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

**2nd draft (20 Sep 2018): CLEAN**

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# Glossary

*[Note: to be added]*

# Background

Marine litter or anthropogenic marine debris, particularly when made of plastic, is amongst the most pervasive problems affecting the marine environment globally (UNEP, 2009; UNGA, 2012; UNEP, 2016). The United Nations Environment Programme defines marine litter as ‘any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment’ (UNEP, 2009).

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

On a global scale, plastics account for 73 percent of all marine litter (Bergmann et al., 2017a) though regional variations are large with plastic making up between 60 and 90 % of marine litter (UNEP, 2016). The remaining fraction is made of paper, wood, textiles, metal, glass, ceramics, rubber and any other material that does not degrade within days or months. Most of the attention placed on marine litter has been devoted to plastic items, particles and their fragments due to the fact that plastic is durable, i.e. degrades very slowly, light, i.e. has a density similar to water allowing it to be transported for long distances, animals interact with it in multiple ways and, it has or accumulates toxic substances.

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

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 leading to an estimated 4.6 to 12.7 million tonnes being added yearly to our oceans (Jambeck et al., 2015). While there is an increasing number of models attempting to gauge the contribution of plastic litter from land (Jambeck et al., 2015), including the contribution transported via rivers, (Lebreton et al., 2017; Schmidt et al., 2017) there is no recent global estimate of the contribution from activities at sea (i.e. fishing, shipping, aquaculture, etc.) and therefore it is impossible to accurately rank land-based 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.

Even if the Arctic coastal region is sparsely populated and has limited terrestrial transport and industrial infrastructure, maritime activity in certain areas of the Arctic Ocean is intensive due to the numerous rich fishing grounds and growing shipping routes providing the most cost-effective goods transportation within and across the Arctic region. In addition, as for any other part of the world’s ocean, marine plastic pollution in the Arctic is not only a result of the pressure resulting from activities within the Arctic seas or its coastal areas but also linked to input arriving from inland areas through rivers and from remote oceanic areas through global oceanic circulation. The logical result of the combination of these pressures is that marine litter, including plastic debris and microplastics, is also present and threatens the Arctic marine and coastal ecosystems and its services.

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 (GPA) for the Protection of the Marine Environment from Land-Based Activities, and as such provides a framework for addressing the main pollution source categories and responding to the global concerns. Marine litter is one of eight contaminants or effects of land-based activities of concern in the GPA and in the Arctic RPA.

The seven remaining are persitant organic pollutants (POPs), heavy metals, physical alteration and destruction of habitats, radionuclides, petroleum, hydrocarbons, sewage and nutrients and sediment.

[Paragraph on the history of the development of the PAME marine litter project that has led to the development of the desktop study]

# 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;

With the aim to:

* + - 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 geographic scope

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 litter, marine plastic litter, marine plastic debris, 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. 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 litter* 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. 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.

* **Definition:**Marine debris, also known as marine litter, has been defined as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (UNEP 2009).
* **The geographic scope** in this report is based on the Arctic Ocean Review (PAME, 2013) Report i.e.: *The marine area the project covers the central Arctic Ocean, and in addition, the surrounding seas: the Bering Sea, the East Siberian Sea, the Chukchi Sea, the Beaufort Sea; the Northwestern Passages, Hudson Strait and Hudson Bay; the Baffin Bay, Davis Strait and Labrador Sea; the Greenland Sea, the waters around Iceland and the Faroe Islands, and northern parts of the Norwegian Sea; the Barents Sea, the Kara Sea, and the Laptev Sea.*

The map of the 18 Arctic Large Marine Ecosystems (LMEs) below, as adopted by the Arctic Council at the Kiruna Ministerial Meeting in 2013, is used to illustrate the geographical coverage.



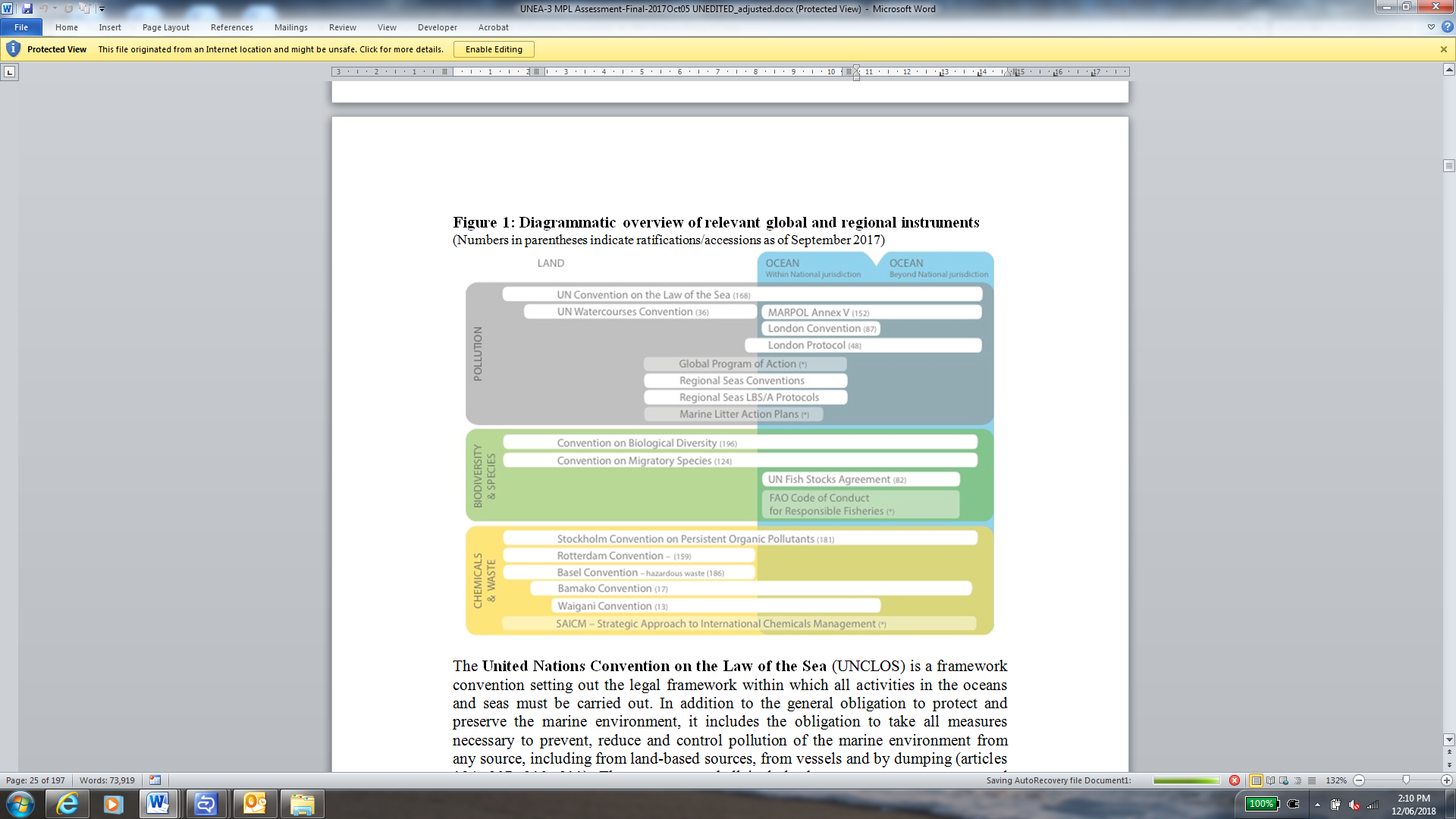
|  |  |  |
| --- | --- | --- |
| **Nr.** | **Name of LME** | **Area**  **(million km2)** |
| 1 | Faroe Plateau LME | 0.11 |
| 2 | Iceland Shelf and Sea LME | 0.51 |
| 3 | Greenland Sea LME | 1.20 |
| 4 | Norwegian Sea LME | 1.11 |
| 5 | Barents Sea LME | 2.01 |
| 6 | Kara Sea LME | 1.00 |
| 7 | Laptev Sea LME | 0.92 |
| 8 | East Siberian Sea LME | 0.64 |
| 9 | East Bering Sea LME | 1.38 |
| 10 | Aleutian Islands LME | 0.22 |
| 11 | West Bering Sea LME | 0.76 |
| 12 | Northern Bering-Chukchi Seas LME | 1.36 |
| 13 | Central Arctic LME | 3.33 |
| 14 | Beaufort Sea LME | 1.11 |
| 15 | Canadian High Arctic-North Greenland LME | 0.60 |
| 16 | Canadian Eastern Arctic-West Greenland LME | 1.40 |
| 17 | Hudson Bay Complex LME | 1.31 |
| 18 | Labrador-Newfoundland LME | 0.41 |

