marine litter in the Arctic, and its effects on the Arctic marine environment;
* Increase 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.

## [Definitions and scope]

*[Note: to be further developed]*

The annotated outline below assumes that as part of the text dealing with the scope of the Desktop Study, within Section I, there will be clarification of the terms marine plastic litter, marine plastic debris, marine plastic pollution, macroplastics, mesoplastics, microplastics and nanoplastics. That would ensure coherence of the content across the Desktop Study and how these terms are used and should be understood by the reader. GRID-Arendal could provide some suggestions on these but the experts in charge for Section I or the whole study may have already defined these terms. How the terms are used and defined could have a bearing on the title and content of the report and, it may therefore be desirable to discuss/clarify this with the whole group of experts. Below the term *marine plastic pollution* is used pending further clarification as it is generic enough to include the whole size spectra but specific enough to make it clear that the focus is directed towards particles of any size made mainly of plastic. Therefore, in every subsection, information will be collected regarding macro, meso and microplastics. When the information is specific to a certain size group, it will be mentioned, especially if separate consideration would be required or advisable in terms of policy recommendations.

In addition, the scoping section of the desktop study should define the adequate geographic scope for it. GRID-Arendal has so far worked under the assumption that the core geographic area of this desktop study would be the marine areas within the geographical coverage of the Arctic Monitoring Assessment Programme (AMAP) as defined in AMAPs 1998 assessment report (Murray et al., 1998) and referred as Arctic marine areas from now on. On the Atlantic side this area includes Hudson Bay, the Labrador, Greenland and Norwegian Seas, the Fram Strait, the northernmost reaches of the North Atlantic offshore Greenland, Iceland and the Faroe Islands and any areas north of these. On the Pacific side includes the coastal areas of the Gulf of Alaska, including Prince Edward Sound and the Cook Inlet, the coastal waters of the Aleutian Islands and the whole of the Bering Sea.

Because of the interconnectivity of the world oceans and the positive or slightly negative buoyancy of plastics, marine plastic pollution within the Arctic could, in theory, originate from virtually anywhere in the ocean and therefore we should consider the whole world as a potential source for plastic pollution 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. The input from these areas will be discussed in more detail within the “Pathways and Distribution” section. In addition, any other areas that are identifiable as regions of origin of the marine plastic pollution found within the Arctic marine areas should be considered.

In turn marine plastic pollution found within the Arctic marine areas could theoretically originate from any point within the Arctic watershed when considering land-based sources of pollution and therefore the limit of the Arctic watershed should be used as the land boundary for the geographic scope of this Desktop Study. In this respect, we have defined the Arctic watershed as including the watersheds of the rivers flowing into the marine areas with the AMAP geographic area.

# Section II: Mandates

*[Note: the paragraph below will be merged into Section I “Background”]*

Minimizing the presence of and impacts from marine litter is an ongoing problem, presenting new and recurring challenges for the international community and compounded by the fact that sources of marine litter occur on land and at-sea. This Desktop Study begins with an overview of some of the principal agreements and initiatives that are relevant to the prevention of marine litter, including plastics and microplastics. It then explores published scientific literature on the topic, assessing the sources and drivers, interactions and impacts, and responses and monitoring. The study is intended to serve as a springboard for further discussion to explore the possibility of an outline for a framework on an Arctic regional plan on marine litter.

**I. International Concern Embodied in Publications and Resolutions**

*[note: timeline will be added to the next draft]*

Since its inception, the Arctic Council has been involved in efforts to address the issue of marine litter and debris, 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]](#footnote-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]](#footnote-2) Subsequently, and shortly after the adoption of the Arctic Marine Strategic Plan in 2004, the Arctic Council of Ministers requested PAME to review and update the RPA.[[3]](#footnote-3) PAME amended the RPA and released the updated version on 29 April 2009.

Recently, in 2017, the Arctic Council’s Fairbanks Ministerial Declaration 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]](#footnote-4)

Similarly, the wider international community has been highlighting its concern over the need to address marine litter and debris. On 17 November 2004, the United Nations General Assembly (UNGA) requested that the Secretary-General convene the sixth meeting of the Consultative Process for Oceans and Law of the Sea the following June and recommended that it focus on two topics: fisheries and marine debris.[[5]](#footnote-5)

In response to the report from that sixth meeting, the UNGA encouraged “States to develop partnerships with industry and civil society to raise awareness of the extent of the impact of marine debris on the health and productivity of the marine environment and consequent economic loss.”[[6]](#footnote-6) The Assembly also urged “States to integrate the issue of marine debris into national strategies dealing with waste management in the coastal zone, ports and maritime industries, including recycling, reuse, reduction and disposal, and to encourage the development of appropriate economic incentives to address this issue.”[[7]](#footnote-7)

In June 2012, following ten days of meetings focusing on sustainable development in Rio de Janeiro, Brazil, government delegations representing nearly 200 U.N. Member States and Observers concluded negotiations on a resolution titled “The Future We Want.” In this resolution, the U.N. General Assembly noted its concern that the “health of oceans and marine biodiversity are negatively affected by marine pollution, including marine debris, especially plastic, persistent organic pollutants, heavy metals and nitrogen-based compounds, from a number of marine and land-based sources, including shipping and land run-off” and therefore committed to “take action to reduce the incidence and impacts of such pollution on marine ecosystems.”[[8]](#footnote-8) Three years later, the U.N. General Assembly established the 2030 Agenda for Sustainable Development, which included 17 sustainable development goals. Goal 14 provides that, by 2025, states should “prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.”[[9]](#footnote-9)

The United Nations Environment Assembly (UNEA) has similarly expressed concern and a desire for further action to address marine litter, including plastics and microplastics. In 2014, the UNEA requested the presentation of a study relating to the marine litter issue at its second session.[[10]](#footnote-10) Following that second session, the UNEA adopted a resolution requesting the U.N. Environment Programme Executive Director to assist Member States, especially developing countries, to address sources of marine litter and to undertake “an assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches to combat marine plastic litter and microplastics.” [[11]](#footnote-11) Finally, at its third session, the UNEA resolved to convene an expert group to “to furtherexamine the barriers to, and options for, combating marine plastic litter and microplastics from all sources, especially land based sources.”[[12]](#footnote-12)

On 18 October 2016, the International Maritime Organization released the Report of the Thirty-Eighth Consultative Meeting and the Eleventh Meeting of the Contracting Parties. Annex 8 provides that, recalling the Rio +20 outcome document, The Future We Want, the contracting parties express concern about plastic litter and microplastics in the marine environment and encourage member states to “make every effort to combat marine litter, including through the identification and control of marine litter at source and to encourage monitoring, additional study and knowledge-sharing on this issue.” LC 38/16, Annex 8, p. 1 (19-23 Sept. 2016). [**Update cite – this is from draft].**

Recently, on 13 April 2018, the IMO’s Marine Environment Protection Committee referenced Sustainable Development Goal 14, recent studies, and comments relating to marine plastic litter, and agreed to, among other things, “include a new output ‘Development of an action plan to address marine plastic litter from ships’ in the [Committee’s] 2018-19 biennial agenda.”[[13]](#footnote-13)

**II. International Instruments**

*A. UNCLOS*

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) is an international agreement governing uses of the oceans and their resources.[[14]](#footnote-14) The Convention entered into force in 1994. Part XII of UNCLOS addresses preservation of the marine environment. Within that Part, Article 194 provides the general direction that “States shall take, individually or jointly as appropriate, all measures consistent with this Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities, and they shall endeavour to harmonize their policies in this connection.”[[15]](#footnote-15)Provisions particularly relevant to the issue of marine litter are Articles 207, 210, and 211.

Article 207 directs states to “adopt laws adopt laws and regulations to prevent, reduce and control pollution of the marine environment from land-based sources, including rivers, estuaries, pipelines and outfall structures, taking into account internationally agreed rules, standards and recommended practices and procedures”.Articles 210 and 211 have similar provisions concerning pollution by dumping and pollution from vessels. Additionally, under Article 192, States have a general obligation to protect and preserve the marine environment. At present, 168 parties have ratified UNCLOS. The agreement, however, has not resulted in significant reductions in marine litter, particularly plastics and microplastics.

In 1995, parties at the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks adopted the UN Agreement for the Implementation of the Provisions of the UN Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (“U.N. Fish Stocks Agreement”). The purpose of the Agreement is to ensure international cooperation with respect to conservation and sustainable use of fish stocks and highly migratory fish stocks.[[16]](#footnote-16) Article 5(f), which is of particular relevance, provides that States shall “minimize pollution, waste, discards, catch by lost or abandoned gear . . . through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques”.[[17]](#footnote-17) In response, States and Regional Fisheries Management Organizations have taken some actions to address lost or abandoned fishing gear.[[18]](#footnote-18) [*If we have data on removals/reductions in lost gear, include reference here.*]

*B. MARPOL 73/78*

The International Convention for the Prevention of Pollution from Ships (MARPOL) addresses pollution of the marine environment by ships, including accidental pollution and that from routine operations. The Convention was adopted in 1973 but had not entered into force when the Protocol of 1978 was adopted. The combined instrument entered into force in 1983. The Protocol of 1997 entered into force in 2005, amending the Convention to include the new Annex VI. The Convention currently includes six technical annexes, aimed at preventing and minimizing pollution from ships.

Annexes IV and V are particularly relevant to marine debris. Annex IV contains requirements to control pollution of the sea by sewage and Annex V addresses operational discharge of garbage from ships and sets standards for where and when certain garbage may be discharged. Significantly, Annex V imposes a complete ban on the dumping into the sea from ships of plastic, such as “synthetic ropes, synthetic fishing nets and plastic garbage bags.”[[19]](#footnote-19) Thus, MARPOL regulations focus on the flow of plastic from ships to sea, but they do not address land-based sources of marine debris.