*Figure X:*

Because of the interconnectivity of the world oceans, as well as the buoyancy of items such as some plastics and processed wood, marine litter within the Arctic could originate from virtually anywhere in the ocean and therefore we should consider the whole world as a potential source for litter in the Arctic. Of course, areas in the immediate vicinity of the Arctic marine areas should be considered as most likely potential source areas, especially the North Atlantic and the North Pacific. 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 litter found within the Arctic marine areas should be considered.

In turn, marine litter found within the Arctic marine areas could theoretically originate from any point within the Arctic watersheds 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 Arctic marine environment.

# Section III: Applicable Governance Frameworks



## I. International Concern Embodied in Publications and Resolutions

Since its inception, the Arctic Council has been involved in efforts to address the issue of marine litter, a matter of growing international concern. In 1998, the Arctic Council adopted the Regional Programme of Action for the Protection of the Arctic Marine Environment from Land-Based Activities (RPA).[[1]](#footnote-2) 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-3) 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-4) PAME amended the RPA and released the updated version on 29 April 2009.

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

The 2017 Fairbanks Declaration of the the Arctic Council Ministerial (Fairbanks, Alaska) noted “with concern the increasing accumulation of marine debris in the Arctic, its effects on the environment and its impacts on Arctic communities, and decide[d] to assess the scope of the problem and contribute to its prevention and reduction, and also to continue efforts to address growing concerns relating to the increasing levels of microplastics in the Arctic and potential effects on ecosystems and human health”.[[4]](#footnote-5)

Within the wider international community, the United Nations General Assembly (UNGA) has requested and organized substantial efforts to focus the international community’s attention on developing national and international strategies to address marine litter. [[5]](#footnote-6) United Nations Environment Programme (UNEP; 1972) and United Nations Environment Assembly (UNEA; 2012) have played leading roles in those efforts. Notably, 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 UNGA 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.”[[6]](#footnote-7) 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.”[[7]](#footnote-8)

Recently, the UNEA has requested that the U.N. Environment Programme Executive Director produce two reports and “an assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches to combat marine plastic litter and microplastics.” [[8]](#footnote-9) Additionally, in 2017, the UNEA called for an ad hoc open ended expert group “to furtherexamine the barriers to, and options for, combating marine plastic litter and microplastics from all sources, especially land-based sources.”[[9]](#footnote-10)

## II. International Instruments

### There are a variety of international instruments relevant to marine litter, including general obligations to protect the marine envirionment, specific obligations to prevent pollution, and obligations to promote biodiversity. UNEP has recently examined many of those instruments.[[10]](#footnote-11) Below, we provide a brief overview of several of them.

### A. UNCLOS

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) sets forth the legal framework within which all activities in the oceans and seas must be carried out and is of strategic importance as the basis for national, regional and global action and cooperation in the marine sector.[[11]](#footnote-12) The Convention entered into force in 1994, and 168 States are parties to it. UNCLOS is an umbrella agreement which serves as a framework for corresponding implementing acts, e. g. the International Convention for the Prevention of Pollution from Ships (MARPOL).

Part XII of UNCLOS addresses the preservation of the marine environment. Under Article 192, States have a general obligation to protect and preserve the marine environment. 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.”[[12]](#footnote-13)Provisions particularly relevant address the difference sources of marine litter are Articles 207, 210, and 211.

Article 207 stipulates to “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.

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.[[13]](#footnote-14) 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.”[[14]](#footnote-15) In response, States and Regional Fisheries Management Organizations have taken some actions to address lost or abandoned fishing gear.[[15]](#footnote-16) [*If we have data on removals/reductions in lost gear, include reference here.*]

### B. MARPOL

The International Convention for the Prevention of Pollution from Ships (MARPOL) addresses pollution of the marine environment by ships, including accidental pollution and 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. Another Protocol, adopted in 1997 and entered into force in 2005, amended the Convention to include the new Annex VI. There are currently 152 Contracting Parties. 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 for the discharge of sewage into the sea. 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 disposal from ships into the sea of all forms of plastic, such as “synthetic ropes, synthetic fishing nets and plastic garbage bags.”[[16]](#footnote-17) Thus, MARPOL regulations focus on the flow of plastic from ships to sea, but they do not address land-based sources of marine debris. However, MARPOL Annex IV and V are optional, *i.e.*, they have to be ratified separately and States may opt not to be bound by either of them.

The International Code for Ships Operating in Polar Waters (Polar Code), which entered into force on 1 January 2017, reiterates the requirements of MARPOL Annex IV and V and adjusts them to the special circumstances of ships operating in polar waters. This contains for example additional obligations that are equivalent to, and even exceed, the requirements that apply in Special Areas under Annex V.

In most parts of the Arctic the necessary infrastructure for adequate port reception facilities (PRF) for ship-generated wastes is still lacking (PAME 2009) and significant differences exist between ports. The Arctic Council has recognized the importance of improved waste management in Arctic ports, and is currently exploring options for regional arrangements on reception facilities to ensure compliance with Polar Code requirements (PAME 2017b).

### C. London Convention and London Protocol

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters from 1972 (London Convention) and the Protocol to the Convention from 1996 (London Protocol) require Contracting Parties to take effective measures to prevent pollution of the marine environment caused by dumping at sea.

The London Convention applies a listing-approach in which the dumping of Annex I listed substances is prohibited, thereby allowing the dumping of Annex II substances, after a prior special or general permit has been issued.[[17]](#footnote-18) 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.”[[18]](#footnote-19) The Convention does not apply to accidental discharges, such as those incidental to routine operations, or to discharges from land-based sources.

The London 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 establishes a “reverse listing approach” which prohibits all dumping except those wastes or other matter described in Annex 1 of the Protocol, and also stipulates the application of the polluter pays principle.[[19]](#footnote-20) The London Protocol is a treaty that entered into force internationally in 2006 and is intended to ultimately replace the Convention. Fifty States are parties to the London Protocol.

The Parties to the Londong Convention and London 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.

A recent study undertaken within the framework of the IMO concluded that it is currently impossible to make general statements on the litter content of either sewage sludge or dredged materials with regard to litter types, properties and quantities. It was outlined that further studies need to be conducted for assessing microplastic contamination in these substances (IMO 2016, Review of the current state of knowledge regarding marine litter in wastes dumped at sea under the London Convention and Protocol). In addition, in April 2018 the IMO Marine Environment Protection Committee agreed to include a new output “Development of an action plan to address marine plastic litter from ships” in the 2018-19 biennial agenda of the Committee.

### D. Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal 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 wastes, which covers a wide range of wastes based on their origin and/or composition and characteristics, and other wastes, inlcuidng household waste and incinerator ash. One hundred and eighty-six States are parties to the Basel Convention. Parties are required to minimize waste volumes and ensure the availability of disposal facilities for the environmentally sound management of hazardous and other wastes.[[20]](#footnote-21) The Convention covers plastics containing listed hazardous wastes, such as cadmium and PCBs, and plastics from household waste.

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.[[21]](#footnote-22) The Ban Amendment has not yet been ratified by three-fourths of the Parties who accepted it 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.[[22]](#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.[[23]](#footnote-24)

### E. The Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) aims to protect human health and the environment from POPs, defined as organic chemicals that remain intact in the environment for long periods, bioaccumulate in humans and wildlife, have harmful effects, and have the potential for long-range environmental transport. The Stockholm Convention entered into force on May 17, 2004. The Convention has been ratified by 182 Parties.

Parties are required to prohibit and/or eliminate the production and use, as well as the import and export, of intenaionlly produced POPs listed in Annex A to the Convention (Article 3). Parties are also required to restrict the production and use, import and export of intentionally produced POPs listed in Annex B (Article 3), and reduce or eliminate releases from unintentionally produced POPs listed in Annex C (Article 5).

The Convention also establishes the Persistent Organic Pollutants Committee, composed of experts, to examine proposals for the listing of additional chemicals (Article 8).

As of 2018, 28 POPs are listed under the Convention. Several of these POPs, including PCB, DDT, and dioxins, are often detected in marine plastic litter.

### F. The Convention on Biological Diversity

The Convention on Biological Diversity entered into force on 29 December 1993, and 196 States are parties to it. 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.[[24]](#footnote-25) Article 6 of the Convention, 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 of the Convention, 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.[[25]](#footnote-26) 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.”[[26]](#footnote-27) In December 2016, at the 13th Meeting of the Conference of the Parties (COP), the COP adopted Decision XIII/10 “Addressing impacts of marine debris and anthropgenic underwater noise on marine and coastal biodiversity.”[[27]](#footnote-28)

### G. UN Watercourses Convention

The Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention) provides a framework for the governance and management of international watercourses. Article 7 of the Convention imposes upon Watercourse States the obligation to “take all appropriate measures to prevent the causing of significant harm to other watercourse States.” The Convention entered into force in August 2014. There are currently 36 Parties to the Convention.

Article 21 of the Convention 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 Regional Programs

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.”[[28]](#footnote-29)

The U.N. Environmental Programme’s Regional Seas Programme 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.[[29]](#footnote-30)

Through the Regional Seas Programs, the Global Partnership on Marine Litter, and Action Areas, UNEP has supported (and continues to support) the development of regional and national action plans on marine litter. At present, there are several regional action plans in existence and several that are in progress. The regional action plans include: the OSPAR Commission’s Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic (2014), the Baltic Marine Environment Commission’s (HELCOM) Regional Action Plan for Marine Litter in the Baltic Sea (2015), the Regional Plan on Marine Litter Management in the Mediterranean (2013), the Regional Action Plan on Marine Litter Management for the Wider Caribbean Region (2007), the Coordinating Body on the Seas of East Asia’s (COBSEA) Regional Action Plan on Marine Litter (2008), and the Southeast Pacific Regional Programme for the Integrated Management of Marine Litter (2007), and the Northwest Pacific Regional Action Plan on Marine Litter (2008). These plans are non-binding; however, they may correlate with binding agreements.

In general, the plans identify actions to minimize inputs from sea-based and land-based sources of marine litter; promote actions to remove existing litter from the marine environment; support education and outreach efforts to increase public awareness, promote better commercial and recreational fishing practices, and promote collaboration among governments, private industry, and non-governmental organizations; and identify ways to monitor and assess the marine environment and the efficacy of these actions to minimize impacts from marine litter. In addition, some of the plans contain specific actions to be accomplished within timelines. For example, the OSPAR Commission’s Regional Action Plan includes a list of over fifty actions organized by each of its themes (e.g., actions to combat sea-based sources), the lead party for implementing each action, and the time frame for implementation.

The plan’s action may also relate to obligations under other instruments. For example, OSPAR’s contracting parties are directed to ensure regional coordination on the implementation of EU Directive 2000/59/EC[[30]](#footnote-31) in connection to MARPOL Annex V ship generated waste.[[31]](#footnote-32)

The Coordinating Body on the Seas of East Asia’s Regional Action Plan on Marine Litter is also illustrative of a typical regional plan. It contains a list of six general actions:

Action 1: Preventing and reducing marine litter from land-based sources;

Action 2: Preventing and reducing marine litter from sea-based sources;

Action 3: Preventing and reducing lost and abandoned fishing gear;

Action 4: Mitigating the impacts of marine litter;

Action 5: Raising awareness of marine litter; and

Action 6: Monitoring and assessing marine litter.

The COBSEA’s Regional Action Plan then breaks each action into parts or activities, such as encouraging and assisting countries to promote integrated management systems for major municipal areas and coastal towns and villages and, similar to OSPAR, supporting MARPOL Annex V. Finally, for each activity, the plan includes a table of the timeline for implementation, the entity with responsibility for doing so, and the estimated cost.

*Left to write:* [Discussion of gaps within regional seas program

1. Some of the Arctic Council states participate in regional action plans, but most of the Arctic’s marine environment is not covered.

# Section III: Literature Review

*Note:* The guiding paragraphs in blue at the beginning of each subsection should be removed once it is agreed that the subsection is covering what it should. The inclusion of more detailed proxy information and data still needs to be discussed as even if recommended during the workshop there is no time/budget to actually do this. Maybe some of it can be included in the maps in a coarse manner.

## 1. Sources and Drivers

[Introduction to potential sources of marine litter. 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 litter 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 first 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). 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.

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/leakage mechanism by which plastic raw materials, components, objects and/or their fragments leave the intended lifecycle through the supply chain, regular use and waste stream. 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 items or their fragments become litter but also their mode of entry or pathway into the environment (Veiga et al., 2016).

When plastic objects are already within the marine environment at the time that they leave this intended cycle, the pathway of entry is either very short (i.e., a wave washing over the deck of a boat where objects are not secured or a wind gust taking a plastic bag left behind on a beach) or nil (i.e. fishing gear being disposed, 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 litter 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. Although some of the debris collected during beach surveys can be easily singled out as unequivocally originating from certain sea-based sources (mostly fisheries), this is not the case for other 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 plastic litter from either land or sea. They concluded that, on the basis of the world ratios of vessels per coastal inhabitant, sea-based sources of plastic litter in the Arctic region must be particularly relevant in relation to the land-based sources. Similarly, Tekman et al. (2017) used the number of ships calling at Lonyearbyen harbour and the number of cruise passengers as a proxy of ship traffic and cruise tourisms in the area.

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 litter 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 and offshore resource exploration. 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 potential discharge of plastic materials contained in offshore chemicals (Moskeland et al., 2018) .

**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; Weslawski and Kotwicki, 2018). Besides ALDFG, the use of fishing gear always involves wear and tear that will lead to fragments or pieces of the gear being released in the ocean. For example, in bottom fishing during each haul, nets loose large quantities of attached dolly ropes aimed at protecting the net from abrasive ground contact (e.g. Murray and Cowie, 2011).

Classification of the objects collected during beach surveys in Svalbard established that between 44 and 100% of the mass of litter collected was contributed by fisheries-related items (Bergmann et al., 2017a). Fisheries-related objects are large and relatively dense and therefore their relative mass contribution will always be large in comparison to the number of objects collected. 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 may have been used on trawlers or by other sea- and land-based industries. Trawling-related gear tends to predominate in the surveys either because trawling has a higher rate of gear loss than other fishing methods, or 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, originated from Norway, Denmark, Spain, United Kingdom, Iceland and Faroe Islands providing an indication of the fleets active in the region (and contributing to litter), although crates also tend to circulate among vessels from different countries. 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). The analysis of 43 fishing nets collected during clean-ups in Svalbard during the summer of 2017 revealed that almost all of these fishing nets were parts of nets that had been replaced by new parts after they got damaged during fishing operations. Since these repairs have most likely taken place on board fishing vessels where the replaced parts could have been otherwise stored, the chances of these nets having been deliberately discarded at sea are quite high. Many of the nets exceeded 10 square metres, some more than 20 (Strietman et al., unpubl. data).