*C. London Convention and London Protocol*

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters (London Convention) and London Protocol requires Contracting Parties to take effective measures to prevent pollution of the marine environment caused by dumping at sea.

Article IV of the Convention prohibits parties from dumping any wastes or other matter, except for certain substances identified in an annex and those require a permit to dump.[[20]](#footnote-20) The Convention defines “dumping” as requiring a deliberate act, including “any deliberate disposal into the sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea.”[[21]](#footnote-21) The Convention does not apply to accidental discharges, such as those incidental to routine operations, or to discharges from land-based sources.

The Convention entered into force in 1975, and 87 States are parties to it. The 1996 London Protocol resulted from a comprehensive review of the London Convention undertaken in the early 1990s by Contracting Parties to the Convention. The London Protocol implements a precautionary approach that prohibits all dumping except those wastes or other matter described in Annex 1 of the Protocol, and also adopts a polluter pays principle. **Cite** (Art. 3(1) and 3(2)). The London Protocol is a freestanding treaty that entered into force internationally in 2006 and is intended to ultimately replace the London Convention.

The Parties to the London Convention and Protocol meet jointly and have developed a number of guidance documents to support ocean dumping management. These resources include waste assessment guidance for Annex 1 wastes and other material, circulars responsive to information requests, and technical references related to ocean disposal and marine environmental quality.

*D. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal*

The Basel Convention entered into force in 1992 and imposes limits on the global export, import, and disposal of hazardous wastes. The principal objective of the Basel Convention is to protect human health and the environment against adverse effects of hazardous waste, which covers a wide range of waste based on their origin and/or composition and characteristics, as well as household waste and incinerator ash.

The limitations on the movement of such wastes include the prohibition of their export or import to/from a nonparty nation (unless pursuant to a separate multilateral or bilateral agreement); a requirement of notification of transboundary movements between parties or through territories of nonparties; and requirements for their packaging, labeling, and transportation.

In 1995, the “Ban Amendment” to the Basel Convention was adopted. This Amendment requires Parties listed in Annex VII and members of the Organisation for Economic Co-operation and Development (OECD), European Union, Liechtenstein to prohibit all transboundary movements of hazardous wastes destined for recovery or recycling operations from OECD to non-OECD States.[[22]](#footnote-22) The Ban Amendment has not yet been ratified by three-fourths of the Member States and therefore, at present, has not entered into force.

Since 2002, the Conference of the Parties has worked on the management of plastic wastes. At the 6th meeting, the COP adopted Technical Guidelines for the Identification and Environmentally Sound Management of Plastic Wastes and For Their Disposal.[[23]](#footnote-23) In May 2017, the COP established the Work Programme of the Open-ended Working Group for the biennium 2018-2019, which indicates that the Parties will consider relevant options under the Convention to further address issues related to marine plastic litter and microplastics.[[24]](#footnote-24)

*E. The Convention on Biological Diversity*

The Convention on Biological Diversity entered into force on 29 December 1993. The Convention has three main objectives: (1) the conservation of biological diversity; (2) the sustainable use of its components; and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.[[25]](#footnote-25) Article 6, General Measures for Conservation and Sustainable Use, directs the contracting parties to develop national strategies for the conservation and sustainable use of biological diversity. Article 8, In-situ Conservation, directs each party, as far as possible and appropriate, to take develop strategies and take action aimed at protecting ecosystems. In 2012, the Secretariat of the Convention published a report on the impacts of marine debris on biodiversity.[[26]](#footnote-26) Most recently, in 2016, the Secretariat published another report focusing on the issue of marine litter, “Marine Debris: Understanding, Preventing and Mitigating the Significant Adverse Impacts on Marine and Coastal Biodiversity.”[[27]](#footnote-27)

*F. UN Watercourses Convention*

(entered into force August 2014, 36 Parties):

The Convention on the Law of the Non-Navigational Uses of International Watercourses provides a framework for the governance and management of international watercourses. Article 7 imposes upon Watercourse States the obligation to “take all appropriate measures to prevent the causing of significant harm to other watercourse States.”

Article 21 requires Parties using an international watercourse to prevent, reduce, and control pollution of an international watercourse. Pollution is defined as “any detrimental alteration in the composition or quality of the waters of an international watercourse which results directly or indirectly from human conduct.”

**III. International Initiatives**

One of the first initiatives to address UNCLOS’s mandate to “reduce and control pollution of the marine environment from any source” was the Montreal Guidelines for the Protection of the Marine Environment Against Pollution from Land Based Sources. Drafted in 1985, the guidelines created a list of prohibited items, which included “Persistent synthetic materials which may seriously interfere with legitimate uses of the sea.” [**Cite = Guidelines at 20].**

In 1992, the U.N. Conference on Environment and Development in Rio de Janeiro adopted Agenda 21, Chapter 17, titled “Protection of the Oceans, All Kinds of Seas, Including Enclosed and Semi-Enclosed Seas, and Coastal Areas and the Protection, Rational Use and Development of Their Living Resources.” [Cite = U.N. Conference on Environment and Development, June 3-14, 1992, Agenda 21, Chapter 17, P 17.18, U.N. Doc. A/CONF.151/4 (1992)]. Chapter 17 “sets forth rights and obligations of States and provides the international basis upon which to pursue the protection and sustainable development of the marine and coastal environment and its resources.” Para. 17.1. The document identified “litter and plastics” as among the “contaminants that pose the greatest threat to the marine environment” and called for an international forum to address the protection of the marine environment from land-based activities. [Paras. 17.18 and 17.26].

The U.N. Environmental Programme’s Regional Seas Programme embodies some of the purposes of Agenda 21, Chapter 17. That program currently includes efforts of 143 countries participating through 18 Regional Seas Conventions and Action Plans. The Programme’s focus is to address the degradation of the world’s oceans by engaging neighboring countries to protect their common marine areas through the development and implementation of comprehensive action plans. Potential strategies include the promotion of international and regional conventions, guidelines and actions for the control of marine pollution and for the protection of aquatic resources, assessment of the state of marine pollution and its sources and trends, assessment of the impact of pollution on the marine ecosystem, and coordination of these efforts with regard to the management of marine and coastal resources. **[Cite, UNEP Guidelines and Principles for the Preparation and Implementation of Comprehensive Action Plans for the Protection and Development of Marine and Coastal Areas of Regional Seas].**

At present, there is the foundation for an Arctic program coordinated by Iceland and the Arctic Council has directed Member States “to consider the utility of a regional seas program as a platform for implementing ecosystem-approach principles to the Arctic marine areas.” Senior Arctic Officials’ Report to Ministers, Action item 6 at p. 134 (24 April 2015).

As a follow-up to Agenda 21, the U.N. Environment Programme held an intergovernmental conference in Washington, D.C. in 1995 that resulted in the publication of The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities. The report recognizes that there has been “international action to prevent the discharge of plastics and other persistent wastes from vessels,” but notes and estimates that “approximately 80 percent of persistent wastes originate from land.” [Intergovernmental Conference to Adopt a Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, Washington D.C., 23 Oct. – 3 Nov. 1995, UNEP(OCA)/LBA/IG.2/7 (Dec. 5, 1995) at para. 142.]

With regard to rising concerns over impacts from untethered fishing gear polluting the marine environment, the Food and Agriculture Organization of the United Nations (FAO) has published a series provisions and standards, the Code of Conduct for Responsible Fisheries. The Code is voluntary and global in scope; it is directed to both members and non-members of the FAO. Some of the standards are particularly relevant to marine litter. For example, section 8.4.6 provides that “States should cooperate to develop and apply technologies, materials and operational methods that minimize the loss of fishing gear and the ghost fishing effects of lost or abandoned fishing gear”.[[28]](#footnote-28) There also are provisions relating to the management of garbage and waste.[[29]](#footnote-29) For example, section 8.7.2 and .3 encourage waste minimization and treatment.

*[Note: Need conclusion/transition paragraph to next section.]*

*Note: Optional sections if participants would like to include it:*

IV. Considerations Towards a Framework on an Arctic Regional Plan on Marine Litter

 A. Lessons from existing agreements and initiatives.

 B. Key components for the framework.

V. Regional Efforts?

 A. Barcelona Convention.

 B. HELCOM.

 C. Northwest Pacific Action Plan’s Regional Action Plan on Marine Litter.

 D. OSPAR’s Regional Action Plan on Marine Litter.

 E. EU Marine Strategy Framework Directive and Waste Framework Directive.

 F. Caribbean Environment Programme.

 G. UNEP Regional Office for North America.

 H. Others?

VI. Non-Governmental Efforts?

 A. Declaration of the Global Plastics Associations for Solutions on Marine Litter

 B. Trash Free Seas Alliance

 C. Others?

VII. National Efforts (To be included in an Annex)

If the Desktop Study is to include national efforts, we would ask the each member provide a short section on what its respective country has adopted or implemented to prevent, mitigate, manage, and/or reduce marine litter from its boundaries.

# Section III: Literature Review

## 1. Sources and Drivers

[Introduction to potential sources of marine plastic pollution. Sources will be associated to different kinds of human activities carried out in the Arctic region, immediate vicinity and other identifiable regions of origin of the marine plastic pollution found within the Arctic marine areas. When specific information on sources is limited, information on the drivers could be used as proxy but we will request guidance on the need/will to include this after “zero” draft has been delivered. Suitable proxies will be discussed and listed. Sources will be split between sea-based and land-based sources. Sources associated with coastal activities (i.e., coastal tourism and harbour activities) will be considered under land-based sources.]

Plastic pollution has become ubiquitous in the global ocean (UNEP, 2016) due to the increased production, use and consumption of products containing or packaged in plastic. Plastic is used in each and every link of the production chain and can be made into products or products components with infinite shapes and sizes. These products or their residues can end up leaking into the environment during the product’s life or at the end of it. The design of plastic products has so far not taken into full consideration the need for a sustainable end-of-life for plastics.