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



*Figure #. Litter items with readable inprints collected from a beach of the Hinlopen Strait, Svalbard Archipelago (Credit: M. Bergmann, AWI).*

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 tsunami in Japan is also detected (Polasek et al., 2017). Trawl net fragments (ropes, nets, floats, straps, etc.) were the primary type of litter, the number of which kept increasing from year to year, with the highest quantity of 216 fragments/km in Little Tanaga Island (Johnson, 1990). Beach litter studies carried out in Amchitka Island in 1972 (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 one 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 shores 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 especially 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 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. 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. While Canada is the second largest producer amongst the Arctic nations, concentrating also on salmonids and shellfish, this is largely due to production in British Columbia, well south of the Arctic region, and only 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**

[Under shipping sources, consideration is made regarding sources connected to all types of ships except fishing vessels that were consireded separately above.This category includes all kinds of materials and goods transporting ships, offshore industry ships and passanger ships including cruise tourism ships.]

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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. Common houselhold items (food, cleaning and personal higyene products, etc.) are part of the waste genereated onboard vessels. When this type of litter is found at sea, it is virtually impossible to determine whether the release occurred in a vessel or on land.

Nashoug (2017) reports that a large amount and variety of household plastics (bottles and containers for beverages, ketchup, hygiene and laundry products, etc., see also Fig. #) 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 release from either fishing, merchant or cruise ships plausible. Also, large-sized food containers could indicate their release being connected to the galleys of larger vessels.

In addition to the discard or loss of solid domestic waste or other activity related waste i.e. packaging or securing materials, the discharge of greywater, sewage and/or sluge could also contribute microplastics from cosmetics or microfibers from textiles and clothing – although the exact contribution is yet unknown. Furthermore the discharge of processed (comminuted) food waste can also lead to leak of plastic debris and microplastics if waste separation is not adequately carried out.

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 allow a monthly and yearly analysis of shipping intensity allowing assessments of seasonal and long term variability in inputs.

**Offshore resource exploration and exploitation**

In addition, and although the limited knowledge about microplastic from oil and gas extraction activities is not fully conclusive (Moskeland et al., 2018), its contribution should be certainly considered in future source assessments. Moskeland et al. (2018) identified through their study of the Norwegian continental shelf that highest microplastics concentrations are in general found at locations close to Oil & Gas installations. 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 and wastewater 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 generally low population densities in Arctic coastal areas, the localized 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; settlements not covered by any waste collection schemes; remoteness, meaning lack of connection with network of large (regional or national) waste management systems; and lack of or deficient local waste management systems, may lead to locally high inputs linked to industrial or domestic waste management.

In small Arctic communities, solid waste collection and disposal is very basic. Recycling and baling facilities are rare and generally limited to larger communities. Collection in very small communities is typically by self-haul while larger communities often use community-haul systems (Warren et al., 2016). Traditional waste management solutions are uncontrolled waste dumps, sometimes along the shoreline, and simple incinerators with no or limited flue gas treatment (Kirkelund et al., 2017). This has been documented to be the case for example in Greenland (Eisted and Christensen, 2011) and in Iqaluit in the Canadian Arctic (Samuelson, 1998). Inadequate or lacking wastewater treatment further contributes to the waste management problem as wastewater often contains traces of personal care products and many other contaminants originating from both households and industrial facilities (Gunnarsdóttir et al., 2013). Sewage and waste water treatment is generally lacking in the Arctic, resulting in a continuous discharge of sewage and waste water from households, hospitals and smaller industries directly to the coastal waters (Granberg et al., 2017). Magnusson et al. (2016) investigated effluent water from the Klettagarđar waste water treatment plant receiving waste water from the city of Reykjavik. The treatment is mechanical consisting only of a coarse grid that retains mainly larger debris. The authors found that around 6 million microlitter particles (≥ 100 µm) were released per hour into the sea from this waste water treatment plant. In the same study, effluent water from six Nordic wasterwater treatment plants were investigated and the efficiency of different treatment systems compared. Large quantities of microplastic fibers shed from washing synthetic textiles (de Falco et al., 2017), which are particularly frequently worn in the cold polar regions, will reach the marine environment as mechanical treatment will not capture these.

There are very few studies looking specifically at the leakage and marine input of plastic debris linked to Arctic waste management systems but ongoing work to quantify and characterize beach litter (Kirkfeldt, 2016; Strand and et al., in prep.) points towards potential input from inadequate waste management on the western shores of Greenland where 90% of the Greenlandic population is concentrated. The composition of the waste accumulated in western Greenland survey sites resembles the composition of surveys carried out in the Skagerrak region where the influence from higher population density along the coastline is 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 an imprint of intense fishing activities was registered (Strand, 2018). To this respect it is important to note that high quantities of microplastics were detected in land-fast sea ice from Northeast Greenland (4.1 × 106 N m−3) (Peeken et al., 2018), the majority of which was polyethylene, a major component of packaging material. Obbard et al. (2018), in her review of microplastic in polar regions, also points towards other potential origins of microplastic particles and microfibers like clothing, disposable diapers, cigarrete filters and marine industry.

In addition, a study looking into microplastics in the vicinity of Reykjavik, Iceland (Dippo, 2012) has reported exceptionally high concentrations of small plastic fragments and microplastics from a sandy beach near Reykjavik harbor. Though not specified in this report, 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 into 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 of the regions within the Arctic that need more attention to this potential source of plastic pollution. Of course, information on the quality of sewage treatment plants and waste management systems, i.e., coverage of waste and wastewater collection schemes, distribution of waste transfer and management facilities and dumpsites and their standards, would allow further inferences to be drawn on the potential and intensity of release. Jambeck et al. (2015) used national average values for waste mismanagement to estimate the contributions at the national level but due to the singularities of the Arctic, it would be desirable to use higher-resolution information 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 plastic waste transportation, the distribution of goods, including plastic in any of its intermediate forms (pellets, powders etc.) before it is incorporated or turned into a product, can lead to 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. Because of 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-use plastic 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 mitigation.

## 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 (land-based sources). Under pathways only influx involving a fluid flow (continuous or intermitent 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 million 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. In addition, the waste water generated by remote Arctic populations may be characterised by low population equivalents such that their effluents undergo only low or mostly no sewage treatment at all resulting in (micro-)plastic leakage into water courses connected to the Arctic Ocean. The leakage may even increase when areas with combined sewage and stormwater sewer systems are not capable to receive large volumes of wastewater during severe rainfalls and allow an overflow of untreated sewage and polluted stormwaters into receiving surface waters. In these occasions the overflow may not only contain microplastics but even meso and macroplastics (Axelsson and van Sebille, 2017).

Lebreton et al. (2017) and Schmidt 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 in the global database used and therefore this global model does not include the plastic input from Arctic rivers. The relative importance of plastic input through Arctic rivers should be further considered in the light of the facts outlined 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 currently 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 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 in the Arctic region (Halsband and Herzke, 2017). However, microplastics were detected in all of the snow samples taken from drifting sea ice in the Fram Strait and Svalbard with up to 10,000 microplastic particles per liter snow, indicating atmospheric transport and fallout as a prime pathway (Bergmann et al., in prep.).

**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 lower (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 out that the significance of various pollutant transport routes does not depend only on absolute mass fluxes but also on bioaccumulation in marine food chains as will be discussed later.

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

### Distribution

[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). It should be borne in mind that the 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 subsection.