Of course, not every process or activity involving plastic will lead to leakage to the marine environment. Mostly processes run in the open environment (outdoors) are the ones that may ultimately lead to pollution if there is a release mechanism by which plastic objects or their fragments leave the intended cycle. Also processes carried out indoors 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 plastic pollution effectively, we need to understand not only the reasons why objects or their fragments become litter but also their mode of entry or pathway into the marine environment (Veiga et al., 2016).

When plastic objects already within the marine environment leave the intended cycle, the pathway of entry is either very short (i.e., a wave washing over a boat deck where objects are not secured or a wind gust taking a plastic bag left behind on a beach) or nil (fishing gear being lost or worn out in the ocean) and therefore lead to immediate pollution. It is therefore logical to organize the analysis of the sources of marine plastic pollution as either sea-based (no pathway needed) or land-based sources (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 plastic pollution 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 plastic into the Arctic. While some of the debris collected during beach surveys can be easily determined to unequivocally originate from certain sea-based sources (mostly fisheries), this is not the case for other plastics that are 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 normalized against the surface of the Arctic Ocean as proxies for the likely input of pollution from either land or sea. They concluded that, on the basis of the world ratios of vessels per coastal inhabitant, sea-based sources of pollution in the Arctic region must be particularly relevant in relation to the land-based sources.

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 plastic pollution and to provide information on the size and geographical distribution of the drivers or activities leading to the release of plastic into the environment.

### Sea-based sources

[A priori this will include mainly fisheries (including commercial, subsistence, and recreational), aquaculture, shipping and cruise tourism. Details will be provided on the specific types of activities within each sector that may lead to plastic pollution, whenever possible.]

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 discharge of plastic materials contained in offshore chemicals.

**Fisheries**

Abandoned, lost or otherwise discarded fishing gear (ALDFG) is recognised as a major source of marine plastic in the Arctic, more concretely in the Greenland, Norwegian, Barents and Bering Seas, the Gulf of Alaska 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; Grøsvik et al., 2018). Besides ALDFG the use of fishing gear always involves wear and tear that will lead to fragments or pieces of the gear been released in the ocean.

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. Most of fishing gear originates from trawlers: netting from cod and shrimp trawls; trawl bobbins and floats, including those that were attached to the nettings; bundles of plastic packing bands that might have been used on trawlers or by other sea- and land-based industries. Trawling-related gear tends to predominate in the surveys because trawling has a higher rate of gear loss than other fishing methods, and because bottom trawls are widely used for the species exploited in the Svalbard Fisheries Protected Zone (Nashoug, 2017). Fish crates that might also be used at sea or on land, originate from Norway, Denmark, Spain, United Kingdom, Iceland and Faroe Islands providing an indication of the fleets active in the region (and contributing to pollution), although crates also tend to circulate among vessels from different countries. Detailed observations of the objects for which origin can be determined, i.e., fishing nets or ropes, may sometimes allow the identification of the release mechanism (e.g., cuttings of trawl nets likely the result of overboard discard or poor waste management on deck) (Nashoug, 2017).

Litter from the fishing industry was also prevalent in the Subarctic Northern Pacific and Bering Sea, 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 tusnami 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 (before the entry in force of MARPOL 73/78) allowed Merrell (1980) to estimate that a fleet of 1457 vessels operating in the North Pacific and Bering Sea released ca. 1665 metric tons of plastic litter per year into the ocean so more than a metric ton per vessel per year. A correlation between the quantity of litter on Amchitka Island 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 plastic found on Aleutian beaches were Japan, USSR, USA, China, Korea with Japanese fishing nets being positively identified the most often (Merrell, 1980, 1984; Johnson, 1990; Manville, 1990). Positive identification of the fleet of origin of the fisheries-related items allowed conclusions to be drawn on the relationship between the decrease in the presence of litter and the establishment of fisheries area regulations.

In the central Bering Sea crab fishery has been identified as a major contributor to litter washed off on the shores of the Pribilof Islands with up to 70% contribution from this activity and annual accumulation rates of up to several hundreds of kg per km (King, 2009).

The areas identified as most severely affected by pollution related to fisheries coincide with the areas with the highest fishing (and specially trawling) effort as depicted in Kroodsma et al. (2018). 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.

**Aquaculture**

Studies of marine litter in the Arctic do not provide information about the presence of plastic debris associated specifically with aquaculture as it is difficult to identify items that are specific to this activity unless they are recovered in close proximity to where aquaculture activities occur. Overall, the importance of this sector, and therefore its potential contribution to marine litter, is relatively small compared to the fisheries sector but, on a local scale, it may still contribute significantly and in certain areas of the Norwegian coast is estimated to be the source of about 30% of the total amount of marine litter (OSPAR Commission, 2009).

As for fisheries, detailed mapping of the areas where aquaculture is occurring would provide an indication of where the highest potential pressure associated with aquaculture may occur. 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. Canada is the next largest producer concentrating also on salmonids, largely in British Columbia with some operations in Newfoundland and Quebec. Iceland has an incipient but valuable production of arctic char (Hermansen and Troell, 2012; Troell et al., 2017).

**Shipping**

The potential contribution from shipping to marine plastic 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) but as is the case for aquaculture it is difficult to ascertain its relative contribution to marine plastic pollution based on source identification of the plastic debris as there is no unequivocal identification of objects or fragments contributed by ships on transit across Arctic waters.

Nashoug (2017) reports that a large amount and variety of household plastics (bottles and containers for beverages, ketchup, hygiene and laundry products, etc.) of different nationalities was found on the beaches of Northwestern Svalbard. The remoteness of the locations where they were found, far away from large population centers, makes the intentional discard from either fishing, merchant or cruise ships plausible. Also, large size food containers could indicate intentional discard from kitchens of larger vessels.

The data contained in the [Arctic Ship Traffic Database](https://pame.is/index.php/projects/arctic-marine-shipping/astd) 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 allows a monthly and yearly analyisis of shipping intensity allowing to assess seasonality in potential inputs and long term trends.

In addition, and although the limited knowledge about microplastic from oil and gas extraction activities is not conclusive (Moskeland et al., 2018), it’s very likely they consitute a source of plastic pollution, including microplastic and fibers, emphasizing that it should be certainly considered in future source assessments. The mapping of the distribution of rigs and platforms in the Arctic also provides proxy data for the geographic distribution of the potential input related to this kind of activities.

### Land-based sources

[Similar to sea-based sources, this will address activities on land that constitute the largest sources of land-based plastic pollution in Arctic marine environments. As for other regions, mismanaged domestic and industrial waste will likely dominate the land-based sources though documentation may be limited. Other potential sources that will be considered are transportation/logistics, mining and agriculture. Any other land-based sources that are identified in the Arctic region will be documented.]

**Waste management**

At the global level, the major challenge to tackle the input of plastic debris from land into the ocean is the lack of adequate waste management in coastal regions with a high and growing population density (Jambeck et al., 2015). As discussed above, due to overall general low population density in Arctic coastal areas, the pressure resulting from land-based inputs should be relatively low overall. Nevertheless, some specificities of the Arctic, such as population concentration along the coastline and river courses; temporary settlements not covered by 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). Traditional waste management solutions are uncontrolled waste dumps 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 personal care products (Gunnarsdóttir et al., 2013). There are no studies looking specifically at the leakage and marine input of plastic debris linked to these waste management systems but ongoing work to quantify and characterize beach litter here (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 being registered. In contrast, the composition of beach litter registered in Eastern Greenland, where there are fewer settlements, more closely resembles that of northern Norway and Svalbard where the imprint of intense fishing activities is registered (Strand, 2018).

In addition, a study looking into microplastics in the vicinity of Reykjavik, Iceland (Dippo, 2012) has detected exceptionally high concentrations of small plastic fragments and microplastics in a sandy beach near Reykjavik harbor. Though not specified in this report, this exceptionally high concentration of microplastics, including large amounts of plastic fibers and film, could be linked to this particular location being 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 in due consideration.

In order to gain further insight on the potential release of plastics associated with waste management, it would be useful to map the distribution of population density as well as the location of urban agglomerations and 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 to allow identification the regions within the Arctic that need more attention to this potential source of plastic pollution. Of course, information on the quality of waste management systems, i.e., coverage of waste 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 for waste mismanagement to estimate the contributions at the national level but due to the singularities of the Arctic mentioned above, it would be desirable to use higher resolution information specific for the Arctic region or local assessments to better gauge the contribution from this source.

**Transportation and logistics**

In addition to releases linked to the management of plastic waste during its transportation, the distribution of goods, including plastic in any of its intermediate forms before it is incorporated or turned in a product, can lead to plastic 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. Due to the lack of specific assessments on the contribution from releases during transportation, and as for shipping, a map of the main transportation network including roads and harbours would 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 also 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 and mining, construction and tourism, also run all or part of their operations outdoors in the natural environment and may also be a source of plastic 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 plastic pollution in the Arctic region. The compilation of proxy indicators for the potential release from these activities - such as geographic distribution and how plastic intensive they are (i.e., plasticulture, amount of plastic used in Arctic construction, single-plastic use in outdoor tourism industry), and indications on the ratio of release into the environment - would allow a better assessment of their potential contribution to marine litter and the need for remediation.

## 2. Pathways and Distribution

[Description and understanding of the pathways of entry of marine plastic pollution into the Arctic marine environment is a crucial element in tracing the pollution back to its sources and developing preventive policies and action. In addition, the knowledge and understanding of the distribution of marine plastic pollution within the Arctic is limited and therefore the consideration of potential pathways and documented (if any) inflow of plastic pollution to the Arctic Ocean is a meaningful proxy to the distribution by pointing at likely areas for passage or (temporary) accumulation of plastic particles.]