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 was estimated to correspond 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 4,196 kg/km but only 63 kg/km on the southeastern shores of Chukchi, lower than previously observed in the southern Bering Sea. While the shores of parks facing the Gulf of Alaska are directly exposed to inputs resulting from intense fishing and shipping activities in the Gulf of Alaska and northeastern Pacific, the shores of the southeastern Chukchi Sea receive fewer inputs due to much lower local fishing and shipping activity and only limited input related to drifting of debris drifting from the Bering Sea northwards into the Arctic Ocean through the Bering Strait.

In the OSPAR region beach litter is monitored at 17 sites within the Atlantic Arctic with 36 surveys conducted in 2017. The amount of beach litter varied from a mean of 1475 items per 100 m (14,750 per km) in the spring to 195 items per 100 m (1,950 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 185 to 1,354 kg/km, with the exception of a site where density reached a maximum value of 7,331 kg/km due to the presence of a heavy fishing net in the area surveyed (Bergmann et al., 2017a). As on the shores of the Gulf of Alaska, Bering and Chukchi Seas, fisheries-related plastic litter dominated the litter composition on Svalbard’s beaches accounting for 48 to 100% of the mass. This dominace has also been reported out of the study by Weslawski and Kotwicki (2018) carried out on west the coast of Prins Karl Forlandet (westernmost island of Svalbard archipelago). Surveys on the northwestern tip of Iceland revealed lower densities of litter, mostly plastic, with an average of 1,040 items/km corresponding to an average of 104 kg/km originating mostly from Icelandic fisheries (Kienitz, 2013). Surveying according to the OSPAR beach protocol 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 30 items/km in the East. Analysis of the type of objects collected reveals the dominance of local sources, i.e. mismanaged domestic waste or Barents/Greenland Sea fisheries over long-range transport, especially for west Greenland.

**Sea ice**

Observations of 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 revealed even higher concentrations of microplastics in sea ice reaching maximum values of 1.2 ± 1.4 × 107n/m3 in pack ice in the Fram Strait and minimum values of 1.1 ± 0.8 × 106n/m3 just north of Svalbard. These concentrations are several orders of magnitude higher than those of Obbard et al. (2014), likely due to different methodology used, and further confirm that sea ice is an important temporary sink of plastic pollution. The second highest concentration was recorded in landfast ice, which was formed locally off east Greenland highlighting a contamination of east Greenland surface waters at the time of ice formation. However, back-tracking of the other ice cores showed that microplastics were likely entrained into the ice in the Kara and Laptev Seas and the central Arctic Ocean and transported to the south with the Transpolar Drift. In addition, the differences in the amounts and composition of microplastic in different depths of the cores point to strong local differences in microplastics present in seawater during the process of ice formation.

**Surface and sub-surface waters**

Information on 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 are available (Bergmann et al., 2016) while the smaller fractions are studied through the use of surface samplers, water pumps and stomach content analyses of the seabird *Fulmarus glacials* or northern fulmar (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 of 0.333 - 0.5 mm and therefore sampling mostly microplastics (<5 mm) and mesoplastics) decreased from the Subarctic North Pacific towards to the Gulf of Alaska and the Bering Sea (Table 2.2). However, concentrations in the Bering Sea seem to have increased from the 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 in the Atlantic Arctic in 2014 (0.34±0.31 n/m3, Lusher et al., 2016). Cózar et al. (2017) recorded surface concentration of plastics in parts of the Norwegian and Barents Sea to have a median value of 0.063 n/m2 in 2013. 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 medians 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 recorded in the Barents Sea (0.32 n/m2; Cózar et al., 2017).

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

Scattered information from subsurface water samples (Lusher et al., 2015; Sundet et al., 2017) could not provide any insight on the vertical distribution of microplastics near the surface. The increase of plastic 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 Cózar 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 recet study by Peeken et al. (2018) somehow challenges this notion or rather points to further pathways, i.e. southwards drift of particles from the Central Arctic to the Fram Strait with the Transpolar drift. The Fram Strait may harbour such high quantities of litter and microplastic because of (1) increasing local sources, (2) transport N->S (Transpolar Drift, engaging also pollutants from the Pacific and rivers) and (3) transport S->N (thermohaline circulation). Van Sebille et al. (2012) and Cózar et al. (2017) did not really consider the transpolar drifts in their models and regarded the ice as a barrier more than a source.

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

**Water column**

Data on the concentration of plastic within deeper parts of the water column to gain insight on the three-dimensional distribution of plastics in the Arctic or even other parts of the ocean is 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 (Lusher et al.2016). Morgana et al. (2018) reported values for the Northeastern Greenland Sea very similar the values reported by the previous two studies in nearby regions confirming the ubiquitous presence in the Greenland Sea and Fram Strait.

Kanhai et al. (2018) showed a vertical distribution of microplastic abundance (n/m3) in the Arctic Central Basin as follows: Polar Mixed Layer (0–375) > Deep and bottom waters (0–104) > Atlantic water (0–95) > Halocline i.e. Atlantic or Pacific (0–83) and confirmed the presence of microplastics in the central Arctic Ocean, that they are being transported downwards out of the surface waters and that the water column constitutes on of the reservoirs of microplastics in the region. Using large volume pumps and uFTIR imaging techniques, Tekman et al. (in prep.) detected higher mean microplastic concentrations of 510 n/m3 at the sea surface and 190 n/m3 at 300 - 2500 m water depths in the eastern Fram Strait, indicating that higher abundance of microplastics and presence throughout the water column in this region of the Arctic marine environment. The similar density of most plastic polymers to that of seawater (GESAMP, 2015) and aggregate formation processes (Kanhai et al., 018) warrants its efficient dispersal through the water column.

**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). 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 items or debris per square kilometre.

Concentrations of litter on the seafloor of the Greenland Sea at the deep-sea observatory HAUSGARTEN based on photo transects (Bergmann and Klages, 2012; Tekman et al., 2017) have revealed a surprising increase in litter concentrations between 2002 and 2014, and especially at the northern station of the observatory where concentrations of litter increased 23-fold from 346 objects per km2 in 2004 to 8082 objects per km2 in 2014. Addition of more recent surveys and more stations revealed yet a 29-fold increase over time at the northern station (2016: 10358 ± 2117 objects per km2) (Parga-Martinez et al. in prep.) Buhl-Mortensen and Buhl-Mortensen (2017) carried out an extensive study of marine litter on the seafloor of the Barents and Norwegian seas and reported background density values of 202 and 279 items/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 temporal differences as a number of surveys by Buhl-Mortensen and Buhl-Mortensen (2017) were conducted before 2011 when litter densities were still low at HAUSGARTEN, too. Alternatively, in addition to Atlantic inputs HAUSGARTEN may receive litter transported from the Central Arctic to the south via the transpolar drift. The study carried out by Grøsvik et al. (2018) included data from bottom trawls and provided weight of litter by seafloor area averaging 26 kg per km2 with 66% of this corresponding to processed wood while plastic litter accounted for more than 11% of the total but dominating the number of observations (2.9 kg per km2).

Through trawl sampling and in some instances through photo/video transects it is often possible to recognize objects or fragments of objects that allow tracing them to the potential sources 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. At HAUSGARTEN, however, most of the items were plastic film fragments, which could not be clearly attributed to any particular source.

Due to the scarcity of information and lack of a formal monitoring program within the Arctic, it is difficult to assess trends on marine plastic pollution over time but Bergman and Klages (2012) and Tekman et al. (2017) indicate that the abundance of plastic in the Arctic seafloor is increasing as is the amount of smaller items.

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

Plastic particles have also been identified in some of the beach sediment samples collected in several locations in Svalbard (Sundet et al., 2016; 2017). The sample containing the largest number of particles (111 n/l) was taken at the high-water mark or wrack line where plastic particles may be washed off during largest waves or the last high tide and accumulate temporarily. On the other side of the Arctic, another recent study (Whitmire and Van Bloem, 2017) identified between 40 and 130 pieces of plastic per kg of dry sediment collected at 6 different national park beaches bordering the Gulf of 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 reaching several thousands of particles per litter or kilogram of sediment. This emerging trend would need to be confirmed through studies using a targeted approach and homogenous methodology. Both Woodall et al. (2014) and Bergmann et al. (2017b) postulate that the deep sea could be an area for preferential accumulation of small plastic particles constituting a large sink of the plastic that has entrained the ocean during the last decades. Bergmann et al. (2017b) also explores the linkages between the presence of the sea ice margin, including the role of the formation of algal aggregates during ice margin production blooms, and the highest concentration of plastics (6595 n / kg sediment) of all the studied sites . This possibility is further emphasized by the potential role of the 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 litter and microplastic in the Arctic are, as in other areas, multiple and complex. Litter and microplastics in the environment impacts biota, habitats and ecosystems. When litter is found in the same areas where human activities are carried out it also causes direct socio-economic and cultural impacts. In addition impacts to the natural environment may also lead to further socio-economic and cultural impacts. The severity of the resulting socio-economic impacts will depend on which ecosystem service is affected and how fundamental for the functioning of the ecosystems are the processes disrupted by the presence of litter and microplastics. Some studies are already focussing on the impacts to the natural environment in the Arctic while the resulting socio-economic impacts have, at most, been discussed qualitatively.

### Interactions with biota, biological and ecological impacts

[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 (Kühn et al., 2015; Lusher, 2015; Ryan, 2015; Rochman et al., 2016; Werner et al., 2016; Provencher et al., 2017) covering impacts at the suborganism, organism, population, assemblage, habitat and ecosystem levels. Though impacts have often been demonstrated at the suborganismal levels, impacts from and beyond the population level will be the most 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 harm through entanglement there is, still, little evidence for this contamination having an impact on their population (Rochman et al., 2016; Galloway et al., 2017). The extensive study on the impacts of marine litter (Werner et al., 2018) concludes that the monitoring of impacts on biota is challenging and that linking evidence of the substantial numbers of individuals affected by marine litter and microplastics to negative effects on populations is difficult and not possible to date for most affected species. Small scale studies have nevertheless shown that plastic pollution can modify marine assemblages (Green et al., 2016) and there is growing evidence that marine plastic pollution, in combination with other anthropogenic stressors, represents a substantial challenge to marine biodiversity, ecosystems and its services. As with many other anthropogenic stressors quantifying the ecological effects of marine plastic pollution in isolation is challenging but that is not conclusive with the lack of impact.

Similarly within the Arctic region there are, so far, no studies demonstrating the interaction and impact beyond the organisms level. Still, even if the far-reaching implications of marine plastic pollution at systemic levels are still not widely documented and understood, it is important to recognize that the policy decisions on responses aimed at preserving biodiversity, ecosystem services and achieving ecological sustainability could be based on already documented evidence of harm herein (Rochman et al., 2016; Villarrubia-Gómez et al., 2017).

The synthesis below is organized following the different kinds of direct interaction that plastic debris and microplastics have with organisms in the Arctic, i.e., ingestion, entanglement and rafting. In addition, it also considers the implications of the interactions in terms of constituting additional pathways for input and/or redistribution and providing for one last reservoir or matrix in which plastic 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 a multitude of studies across the Arctic and its vicinity since the 1970s (see table 3.1). Plastic has been found in Arctic seabirds (on which most studies are focussed), 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, and distribution across the northern Hemisphere allowing for standardized comparisons to be made (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, according to some studies, relatively short, with a 75% turnover within a month (van Franeker and Law, 2015). If this is so plastic in the stomach contents of northern fulmars is a relatively robust indicator of local pollution levels. If sampling is carried out shortly after migration, the amount of plastic in the stomach contents may be an indicator of plastic pollution in their foraging areas along their migratory pathway but this will not mask the trends in multiyear datasets of geographically distinct regions (van Franeker et al., 2011; Trevail et al., 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 and accurate measures of ingested plastic retention times are needed to better understand temporal and spatial patterns in ingested plastic loads within marine organisms (Ryan, 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) and has meanwhile been established as an OSPAR Common indicator. The methodology initially developed for monitoring the incidence of plastic pollution in the North Sea is now being used for the areas of the eastern North Atlantic, of the western North Atlantic and of the North Pacific where northern fulmar is found. This includes of course observations within the Arctic region thus allowing relevant comparisons within and across Arctic regions. Some of the most recent examples of such extensive comparisons, including data from within and outside the Arctic region, are included in the works of [Trevail et al., 2015a](#_ENREF_107); [van Franeker and Law, 2015](#_ENREF_115); [Avery-Gomm et al., 2017](#_ENREF_7); [Provencher et al., 2017](#_ENREF_86); and [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 northwards decreasing trend in plastic contents in the Eastern North Atlantic, Western North Atlantic and Eastern North Pacific (Kuhn and van Franeker, 2012). Therefore, northern fulmars foraging in the Arctic contain less plastic in comparison with those which breed and forage closer to highly developed and populated areas further south (e.g., comparative studies of Day et al., 1985; Provencher et al., 2014; Trevail et al., 2014; Amelineau et al., 2016; Avery-Gomm et al., 2017). 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 northern fulmars than in areas at the same latitude or further south in the Eastern North Pacific (Gulf of Alaska) and the Eastern North Atlantic (Northwestern Passages). Increased sea-based human activities (Kuhn and van Franeker, 2012), good connectivity through ocean circulation to areas further south in the Atlantic Ocean (Trevail et al., 2014; Trevail et al., 2015a; Cózar et al., 2017), release from melting sea ice (Obbard et al., 2014; Peeken et al., 2018) and overwintering in the North Alantic during the non-breading season (reference needed) have been suggested as reasons for high levels of plastics in marine birds is the Arctic.

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 (Provencher et al., 2017). Despite a complex pattern with strong variability in the abundance and mass of total plastics, dominated by user plastics (fragments of plastics of multiple origins), a clear 75% reduction of industrial plastic particles (pre-production pellets) in the stomach content of northern fulmars in the North Sea has been recorded. This reduction has also been detected in floating particles in the North Atlantic gyre over time proving that measures implemented to reduce the leakage of pellets to the ocean can lead to a reduction of plastic particles 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. However, the most recent [assessment of Plastic Particles in Fulmar Stomachs](https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/marine-litter/plastic-particles-fulmar-stomachs-north-sea/) was undertaken in 2017 as part of OSPAR’s Intermediate Assessment. Since the early 2000s, levels of plastic ingestion by northern fulmars in the North Sea appear to have stabilised at around 60% of individuals exceeding the 0.1 g level of plastic ingestion which no reduction trend in the total plastic load to be observed.

Recent literature reviews and studies of plastic and microplastic in the Atlantic sector of the Arctic (Provencher et al., 2014; Trevail et al., 2015a; Poon et al., 2017; Hallanger and Gabrielsen, 2018) collected information on the ingestion of plastic by three other seabird species, namely Brunnich’s guillemot or thick-billed murre (*Uria lomvia*), little auk or dovekie (*Alle alle*) and black-legged kittiwake (*Rissa tridactyla*) (table 3.1). Records for the common eider (*Somateria mollissima*) and the king eider (*S. spectabilis*) did not show eiders to be ingesting plastic. The systematic review of literature dating back to the 1980s and 1990s (i.e. Day et al., 1985; Robards et al., 1995), and devoted to seabirds elsewhere in the Arctic, including the Russian and Canadian High Arctic, the Bering Sea and Alaska (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 is coherent with the single genus study carried out by Bond et al. (2013) that showed no significant trend over time in the frequency of plastic ingestion by common and thick-billed murres while the number of pieces and mass by individual fluctuated from highest in the 1980s, lowest in the late 1990s, and intermediate in contemporary samples. The review of the incidence of marine plastic debris on seabirds of the northeastern Atlantic (O'Hanlon et al., 2017) 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). As suggested by Avery-Gomm et al. (2013) and Poon et al. (2017) this might be explained by the breeding strategies of the two species: northern fulmars feed in areas further from their breeding ground and almost twice as large as feeding areas for kittiwakes, which allows them to reach areas with higher plastic concentration driven by accumulation due to circulation. Provencher et al. (2014) also highlighted the influence of the foraging strategies (surface seizing vs. pursuit diving) and areas of certain species 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. The lack of studies connecting the effects with exposure to plastic does not mean that they are not there as this have been postulated to be the case for southern latitude studies of northern fulmar. During a mass mortality of northern fulmars in the North Sea in 2004, several indicators suggested a background of hormonal disturbance, which could well be related to persistent high levels of chemicals, some of which may have derived from plastics, circulating in their bodies during a period of prolonged food shortage (Van Franeker et al., 2011). After a long period of population growth, the trend seems to have stopped or reversed since late 1990s and reproductive success is at present frequently poor. Werner et al. (2016) point that many factors are involved in these developments, but reduced adult survival and reduced reproductive output as a consequence of plastic ingestion are population effects that will play a role contributing to the population trends.