The description and understanding of the pathways of the entry of marine plastic pollution into Arctic waters is a crucial element in tracing the pollution back to its sources and developing preventive policies and action. In addition, the knowledge and understanding of the distribution of marine plastic pollution within the Arctic is limited and therefore the consideration of potential pathways and documented (if any) entry or inflow of plastic pollution to the Arctic Ocean is a meaningful proxy to its distribution, pointing at likely areas for passage or (temporary) accumulation of plastic particles. Understanding of the fate of plastic pollution within the Arctic will allow consideration of measures for the removal and therefore reduction of potential impacts caused by the accumulation of plastic particles.

### Pathways

[Riverine influx and marine currents influx will be considered under this subsection. The consideration of riverine input implies that the whole Arctic watershed is considered as a source area and this needs to be addressed in the scoping section of the report. Direct coastal input involving a human mediated pathway (i.e., accidental or intentional dumping) will be considered under the previous subsection as associated to human coastal activities (sea-based sources). Under pathways only influx involving a fluid flow (water courses –including sewage outfalls and marine currents) will be considered.]

A complete understanding of the input of plastic pollution into the Arctic marine environment needs consideration of the source sectors and the mechanisms of release as well as the pathways by which the plastic debris or particles reach the marine environment. 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 plastic debris and microplastics in a part of the global ocean, in this case in the Arctic Ocean, there is a need to consider the transfer of marine plastic pollution into the relevant part of the ocean through the regional circulation pathway.

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 input**

The Arctic watershed is vast and extends well beyond any of the boundaries that are used to define the Arctic region. The largest rivers in the Artic watershed are the Yenisey, Lena, Ob’, Mackenzie, Yukon, Kolyma, Nelson, Indigirka, Pechora and Dvina (AMAP, 1998). In terms of discharge the Yenisey has the largest discharge with 673 km3/year followed closely by the Lena with 581 km3/year. The Ob’ has the largest population in its watershed, with over 28 million people living in it, which is more than three times the population of the second most populated watershed, the Yenisey with 8 million people and more than 25 times the population within the Lena watershed (Shiklomanov et al., 2018). Siberian rivers discharging into the Kara, Laptev, and East Siberian Seas have a huge combined drainage area of 9 000 000 km2 extending far to the south (Shiklomanov and Skakalsky, 1994) and encompassing many industrial and agricultural regions. Massive river discharges make terrestrial influences particularly strong in the Arctic Ocean as while it holds less than 1% of the global ocean volume it 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, decreasing over summer, and reaching minimum values just before spring thaw again. This seasonal pattern affects the transfer of any suspended or floating materials as well as plastic particles which would peak also during thaw. The transfer of floating debris would certainly be hampered during winter when the river surface is frozen.

To date there is no monitoring of the flux of plastics from rivers into the Arctic and though it has been identified as a possible pathway (Kanhai et al., 2018), the contribution of riverine discharge to plastic input 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 deserves some verification in the light of the fact that the population in the Ob’ and Lena watersheds is 38 million people, an order of magnitude larger than the population of the entire Arctic region.

Lebreton et al. (2017) modelled global plastic inputs from 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 60o is not available and therefore the model does not include the plastic input from Arctic reivers. The relative importance of plastic input through Arctic rivers should be further considered in the light of the facts exposed above.

**Atmospheric input**

At the global level, it is assumed that much less plastic debris is transported by wind than by rivers (UNEP and GRID-Arendal, 2016) though, in contrast with rivers, there is no global estimate of the input through this pathway. However, wind transport of plastic debris 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 debris that would not normally be available for transport and carry it directly into rivers and the ocean (Lebreton et al., 2012). Wind-blown litter is likely to be likely considerable as the Arctic is characterized by windy shorelines, it is dry, with frozen ground, for a large part of the year, and there is multitude of small communities with open dumpsites near the ocean.

Though atmospheric circulation has been proven to provide an efficient pathway for the transportation of microfibres and small plastic particles elsewhere (Cai et al., 2017; Dris et al., 2017), there are to date no published data on plastics and microplastics in air and precipitation in the Arctic region (Halsband and Herzke, 2017).

**Oceanic input**

Last, but nonetheless very important, is the input of plastic particles through the movement of marine water masses by currents. 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 very modest (19%) (AMAP, 1998).

The exchange of water, and with it of any drifting plastic pollution, from and to the North Atlantic Ocean has been addressed by the modeling 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 would find a dead end of this plastic conveyor belt. Before these modeling 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, and that of the toxic substances associated with them, concluding that the fluxes associated with plastic drift are 5 to 6 orders of magnitude smaller than those from the same substances dissolved in the sea water or transported to the region through the atmosphere. Nevertheless, they pointed 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 it 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

[The distribution of marine plastic pollution in the different accumulation regions or sinks of the Arctic Ocean will be considered in this subsection. This will be split under beached plastic, sea ice, surface water, water column, seafloor and sediments. Information on composition and concentration of particles and objects amongst accumulation regions and, where possible, on stocks in the different compartments will be documented.]

Plastic has been observed in all environmental compartments across the Arctic. Even in locations distant from the locus of human activities plastic abundance is comparable to that of populated areas close to urban centers (Hallanger and Gabrielsen, 2018). Distribution of documented observations of marine litter including plastics and microplastics is heavily dominated by higher accessibility and increased research activity in the Atlantic Arctic (Norwegian, Greenland and Barents Sea) and in the Bering Sea and the Gulf of Alaska and their coastal areas.

**Beached plastic**

Information on plastic 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 mesoplastics and macroplastics (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 section.

A wealth of information regarding marine plastic debris accumulated on beaches of the Aleutian Islands was compiled during pioneering studies in the 1970s and 1980s. Hundreds of objects per kilometre were counted in 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 corresponded to hundreds of kilograms per kilometre with most of it connected to intense fishing activity by Russian, Japanese and US fishing fleets. More than 90% of the plastic 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 4196 kg/km but only 63 kg/km on the southeastern shores of Ckuckchi, 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 southeastern Chuckchi Sea receive lower inputs due to much lower local fishing and shipping activity and only limited input related to drifting of debris from the Bering Sea northwards into the Arctic Ocean through the Bering Strait.

The OSPAR Commission monitors beach litter at 17 sites within the Atlantic Arctic with 36 surveys conducted in 2017. The amount of beach litter varied from a mean of 14,750 items per km in the spring to 1,950 items per km 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 800 to 1600 kg/km, with the exception of a site where density reached a maximum value of 63000 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 Gulf of Alaska, Bering and Chuckchi Seas, fisheries-related plastic litter dominated the litter assemblages on Svalbard’s beaches making up between 44 and 100% of it. Surveys carried out in the northwestern tip of Iceland revealed lower densities of litter, mostly plastic, with an average of 1040 items/km corresponding to an average of 104 kg/km originating mostly from Icelandic fisheries (Kienitz, 2013). Surveying according to the OSPAR beach protocol of the eastern and western shores of Greenland has also been recently initiated at several locations (Strand and et al., in prep.). Initial results reveal similar median densities for the west coast with 1200 items/km compared to much lower densities of only 30 items/km. Analysis of the type of objects collected reveals the dominance of local sources over long-rande transport specially for West Greenland.

**Sea ice**

Observations of plastic particles within sea ice in the Arctic are limited (Table 2.2). Obbard et al. (2014) documented concentrations ranging between 38 and 234 x 103 n/m3 in sea ice cores collected in the central Arctic Ocean and Chuckchi Sea in 2005 and 2010. Recently published results (Peeken et al., 2018) from cores collected in the Fram Strait and the Central Arctic north of Svalbard reveal even higher concentrations of microplastics in sea ice reaching maximum values of 1.2 ± 1.4) × 107N m−3 in pack ice in the Fram Strait and minimum values of 1.1 ± 0.8 × 106N m−3 just north of Svalbard. These concentrations are several orders of magnitude higher than concentrations reported earlier by Obbard et al. (2014), likely due to different methodology used, and further confirm that sea ice is a temporary sink of plastic pollution.

**Surface and sub-surface waters**

Information on plastic marine litter in surface waters is gathered through several methods. For the largest size fractions, visual observations from ships and even low flying helicopter flights is available while the smaller fractions are studied through the use of surface samplers, water pumps and ingestion by biota (i.e. OSPAR Commission, 2015; van Franeker and Law, 2015)*.* As for beached plastic, 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 0.333 mm to 0.5 mm and therefore sampling mostly microplastics (<5 mm) and mesoplastics) decrease from the Subarctic North Pacific towards to the Gulf of Alaska and the Bering Sea (Table 2.2). Concentrations in the Bering Sea seem to have increased from mid 1970’s from tens of particles to thousands of particles per square kilometre. Still concentrations in the Bering Sea in 2006 (0.017±0.010 - 0.072±0.041 n/m3 Doyle et al. (2011)) were one order of magnitude lower than concentrations on the Atlantic Arctic in 2014 (0.34±0.31 n/m3, (Lusher et al., 2016). Cozar et al. (2017) recorded surface concentration of plastics in parts of the Norwegian and Barents Sea to have median value of 0.063 n/m2 in 2013 which are in the same order of magnitude as the average concentrations recorded by Lusher et al., (2015) (0.028 n/m2) in the same region a year later. These concentrations are similar to median concentrations for subtropical accumulation zones associated with the subtropical oceanic gyres (0.044 n/m2) and one order of magnitude above the media for non-accumulation open waters (0.0019 n/m2) (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/m2) are one order of magnitude above maximum values in the Barents Sea (0.32 n/m2).

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). The percentage of birds with more than 0.1g of plastic in their stomachs decreases with latitiude (North Sea 62%, Iceland 28% and Svalbard 23%; Eastern North Pacific 54% and Alaska 25%) indicating a northwards decrease in plastic pollution in surface waters.