Still further research is neded on this area as the studies by Trevail et al. (2014), Ask et al. (2016) and Herzke et al. (2016) that specifically targeted the relationship between toxic substances and the abundance of plastic in northern fulmars from the Faroe Islands and Norway seem to indicate otherwise. 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 stomachs of northern fulmars are more likely to act as a passive sampler of the persistent organic pollutants (POPs) that the northern fulmars receive through their diet despite previous indications that some PBDE and PCB congeners predominantly associatied with plastic due to adsorption compared to overall diet could be transferred to seabird tissues (Yamashita et al., 2011; Tanaka et al., 2013). Except for DDTs and other pesticides, all of these substances are added to plastics during their manufacture 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 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. 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. The authors postulated that the smaller items could easily be expelled with the bones and squid beaks at periodic regurgitations. In 1982, a plastic bucket was found in the intestines of a sperm whale caught close to the Icelandic shore. This sperm whale was in poor condition and the authors argue that the bucket could have contributed to 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).

Anecdotic occurrence of plastic debris in the stomachs of bowheads (*Balaena mysticetus*) from Baffin Bay and the Beaufort Sea was also recorded in the 90’s (Lowry, 1993; Philo et al., 1993; also in Finley, 2001).

In recent years the incidence of lethal impacts linked to ingestion of marine debris by cetaceans has been often reported and covered by the media like the case of a sperm whale (*Physeter microcephalus*) stranded on the Norwegian west coast near Bergen in February 2017. Unfortunatelly most of these incidents have not been the subject of published research studies with some exceptions as it is the case of the stranding of two other individuals of the same species on the coast of northern California (Jacobsen et al., 2010). In one of them the emaciated body condition the animal was found in suggested starvation following gastric blockage, as it was suggested for the one found near Bergen, while for the other gastric rupture following impaction with debris was presumed to be the cause of death. The incidence of ingestion of marine debris by sperm whales has also been documented after the necropsies of individuals stranded along the coast of the North Sea in February 2016 (Unger et al, 2016). Marine debris including netting, ropes, foils, packaging material and a part of a car were found in nine of the 22 individuals. While none of the items was responsible for the death of the animal, the findings demonstrate the high level of exposure to marine debris and associated risks for large predators, such as the sperm whale. The sperm whale, the largest of the toothed whales, has a cosmopolitan distribution, with a large latitudinal range, travels long distances (Whitehead, 2003) and it is commonly sighted, for example, in the Norwegian Sea north of the Lofoten Islands (Halpin et al., 2009).

*Fish*

There are very few studies that have documented the ingestion of plastic by fish in the Arctic. Plastic debris (fishing gear or line) has been found in stomach analyses of Greenland 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 (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). A recent study by Morgana et al. (2018) investigated the presence of microplastics in two mid-trophic level Arctic fishes collected off Northeast Greenland, the pelagic polar cod (*B. saida*) and the demersal bigeye sculpin (*Triglops nybelini*), finding different proportion of ingestion among the species, 18% for *B. saida* (n = 85), substantially higher incidence than for the juvenile individuals sampled in Svalbard by Kühn et al. (2018), and 34% for *T. nybelini* (n = 71). The significant difference in the occurrence of microplastics between the two species is likely a consequence of their feeding behavior and habitat reflecting the ingestion of sinking mcroplastics by the demersal bigeye sculpin. The study of Atlantic cod (*Gadus morhua*) from the Norwegian coast by Bråte et al. (2016) confirms the low or no incidence of plastic ingestion in two more Arctic locations (Lofoten Islands in the Norwegian Sea and Varangerfjorden in the Barents Sea). Additionally Koelmans et al. (2014) conclude that in the case of plastic ingestion by Atlantic cod this does not constitute a significant pathway for exposure to susbtances associated to plastic like nonylphenol and bisphenol.

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

There are currently no studies in the Arctic documenting ingestion of microplastics by fish age classes that predominantly occupy the mesopelagic layer. Mesopelagic fish inhabit the disphotic zone of the pelagic realm (200-1,000 m depth) from the Arctic to the Antarctic with many species undergoing diurnal vertical migrations in the water column by residing at depth during the day before migrating to the surface at night to feed (Gjøsaeter and Kawaguchi, 1980). Smaller mesopelagic species feed on zooplankton while the larger ones feed on decapods and fish, and can thus be exposed to microplastic and plastic ingestion through direct consumption or by feeding on zooplankton or other organisms that had already consumed plastics (Wieczorek et al., 2018). Wieczorek et al. (2018) investigated microplastic incidence in mesopelagic fish of the Northwest Atlantic and documented presence of microplastics in the gut of 73% of all fish, amongst the highest reported for gut contents of fish and much larger than in a similar study in the North East Atlantic (11%) (Lusher et al., 2016) and North Pacific Subtropical Gyre (9.2%) (Davison and Asch, 2011). Wieczorek et al. (2018) attributed the high values to methodological differences with previous studies but also to the fact that the study was carried out in a hot spot for microplastics and mesopelagic fish alike. The study further concluded that colour, size, shape and composition similarities in microplastics found in mesopelagic fishes and those collected in surface waters of the same zone are attributable to surface water feeding by mesopelagic fishes. Wieczorek et al. (2018) also highlighted the key role of mesopelagic fishes by constituting a substantial share of the biomass in the pelagic realm, providing an important food source for organisms high in the trophic chain, including commercially harvestable species and seabirds, 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 is being investigated (Gjøsæter et al., 2017) the potential incidence and implications of microplastic ingestion by mesopelagic fish in the Arctic should be considered.

There are no specific studies on the impact of ingestion of plastics by fish in the Arctic Ocean but the impact of microplastic ingestion by fish has been documented by other studies that recorded the bioaccumulation of chemicals and associated health effects (Rochman et al., 2013) that certainly deserve consideration in the Arctic context.

*Invertebrates*

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).

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

Although microplastic ingestion by zooplankton has not been documented in the Arctic, several studies have shown this can occur in natural conditions, for example in the Northwest Pacific and the coastal waters of Southeast Alaska and British Columbia (Desforges et al., 2015), and in laboratory experiments (Cole et al., 2013). Microplastic ingestion by zooplankton may have far-reaching implications (Galloway et al., 2017; Villarrubia-Gómez et al., 2017) due to the role of this group, together with phytoplankton, at the base of most marine food webs. As for other larger organisms microplastic ingestion by zooplankton may have negative effects, as demonstrated in laboratory conditions, such as gut-blockage, increasing gut-retention times leading to reduced feeding function (Cole et al., 2013), and 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 but evidence is for now scant (Lohmann, 2017). The review by Lohman (2017) did nonetheless highlight that microplastics are possibly and important transfer vector other plastic aditives like flame retardants into marine organisms.