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. Studies incorporating the use of multinets (Kooi et al., 2016) are required for that purpose.

The increase of plastic pollution over time in the Bering Sea may be related to transportation of pollutants 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 Cozar et al. (2017) plastics are 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 flow of water from more polluted areas into the Bering Sea could therefore also explain the increase in plastic concentration in surface waters.

The present and future increase of human activities in a warmer and ice-free Arctic could favor further dispersion and increased concentration of plastic particles in Arctic surface waters (Cózar et al., 2017).

**Water column**

Data on the concentration of plastic within deeper parts of the water column to gain insight on the three-dimensional distribution of plastics in the Arctic or even other parts of the ocean is very scarce (Table 2.2). Amelineau et al. (2016) gathered data on the concentration of microplastics across the top 50 metres 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. Information available to date does not allow an assessment of the transfer to deeper parts of the water column though the similar density of most plastic polymers to that of seawater warrants its efficient dispersal through the water column (GESAMP, 2015).

**Seafloor**

Information on the presence of plastic litter on the Arctic seafloor has been obtained in several studies through trawls or underwater photo and video transects (Table 2.3). Due to methodology constraints, data is limited to mesoplastics and macroplastics. 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 Gulf of Alaska and the Bering Sea recorded concentrations of up to tens of objects per square kilometre, recent surveys in the Barents, Norwegian and Greenland Sea recorded concentrations of hundreds and up to thousands of debris per square kilometre.

Concentrations of litter on the seafloor of the Greenland Sea at the HAUSGARTEN deep-sea observatory based on photo transects (Bergmann and Klages, 2012; Tekman et al., 2017) have revealed the surprising increase in litter concentrations between 2002 and 2014, and especially at the northern station of the observatory where concentrations of litter increased 26-fold from 390 objects per km2 in 2004 to 7699 objects per km2 in 2014. 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/km2 respectively. The much higher values reported for HAUSGARTEN, a much 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 but also to an increased accumulation in this area due to high input.

Through trawl sampling or photo/video transects it is often possible to recognize objects or fragments of objects that allow tracing them to the potential sources of pollution. All of the surveys above that targeted seafloor litter in the Arctic or nearby locations documented debris linked to fishing and/or shipping or activities.

Due to the scarcity of information and lack of a formal monitoring program within the Arctic is difficult to assess trends on marine plastic pollution over time but Tekman et al. (2017) indicate that the abundance of plastic in the Arctic seafloor is increasing.

**Sediments**

The presence of plastics in marine sediments within the Arctic has only been documented in studies published during the last 5 years focusing on beach and shallow water environments and on deep sea regions. Information is constrained to Iceland, Svalbard/Greenland Sea and the Bering Sea and Gulf of Alaska (table 2.4).

Large plastic particles and microplastics were found in almost half of the sites sampled near Reykjavik (Dippo, 2012) with no clear relationship to the distance from town detected. Therefore, it cannot be concluded that local sources play a major role in the distribution of microplastics in Iceland. The sample with the most particles (> 150 n/l), and one that was well beyond the range for all the other locations (0 – 4.5 n/l), could reflect the influence of nearby 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 suggests that offshore fisheries and local meteorological and hydrographic conditions (winds and currents) are contributing 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 during largest waves or 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 in Alaska and the eastern shores of the Bering Sea.

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) seems to point towards an increase in the concentration of microplastics towards deeper waters but 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 entrained the ocean during the last decades. Bergmann et al. (2017b) also explores the potential connection between the presence of the sea ice margin above one of the locations with the highest concentration of plastics within their study. This possibility is further emphasized by the potential role of the transfer 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).

## 3. Interactions with biota and impacts

The impacts of marine plastic pollution in the Arctic are, as in other areas, two-fold. First, the impacts on ecosystems need to be considered in order to assess the potential socio-economic impacts. Ecological impacts are often documented in a quantitative manner, while socio-economic impacts are primarily documented qualitatively. The way these types of data are collected introduces a layer of complexity in the evaluation of ecosystems from a social-ecological perspective.

The impacts of marine plastic pollution in the Arctic are, as in other areas, two-fold. First, the impacts on ecosystems need to be considered in order to assess the potential socio-economic impacts. Ecological impacts are often documented in a quantitative manner, while socio-economic impacts of marine plastic pollution in the Arctic have, at most, been discussed qualitatively. The way these types of data are collected introduces a layer of complexity in the evaluation of ecosystems from a social-ecological perspective.

### Interactions with biota, biological and ecological impacts

The interactions with biota, biological and ecological impacts will be considered and documented when possible at the suborganism, organism or individual, population, assemblage, habitat and ecosystem level. Impacts from and beyond the population level are considered ecological impacts. The different kinds of interactions between organisms and plastic particles and objects i.e., ingestion and derived toxicity, entanglement, transport of invasive species, vector of toxins and others will be considered and documented.

Documentation of interactions between marine organisms and plastic pollution has increased drastically over the past years (Ryan, 2015; Rochman 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, only impacts from and beyond the population level are considered ecologically relevant. For example, for some marine mammals and seabirds, even if it has been proven that the addition of debris to their habitats causes contamination via ingestion or entanglement there is, still, little evidence for this contamination being the cause of any ecological harm (Rochman et al., 2016; Galloway et al., 2017). These ecological impacts, less commonly documented, but in some cases proven, are the ones of ultimate concern. Even if the far-reaching implications of marine plastic pollution at systemic levels are still not widely understood, the associated hazards should be taken into account through the precautionary approach when considering responses aimed at achieving ecological sustainability (Rochman et al., 2016; Villarrubia-Gómez et al., 2017).

The synthesis below is organized following the different kinds of direct interaction of plastic debris and microplastics have with organisms in the Arctic, i.e., ingestion, entanglement and rafting, including the potential biological and ecological impacts. 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 pollution accumulates in the Arctic marine environment besides those covered under “Pathways and Distribution”.

**Ingestion**

The ingestion of plastic debris and microplastics has been documented in multitude of studies across the Arctic and its vicinity since the 1970s (see table 3.1). Plastic has been found in Arctic seabirds, 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 (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 (Trevail et al., 2015a; van Franeker and Law, 2015) and their high vulnerability to plastic ingestion due to their feeding habits (van Franeker et al., 2011). The residence time of plastic in the gastro-intestinal tract of northern fulmars is reported to be relatively short, with a 75% turnover within a month (van Franeker and Law, 2015), making plastic in the stomach contents 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., 2015c). Some caution should still be used when interpreting plastic ingestion data as the influence of the residence time of plastic in the stomachs of seabirds on the environmental conditions inferred from plastic stomach contents has been a subject of discussion (Ryan, 2015).

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). The methodology initially developed for monitoring the incidence of plastic pollution in the North Sea is now being used for the whole eastern North Atlantic as well as the western North Atlantic and the North Pacific, including observations within the Arctic region thus allowing relevant comparisons within and across Arctic regions. Some of the most recent examples of such extensive comparisons are included in the works of [Trevail et al., 2015a](#_ENREF_107); [van Franeker and Law, 2015](#_ENREF_115); [Avery-Gomm et al., 2017](#_ENREF_7); [Provencher et al., 2017](#_ENREF_86); [van Franeker, 2017](#_ENREF_113).

The latest comparison of standardized plastic content in northern fulmars (Avery-Gomm et al., 2017), which added data from the Labrador Sea to the existing dataset, further corroborates the decreasing northwards 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). Nevertheless, the occurrence of plastics in Arctic seabirds is surprisingly high for such a remote area. Out of the three regions, the Arctic areas northwards of the Eastern North Atlantic (Barents and Greenland Seas) are characterised by much higher levels of plastic presence in fulmars than in areas at the same latitude or further south in the Eastern North Pacific (Gulf of Alaska) and the Eastern North Atlantic (Northwestern Passages). While areas in the Barents and Greenland Sea show the highest values for high Arctic latitudes, likely due to 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) and release from melting sea ice (Obbard et al., 2014; Peeken et al., 2018) have been suggested as additional reasons for high levels of plastics in marine birds is the Arctic. The opposite is true for areas in the Northwest Passage which display the lowest values for the areas monitored through plastic content in northern fulmars (Avery-Gomm et al., 2017).

In addition, these standardized research efforts have allowed the assessment of temporal trends in the abundance of plastics in the surface if the North Atlantic over the last 30 years. 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 (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 in the marine environment (van Franeker and Law, 2015). The reduction of industrial plastics has also been detected through similar studies of short-tailed shearwaters (*Puffinus 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.

Recent literature reviews of plastic and microplastic in the European Arctic (Trevail et al., 2015a; Hallanger and Gabrielsen, 2018) collected information on the ingestion of plastic by three other seabird species, namely Brunnich’s guillemot or Thick-billed murre (*Uria lomvia*), little auk or dovekie (*Alle alle*) and black-legged kittiwake (*Rissa tridactyla*). Records for the common eider (*Somateria mollissima*) and the king eider (*S. spectabilis*) did not show eiders ingesting plastic. Literature reviews 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 Canadian and Russian Arctic, the Bering Sea and Alaska (see table 3.1), provide records of plastic ingestion to varying degrees for the common eider and fifteen other species. Trevail et al. (2015c) 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.

Our review of records of plastic ingestion by seabirds (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 evolution, with stable incidence, is better that the results of the global modelling carried out by Wilcox et al. (2015) that postulates the increase of incidence with 99% of the species affected by 2050. The review of the incidence of marine plastic debris on seabirds of the northeastern Atlantic (O'Hanlon et al., 2017), which includes some information derived from records from the Arctic and subarctic, concludes 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.

Our review also documents that the occurrence of plastics in surface-feeding species is two times higher than in pursuit-diving birds (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 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 of occurrence of plastics than kittiwakes (Table 3.2). This might be explained by the breeding strategies of two species: 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 driven by accumulation due to circulation (Poon et al., 2017). It can also be explained by the foraging strategies (surface seizing vs. pursuit diving) and areas of certain species (Provencher et al., 2014) as, for example, documented by the noticeable difference in frequency of occurrence of plastics between kittiwakes and storm petrels. In addition, 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 the chemicals added to plastic during manufacturing and/or absorbed to 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) 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) actually caused such impacts (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.

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) allowed it to be further concluded that plastics in the stomach of fulmars are more likely to act as a passive sampler of the persistent organic pollutants (POPs) that the fulmars receive through their diet despite previous indications that some PBDE and PCB congeners predominantly present in plastic 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 manufacturing besides being 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. This could still be the case for other polymers and other chemical additives and their degradation products reaching the environment only associated to plastics and that have so far not been studied (Ask et al., 2016).

*Marine mammals*

Data relative to the ingestion of plastic debris by marine mammals and sharks is mostly derived from dietary studies and anecdotal records of the presence of plastic in beached or stranded individuals (Table 3.3).

Regarding cetaceans ingested plastic debris have been recorded in individuals of sperm whales (*Physeter microcephalus*) and fin whales (*Balaenoptera physalus*) all of them caught in whaling operations off the eastern coast of Iceland. No other records have been found for cetaceans elsewhere in the Arctic. 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 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 with the largest one weighing 63 kg. This net was firmly stuck between the second and third stomach causing a potentially lethal obstruction through starvation but the authors postulate that the smaller items could easily be voided 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 the disease complex and a caused a lethal intestinal obstruction (Lambertsen and Kohn, 1987). Further, six out of 82 fin whales caught in summer 1985 had plastic material (plastic bags and small pieces of plastic sheeting) in their guts (Sadove and Morreale, 1990).

Plastic debris has been also found in the stomachs of bowheads (*Balaena mysticetus*) in Baffin Bay and the Beaufort Sea (Lowry, 1993; Philo et al., 1993; also in Finley, 2001).

*Fish and invertebrates*

Plastic debris (fishing gear or line) has been found in stomach analyses of Greenland shark (*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 of plastic ingestion (2.8% non-fibrous particles) has been 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).

The study of plastic ingestion by 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 susbtances associated to plastic like nonylohenol and bisphenol.

Besides this and the studies documenting ingestion for the Greenland shark there are no other Arctic specific studies documenting the ingestion of plastics by fish. 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. 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 Atlantic cod, Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*)), and could certainly also be exposed to plastic in polluted areas of the Arctic.

Ingested plastic has been reported for invertebrates on a few occasions as in blue mussels (*Mytilus edulis*) from Svalvard with 90% occurrence and an average of 9.5 items per individual (Sundet et al., 2016) and in 20% of snow crabs (*Chionoecetes opilio*) (Sundet, 2014).

Besides seabirds, marine mammals, sharks, fish, molluscs and crustaceans, some of commercial interest in the Arctic (Bråte et al., 2017), plastic and more concretely microplastic has been proven to be ingested by zooplankton both 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, at the base of most marine food webs. As for other larger organisms microplastic ingestion by zooplankton may have effects, so far demonstrated in laboratory conditions, such as gut-blockage increasing gut-retention times leading to reduced feeding (Cole et al., 2013), function and 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 bioacculumation of plastic associated toxic substances like persistent organic pollutants (POPs) to zooplankton and fishes is being researched, and while evidence is for now scant (Lohmann, 2017), if occurring at a rate relevant compared to the transfer from the natural diet of zooplankton or fish it will likely have additional adverse physiological effects.

Finally, it is worth mentioning that there are no studies in the Arctic focusing on the ingestion of microplastics by mesopelagic fish. 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, 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 the 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 the surface water feeding by mesopelagic fishes. Wieczorek et al. (2018) also highlighted the key role of mesopelagic fishes by constituting a substantial share of the biomass in the pelagic realm, providing an important food source for organisms high up in the trophic chain, including commercially relevant species and seabirds, and 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). While the abundance and diel migration range of Arctic mesopelagic fishes it is being investigated (Gjøsæter et al., 2017) the potential incidence and implications of microplastic ingestion by mesopelagic fish in the Arctic should be considered.

**Entanglement**

Entanglements of various species were documented in studies, most of which anecdotal (e.g. (Beach et al., 1976; Baba et al., 1990; June, 1990; Sadove and Morreale, 1990; Kapel, 1985 in Finley, 2001). 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) (Table 3.4).

*Pinnipeds*

Studies on entanglement of northern fur seals in Northern Pacific Ocean and Bering Sea prevail among others (Merrell, 1980; Scordino, 1985; Fowler, 1987; Fowler et al., 1990; Kuzin, 1990; Fowler et al., 1993; Kiyota and Baba, 2001). Main source of comprehensive data on entanglements of this period was the commercial harvest of fur seals from USA’s Pribilof Islands’ rookeries (Fowler et al., 1990) and Russian Commander Islands (Kuzin, 1990). Systematic monitoring ended with the application on bans of commercial seal hunting.

Rates of entanglement in the Bering Sea increased over time reaching maximum levels 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 feeding ground for seals. In 1984-1988 numbers of seals were decreasing along with the increase of fisheries- related debris in the waters of Pribilof Islands (Baba et al., 1990). On top of that, chances of entanglement where subject to change with the season and location, with the breeding season (May-October) in Pribilof Islands being the riskiest (Ribic and Swartzman, 1990). Juvenile male fur seals are 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, 2000) which in turn reduces foraging abilitiy. For the female fur seals it also impaires maternity care by shortening the length of feeding trips leading to pups gaining weight at a lower rate (DeLong 1988 in Fowler, 2000). The secondary effects are: vulnerability to predation, susceptibility to infections for wounded seals, retardation of growth of young seals (Scordino, 1985; Fowler, 2000) and mortality caused by drowning and starvation (Fowler, 2000; Kühn et al., 2015).

Levels of fatal entanglement of northern fur seals were not studied so entanglement related mortality remains uncertain (Merrell, 1980). Chance of survival of the entangled northern fur seal is less than 39%, and chances for death are increasing along with the size of entangling debris (Fowler et al., 1990). Nevertheless, 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). Still entanglements in ALDFG may cause the decrease of populations of pinnipeds and other species. It is estimated that population of western and eastern Aleutian northern (Steller’s) sea lions declined by half between 1957 and 1988 (Manville, 1990). 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 attributed to the parallel reduction of prey resources (Trites, 1992).

Entanglement has also been observed in Svalbard for several seal species, such as harbour seals (*Phoca vitulina*) and bearded seals (*Erignathus barbatus*) (Bergmann et al., 2017a).

*Cetaceans*

The signs of entanglement of cetaceans has also been documented 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 leat to mortality, specially for smaller individuals, there were no signs that this had an effect on whales population. 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 has been recently highlighted by Stelfox et al. (2016).

*Crustacea and fish*

Theshift from fishing gear made from natural to synthetically manufactured materials has resulted in the last years in the increase of “ghost fishing” which is the process by which abandoned, lost, or otherwise discarded fishing gear (often shortened to 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 couple of studies have looked into the impacts of this. Stevens et al. (2000) documented ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots in Alaska with an incidence of ghost fishing of the target species of 16% of the pots with an average of ca. 1 crab every 2 pots after excluding the maximum outliers. Still they concluded that the data on abundance of pots and number of crabs captured did not allow to draw conclusions on impacts without knowing more about ingress, egress and mortality.

Humborstad et al. (2003) documented on their study 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 gillnest continue to fish for long time and adding to the concern 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 of reindeers in fishing nets in the Aleutian Islands – Aluetian reindeer (*Rangifer tarandus*) (Beach et al., 1976) - and in Svalbard – Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and of polar bears (*Ursus maritimus*) (Bergmann et al., 2017a).

It is therefore clear that the effects of plastic ingestion and entanglement in the Arctic are confirmed and documented at the suborganismal and individual level. Nevertheless, 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. Only two studies have suggested population level effects for the northern fulmar *Fulmarus glacialis* (van Franeker et al., 2011) and the commercially important crustacean *Nephrops norwegicus* (Murray and Cowie 2011). The range of ecological niches that are vulnerable to plastic ingestion in the Arctic, however, highlight the potential for widespread vulnerability of Arctic ecosystems to detrimental effects of plastic pollution (Trevail et al., 2015a).

**Rafting of alien species**

Marine litter functions like natural floating debris, providing a means of travel for non-native – and potentially invasive - species (Barnes and Milner, 2005; Gregory, 2009; Mouat et al., 2010; CIESM, 2014), and is therefore increasingly recognised as a vector for invasive alien species (Watkins et al., 2015) including in Arctic waters (Barnes, 2002; Barnes and Milner, 2005). Marine plastic debris can act as a new pelagic habitat for microorganisms and invertebrates like bryozoans, barnacles, tube worms, foraminifera, corallinealgae, hydroids and bivalve mollusks. Marine litter’s increasing abundance and resistance to degradation contributes to an increased risk of invasions. 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 low temperature of the Arctic is the most important barrier to invasion by marine-borne alien organisms. However, with a warming of the Arctic Ocean and reduction in sea ice cover this barrier is weakened (Barnes, 2002). Of all collected plastic debris in 2002 in Kongsfjorden, Svalbard, 7% had individuals of the exotic barnacle *Semibalanus balanoides* and colonies of the bryozoan *Membranipora membranacea* (Barnes and Milner, 2005).

**Pathways for input and/or redistribution**

One last effect of the interaction between plastic pollution and organisms that is worth reviewing is the transport of plastic by organisms. 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) reports 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 effect of entanglement by nest incorporation is address in the previous section but certainly these birds contribute to the export and accumulation of floating plastic towards the coastal areas where they nest with likely local polluting consequences. The role of seabirds in “cleansing” surface water from plastic connected to feeding habits has also been addressed in studies of northern fulmars in the Bering Sea *[Note: look for reference]*.

Besides seabirds, all marine organisms have the capacity of shifting the location of 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, population size but will be especially relevant when the ingestion and defecation happen in different compartments (i.e., feeding at sea and defecating on land) or different locations within the same compartment (feeding in surface waters and defecating at depth). 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 the carbon cycling in the ocean by exporting carbon from surface to deeper waters through this mechanism (biological pump) and an analogous process could certainly affect plastic particle distribution in the water column. Further when plastic is released at depth it would be packaged in faecal pellets that would certainly behave differently from the individual particle in the water column further impacting its ultimate fate. While this is a process that has implications for the global ocean its role in highly productive waters of the Arctic, like the Barents Sea, in which surface plastic concentration is high needs to be considered.

### Socioeconomic impacts

The socioeconomic impacts of marine plastic pollution in the Arctic region will be considered in a qualitative conceptual way and by documenting any instances of impacts on maritime activities and the communities relying on those activities. This will include traditional subsistence foods provisioning for Arctic indigenous communities (i.e., whaling, marine mammal harvesting and hunting, waterfowl, shorebird and seabird hunting), commercial and subsistence fishing, aquaculture, shipping and coastal/ cruise tourism. Impacts on the well-being (health and economic) of the Arctic communities connected to these activities will also be documented where possible.

Bråte et al. (2017) briefly described the societal and economic impacts associated with marine plastic pollution in Nordic waters which are 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 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 pollution to these sectors.

Fishing and aquaculture can be impacted through different pathways. 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 impacts can only be determined when enough information of the true ecological impacts, i.e., at the population, assemblage or ecosystem level, are confirmed. Additionally, there could be impacts associated to reduced landings of seafood due to entanglement of marine debris with fishing gear or with fishing boats.

A number of indigenous communities are practicing and relying on traditional sealing (harp seal, ringed seal, northern fur seal). The potential decrease in population of these species, as well as shift of rookeries can have a negative impact on both cultural and economic parts of lives of indigenous societies. Though most of seal products (such as pelt, meat, oil) are produced and delivered to the market by commercial undertakings, some are harvested by private seal hunters for local consumption or for sale.

The impact of plastic to boats by, for example, fouling of propellers or cooling systems leading to mechanical problems, navigational hazards, and costs associated with repairs and down time and is a common potential impact with the whole of the shipping sector. The extent of this impact needs special consideration in the Arctic because damage to vessels with these exceptionally harsh and hazardous sailing conditions coupled with the difficulty of rescue operations here may present an additional hazard to human lives.

Plastic pollution has direct and indirect effects on the physical and 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, appeal which is easily worn down by visually explicit pollution such as the accumulation of debris on a barren coastline. The additional draw marketed with the pristine environment is the possibility of observing emblematic fauna linked to specific Arctic biodiversity, and in particular large fauna like cetaceans, seals, polar bears and birds. In this case, even if the impact at the ecological level were low because of relative low incidence, witnessing the suffering caused by marine plastic pollution on a single individual can have detrimental effects on the perception of the pristine nature of a tourist destination. The incipient and growing Arctic tourism and recreation sector may be affected if people are discouraged from visiting areas that are impacted.

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

To our knowledge, the MARP project ([www.marp.no)](http://www.marp.no)) is the only existing effort devoted to the assessment of socio-economic costs of marine plastic pollution in the Arctic and should produce some results by 2020.

## 4. Response and Monitoring

This subsection will collect information on solutions and actions aimed at curbing plastic pollution in the Arctic marine environment and the monitoring of the evolution of effective solutions.

### Arctic Actions and Solutions

As Section II will already include detailed information on existing governance and regulations, and in order to avoid duplication, this section will be mostly focused on documenting implemented or planned action and solutions. It will address actions and solutions driven by public and private actors rooted (or not) in existing regulations. Actions and solutions will be split into pollution prevention, pollution reduction and impact mitigation. If enough documentation is identified in each of these categories a subsection will be devoted to each of them.

As mentioned above a major course of action towards mitigating the effects of marine plastic pollution is in the form of coastal clean-ups organized at different scales and with varying degrees of means across the Artic.

Since 2006, the [NOAA Marine Debris Program has worked with partners to remove about 450 metric tons of marine debris from Alaskan shorelines](https://marinedebris.noaa.gov/alaska) while the Gulf of Alaska Keeper ([www.goak.org)](http://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 cleanups 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 2003 running volunteer cleanups and for example. 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).

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 on marine plastic pollution, a crucial requierement for engaging the society at large in addressing the marine litter challenge.

In 2016 under the framework of the [MARP Project](http://www.marp.no/) experts and fishermen from Norway, Russia and the UK studied some of the litter collected through the Clea Up Svalbard initiative in order to discern the sources and mode of entry of the dominant types of debris, identifying the dominance of fisheries-related waste and waste from other marine activities alongside with household related waste that could originate from land or sea (Nashoug, 2017). This lead 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](https://fiskeribladet.no/nyheter/?artikkel=55648) condemning the disposal of nets and other fishing equipment from any member vessel.

Another line of action that is already under implementation and progressively expanding is the “Fishing For Litter” program that started in Norway in 2016, following the OSPAR approach used in other countries of the northeast Atlantic for already 15 years. The program has 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 is targeted to address the challenges connected with fisheries related waste and ghost fishing gear. In 2016-2017, a total of 92 deliveries totalling to more than 118 metric tons were made in the harbours of Tromsø and Ålesund with more than 60% of it being fisheries-related waste (SALT Lofoten AS (SALT) et al., 2017).

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. Currently there is increasing focus on addressing marine plastic pollution from a preventive perspective through avoiding the leakage of plastic in the environment and avoiding the unsustaible use of plastic where possible. Artic states and communities are developing to different degrees strategies to address plastic production, consumption and waste management but to our knowledge there is no Arctic framework working on this direction.

### Monitoring

Ongoing national or international monitoring efforts covering the Arctic region will be compiled in order to have an understanding of the thematic and geographic scope of the tools available to monitor the evolution of marine plastic pollution in the Arctic.

Monitoring of marine plastic pollution is crucial for assessing the effectiveness of measures implemented.

Under the framework of OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic), 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 the stomachs of fulmars stomachs (OSPAR Commission, 2015) indicators, as part of its monitoring and assessment programme. These allow the abundance, trends and composition of marine litter in the OSPAR Maritime Area to be determined for different marine compartments (coast, seafloor and floating). OSPAR is also currently working to develop a new indicator on microplastics in sediments. Nowadays, there are 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 compostion of litter items. However, as most Arctic beaches have only recently been added to the monitoring network, the datasets do not yet sufficient temporal coverage for the calculation of statistically significant trends in the amounts of overall litter or individual litter items, although this will improve in the future. The monitoring of plastic particles in 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. As mentioned before this monitoring methodology has also been applied to monitor fulmars in the Northwest Atlantic and the Northwest Pacific allowing comparison within and across different regions of the Arctic (Avery-Gomm et al., 2017). Avery-Gomm et al. (2017) and Provencher et al. (2017) praise the use of standardized methods and the formal establishment of a monitoring scheme for the Northwest Atlantic following the OSPAR methodology to evaluate the success of plastic pollution mitigation efforts and progress towards environmental targets. Seabed litter data collected according to the OSPAR protocol is currently not available for the Arctic Region (OSPAR, 2017b).

To our knowledge there are no other extensive monitoring programs targeting marine plastic pollution in the Arctic. Based on the experience of Clean Up Svalbard, 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. This is of course an option for gathering information on marine plastic pollution in coastal areas when focusing on large plastic debris but of course when attempting to sample and gather information on microplastics specifically designed and implemented research programs are needed as the methodology for sample gathering and analysis is much more complex.

[A similar opportunity would be to use traditional ecological knowledge to supplement and/or complement monitoring schemes](https://blog.marinedebris.noaa.gov/marine-debris-work-alaskan-native-communities). As an example, in the US 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](http://www.north-slope.org/departments/wildlife-management/studies-and-research-projects/oceanography-and-sea-ice/oceanography-and-sea-ice-research/satellite-tracked-surface-drifters) (Weingartner et al., 2017). Similar local and traditional knowledge may be available and useful to gather and integrate from other communities in the Arctic. Inuit Hunters, for example, are monitoring plastic pollution and have increased concerns on impacts to subsistence species such as plastic in marine mammals and birds (ICC, pers. comm).

## 5. Gap Analysis

*[Note: work in progress and will be included in next draft]*

Each of the sections above could include a concluding paragraph on the knowledge gaps identified in order to have a good understanding of each of the themes addressed, but we would like to recommend including a subsection to jointly analyze the major knowledge gaps that would need to be addressed by future monitoring and research efforts in order to further guide and inform policy development.

The wealth of information on marine plastic pollution compiled in the previous subsections and the regional analysis that can be drawn from it shows that the systematic compilation and integration of data and information allows already for improved understanding of environmental status and impacts at the level of the Arctic region. Nevertheless this kind of compilation has not been formalized in the past at the level of the whole Arctic region and only some efforts have been done to compile information for parts of the Artic (Trevail et al., 2015b; Hallanger and Gabrielsen, 2018) or for larger regions like the Nordic region including part of the Artic (Strand et al., 2015).

*The analysis of the knowledge gaps below follows the structure of the literature review in section III.*

Regarding **drivers**, there is, to our knowledge, no specific socioeconomic assessment looking at indicators like population and plastic value chain data, including production, consumption and plastic waste generation, recycling and management for the region considered in this review, i.e. the Arctic watershed. As argued within section III.1 the compilation of information relative to the drivers of plastic pollution could constitute excellent proxies to identify **sources** of plastic pollution and their relative contribution as there is, yet, no direct comprehensive assessment of the plastic leaked to the Arctic. In stark contrast to the rest of the world, the assessment of human-driven input of plastic pollution in the Arctic from sea-based sources should be easier than the that of land-based sources due to the limited and geographically constrained 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.

Assessment of the input of marine plastic pollution by fishing, aquaculture and shipping activities based information reported by the operators within the sector is not exisiting and would be fundamental in understading the relative importance of local sourced pollution versus pollution brought to the Arctic by drifting waters. Assessment with high spatial and temporal resolution of the distribution of fishing, aquaculture and shipping intensity would allow gauging the likelihood for potential input of marine plastic pollution related to these activities which are known to represent major sources for local input allowing for a faster regional assessment in comparison with an assessment based on reporting. Similarly compilation of data on population density and distribution of population centers in conjunction with the capacity of waste management systems at the regional and local level would allow gauging potential for litter input connected to domestic solid waste management following the approach from Jambeck et al. (2015). The sparse distribution of population would likely allow the compilation of information on the distribution of waste management facilities, their capacity, condition and location relative to water courses or the coast at the level of the whole Arctic region. Compilation and analysis of data relative to transportation and logistics such as road and port network and traffic intensity on these would allow the identification of areas that are potentially receiving the input related to these activities.

As for **pathways** there is no observational data regarding riverine input of plastic pollution 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 no observations of plastic particle fluxes either suspended or as bed load is available for any of the major Arctic rivers and fresh water ecosystems (Halsband and Herzke, 2017). Modeling of the input of plastic carried out by Lebreton et al. (2017) is hindered in Arctic rivers by the lack of data on the hydrographic network and discharge used in this modeling approach which should be completed latitudes north of 60o N. Similarly to riverine input there is no data on the influx of plastic and microplastics 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) but better estimates of the total input would still benefit from further field data to measure concentrations of plastic particles in surface waters and in the water column. Similarly the flow of plastic debris from the North Pacific into the Bering Sea and the Gulf of Alaska and further into the Arctic Ocean through the Bering Strait is currently unkown.

The information already available on the **distribution and trends** of marine plastic pollution provides valuable understanding of the ubiquitous presence of plastic pollution in the different compartments of the marine environment but this is far from comprehensive. Beach litter data is restricted to the regions and sectors of the coastline which are either more densely populated or that have been identifies as hotspots for accumulation and being targeted by mitigation actions. The expansion of research on beached litter to more remote areas of the Arctic coastal environments like the shores of the Kara, Laptev, East Siberian and Chucktchi Seas on the eastern Arctic and the Beaufort Sea or the Northwestern Passages would improve understanding of presence, and likely sources, of pollution around the Arctic Ocean. Certainly the continued observations on beach plastics for those areas in which information already exists would allow establishing temporal trends.

Information on concentration on sea-ice is limited to two studies and further information on the concentration, accumulation processes and potential release due to sea ice melt would help understanding the implications of plastic pollution on sea ice. Further efforts into backtracking the trajectory of sea ide drift and understanding sea ice formation and scavenging of plastic particles into sea ice could help the understanding of the role of sea ice as a pathway for transfer of plastic pollution between different regions of the Arctic Ocean.

The data on the concentration of plastics on surface waters and in the water column it is also constrained to certain areas of the Arctic where research has been concentrated and there is no data, as for beached plastics, for the Kara, Laptev, East Siberian, Chuckchi Seas and the Beaufort or Northwestern Passages. Also high resolution but also long term series of the concentration of plastic on surface waters and in the water column is of crucial importance for understanding the processes controlling the fate of plastic in open waters, the influx of plastic pollution driven by circulation leading to accumulation zones like in the Barents Sea and potential interaction with organisms and the pelagic ecosystem.

Once more data on presence of plastic debris on the seafloor is limited to certain areas of the Arctic Ocean and research on plastics on the seafloor in other areas of the Arctic would illustrate if larger debris recorded through photography and video transects are also present in other parts of the Arctic. Research should concentrate on other Arctic areas where sea-based activities like fisheries and shipping are concentrated to ascertain the input related to these but also in remote areas to verify if drifting debris can eventually sink and pollute areas devoid of human activity.

The ultimate fate of marine plastic pollution in the Arctic marine environments, the sediments accumulating on the seafloor, should also be targeted by further research as knowledge is limited to very localized studies. Data on the distribution of microplastics in deep sediments in open waters can provide insight on the processes leading to the sedimentation of microplastics from the overlying water column, shed light on the processes driving it and point towards the areas in the Arctic that are more likely to represent sinks and hot spots for the accumulation of plastic pollution. Coupled studies monitoring processes in surface waters, including production and downwards export by measuring chlorophyll concentration, and aggregate forming processes like algal blooms enhancing water column particle fluxes would help understanding vertical transfer of microplastics.

The full understanding of plastic **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 information on interactions with biota only covers certain groups of organisms that are known to interact with plastic pollution and some additional due to anectodical 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 gaps on 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 kittiwake, it is still largely unknown to which degree other species do ingest plastic. The reviews of O'Hanlon et al. (2017) and Provencher et al. (2017) include recommendations for standardization of quantification of ingested debris based on the extensive monitoring efforts on northern fulmars and argues that if standardized methods are adopted, future plastic ingestion research will be better able to inform questions related to the impacts of plastics across taxonomic, ecosystem and spatial scales. Further van Franeker et al. (2011) and Provencher et al. (2017) recommend an optimal monitoring program for plastic pollution to be established in the western North Atlantic using northern fulmar as a biological monitor which would provide a means to evaluate the success of plastic pollution mitigation efforts and progress towards environmental targets, such as the EcoQO (OSPAR Commission, 2015).

Bråte et al. (2017), reviews the gaps regarding Nordic marine biota, which are extensive to the Arctic and highlights the lack of borad understanding of plastic and microplastic ingestion and effects on fish, organisms lower on the trophic chain like zooplankton and the urgent need for underatdning exposure and effects of microplastic pollution of bottom dwelling organisms as sediments seem to be the compartment where most microplastics are accumulating.

With regards to entanglement knowledge was abundant on pinnipeds during the 1980’s and 1990’s in the Bering Sea and Alaska but monitoring efforst have been reduced since. In the rest of the Arctic knowledge is fragmented and certainly covering only some groups or species like whales but certainly further efforst should be placed on researching the incidende of ghost fishing and impacts on the population levels of marine mammals.

Studies on interactions between biota and plastic in the Arctic have overall mostly focused on the interaction and effects at the individual level and therefore information on the effects at the population level are mostly missing for even the better studied species hindering the understanding of true ecological impacts of marine plastic pollution in Arctic.

Besides this also the understanding of the final fate pf plastic pollution in the Arctic and for example the influence that it has on the formation of aggregates, the sinking velocity of these aggregates an the effect that it may have on the population of groups like mesopelagic fishes is also limited and constitutes a major gap in the understanding of systemic impacts of marine plastic pollution.

To our knowledge there are no studies of the socio-economic impacts of marine plastic pollution in the Arctic. This is likely due to the fact that research on plastic pollution it is at its infancy leading to limited understanding and documentation of ecological effects and therefore also to the lack of targeted studies looking at the impacts on socio-economics that are caused by the direct presence of plastic in the environment i.e. loss of scenic value of tourist destinations or change of perception of seafood safety for human consumption.

# Section IV: Recommendations on Next Steps

* the reduction of litter from sea-based sources,
* the reduction of litter from land-based sources,
* the removal of existing marine litter from the marine environment (Fishing for Litter, removal of ghost nets (Norway best example), beach clean ups, etc.),
* Monitoring seems to be missing from this section or is it planned to address that under the proposal for an Arctic Action Plan?
* *Development of an Arctic action plan on marine litter* (e.g., <http://marinelitternetwork.com/global-projects/action-plans/>, OSPAR and HELCOM Regional Action Plans (both are based on the general structure of the Honolulu Strategy (<https://marinedebris.noaa.gov/solutions/honolulu-strategy>) agreed at the 5th International Marine Debris Conference), and
* education and outreach on the topic of marine litter.

# Section V: Conclusion

# Annexes

## Annex I: National Legislations

*[Note: A table summarizing national legistlations (rather than narrative descriptions and/or qualitative assessments) could be really useful here. For example, the United States could include its Marine Debris Act (*[*https://marinedebris.noaa.gov/about-our-program/marine-debris-act*](https://marinedebris.noaa.gov/about-our-program/marine-debris-act) *]*

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5. G.A. Res. 59/24 at para. 92(b). [↑](#footnote-ref-5)
6. G.A. Res. 60/30, para. 65 (29 Nov. 2005). [↑](#footnote-ref-6)
7. Id. at para. 66. [↑](#footnote-ref-7)
8. G.A. Res. 66/288, para. 163 (27 July 2012). [↑](#footnote-ref-8)
9. G.A. Res. 70/1, para 14.1 (25 September 2015). [↑](#footnote-ref-9)
10. UNEA Res. 1/6, paras. 14, 20 (27 June 2014). [↑](#footnote-ref-10)
11. UNEA Res. 2/11, paras. 11, 21 (27 May 2016). See also G.A. Res. 70/235 (23 Dec. 2015) at para. 312 (encouraging “States to further develop partnerships with industry and civil society to raise awareness of the extent of the impact of marine debris on the biological diversity, health and productivity of the marine environment and consequent economic loss, and encourages States to cooperate, as appropriate, to address marine debris and microplastics in the marine environment”). [↑](#footnote-ref-11)
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18. See Rep. Submitted to the Resumed Review Conference in Accordance with Para. 32 of Gen. Assembly R. 63/112 to Assist in Discharging Its Mandate under Art. 36, Para. 2, of the UNCLOS (May 2010), at paras. 124-129 for a description of those actions. [↑](#footnote-ref-18)
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