**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 were 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 ability. For the female fur seals it also impairs maternity care by shortening the length of feeding trips leading to pups gaining weight at a lower rate (DeLong 1988 in Fowler, 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 lead to mortality, especially for smaller individuals, there were no signs that this had an effect on whale populations. In a more recent study looking at non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) Neilson et al. (2009) concluded that the large majority of humpback whales in northern South East Alaska had been entangled but that most whales apparently shed the gear on their own. The lack of cetacean entanglement studies in the Arctic has been recently highlighted by Stelfox et al. (2016).

*Crustaceans 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 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 these impacts. 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 catch of one crab for every two 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 gillnets 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 barren ground caribou (*Rangifer tarandus granti*) in fishing nets in the Aleutian Islands (Beach et al., 1976) – and in Svalbard – Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and of polar bears (*Ursus maritimus*) (Bergmann et al., 2017a).

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

Despite the high abundance of (micro)plastic on the seafloor little is currently known about its impacts on biota. Sixty-six percent of the litter items observed on the seafloor of the HAUSGARTEN observatory were in some way interacting with epibenthic megafauna Encounters were of several kinds: (1) many litter items were entangled in emergent sponges such as *Cladorhiza gelida*, cf. Pachastrellidae, *Caulophacus arcticus*. While some sponge colonies were dead, this cannot be linked with certainty to entanglement; (2) Litter items also served as hard substratum in this soft-sediment environment and were often colonised by sea anemones including cf. *Bathyphellia margaritacea* and Hormathiidae, sea lilies *Bathycrinus carpenterii,* calcareous tube worms and hydrozoans. This affects the local biodiversity and ecosystem function. In addition, (3) litter may also affect infaunal communities inhabiting sedimentary environments, as items lying on the sediments intercept nutrients needed by them and interfere with the exchange of oxygen at the sediment water interface. Still, although the seafloor is considered the final sink for litter, nothing is known about such effects but one study in an Irish beach environment were plastic bags created anoxic conditions within the sediment, reduced primary productivity and organic matter and significantly lower abundances of infaunal invertebrates after nine weeks altering biodiversity and the ecosystem services that infaunal biota provide (Green et al., 2015). Microplastic has been detected in various deep-sea organisms including sea cucumbers and even be preferentially ingested in the laboratory (Graham & Thompson, 2009). Microplastics were also detected in deep-sea starfish *Hymenaster pellucidus* from the Rockall Trough (Courtene-Jones et al., 2017), which also inhabit HAUSGARTEN. Given the enormous concentrations of microplastic in Arctic deep-sea sediments (> 6500 N/kg sediment; Bergmann et al., 2017) and sea ice (12 000 N/ m3; Peeken et al. 2018) it is reasonable to assume that the rate of encounter between organisms and microplastics will be high leading to interaction and likely disturbance.

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 non-indigenous 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 only Arctic specific study looking at the northward dispersal of species by rafting on marine litter was carried out at the western coast of Svalbard and documented large objects (fishing boxes, containers) colonised by barnacles (*Semibalanus sp.*), gooseneck barnacles (*Lepas sp.*), blue shells (*Mytilus sp.*), bryozoans and marine macro-algae (Weslawski and Kotwicki, 2018). The authors concluded that the rafting of groups of adult organisms favours their better biological dispersal compared to larval transport, and is regarded here as the main reason for reappearance of genus Mytilus on Svalbard.

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

Another 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 addressed in the previous section, but it is likely birds can contribute to the export and accumulation of floating plastic in localized coastal areas. Locally 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]*.

Other marine organisms also have the potential for redistributing plastic particles through ingestion and defecation. The influence of this process in the distribution of plastic in the ocean will certainly depend on the amount ingested, population size but will be especially relevant when the ingestion and defecation and/or regurgitation happen in different compartments, i.e., feeding at sea and defecating on land (Provencher et al., 2018) 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.]

Werner et al., (2016) and Bråte et al. (2017) described the societal and economic impacts associated with marine plastic pollution in European and Nordic waters which are mostly analogous to impacts in the Arctic. These impacts are mainly linked to the economic sectors using the Arctic marine ecosystems, namely the fishing and aquaculture, shipping, and tourism and recreation sectors 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 which besides bearing the costs are at the same time potential sources.

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 economic impacts can only be determined when enough information of the ecological impacts at the population, assemblage or ecosystem level, are confirmed. Additionally, there could be impacts associated to reduced landings of seafood due to direct physical interaction with marine litter. Lost or abandoned fishing gear, parts of it and other debris, floating around or lying on the seafloor can get caught in fishing nets, decreasing catch capacity, or its quality by polluting it, and affecting hydrodynamics.

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 indigenous seal hunters for local consumption, cultural use, sale and/or securing food supply.

Potential impacts for sectors relying on marine transportation (fishing, shipping, energy and tourism) include fouling/blockages of propellers, cooling systems or other systems relying in seawater pumped into the vessel leading to mechanical problems, navigational hazards, and costs associated with repairs and down time. The extent of this impact needs special consideration in the Arctic because damage to vessels in harsh and hazardous sailing conditions coupled with the difficulty of assistance and rescue operations 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. Additionally, visitors to the Arctic expect the possibility of observing emblematic fauna linked to specific Arctic biodiversity, and, in particular, large fauna like cetaceans, seals, polar bears and birds. Witnessing the suffering caused by marine plastic pollution on individual animals or media attention on the matter can have detrimental effects on the perception of the Arctic region as an undisturbed destination. The incipient and growing Arctic tourism and recreation sector may be affected if people are discouraged from visiting impacted areas.

Plastic pollution is having an effect on the cultural practices and the harvest of food of communities living in the Arctic. Examples of this are commercial fishing line entanglement on harvested marine mammals and the presence of plastic debris on culturally used areas. Marine plastic pollution is also identified as a driver of food insecurity. For example, communities identify sanitation and waste systems (such as landfills) as contributing to food insecurity because they impact the marine environment integrity and its biota (ICC Food Security Report 2016).

An economic cost that is already occurring is that of cleaning up Arctic shores, something which is normally borne by the public sector, civil society and individual citizens. Information on clean-up programs will be provided in the next sub-section but 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 addressing the assessment of socio-economic costs of marine plastic pollution in the Arctic and should produce some results by 2020.

## 4. Monitoring and Response

[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.]

### 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 prioritization of measures and assessing the effectiveness of measures implemented. Besides harmonized monitoring set-up, in order to achieve comparability with areas that are potential sources of litter to the Arctic, the environmental litter data infrastructure should allow easy data exchange, processing and evaluation.

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 northern fulmars’ stomachs (OSPAR Commission, 2015). Those are common indicators as part of its monitoring and assessment programme. These allow the determination of the abundance, trends and composition of marine litter in the OSPAR Maritime Area for different marine compartments (coast, seafloor and floating). OSPAR is pioneering the development of a new indicator on microplastics in sediments. Currently, 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 northern fulmars has been carried out more exhaustively in the North Sea where the method was originally developed and where multiyear temporal series are available, although data for certain periods is available for the Faroe Islands, Iceland and Svalbard. As mentioned before, this monitoring methodology has also been applied to monitor northern fulmars in the Northwest Atlantic and the Northwest Pacific allowing comparison within and across different regions of the Arctic (Avery-Gomm et al., 2017). 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).

OSPAR is also contributing to the EU Technical Group on Marine Litter, where standardized monitoring protocols are developed (or further developed from existing ones) to assist European Member States in the implementation of the Marine Strategy Framework Directive (JRC, 2013). These monitoring protocols are currently subject to revision in order to harmonise monitoring approaches applied by the different Regional Seas Conventions with relevance to European waters and it is recommendable that the Arctic region, which already contributes to this process through some of the EU Member States, follows up on this process in order to use comparable methods to generate comparable data.

From the discussion above it is clear that most of the monitoring efforts have been so far placed on acquiring coastal, mostly beach, data. Only monitoring of plastic content in the stomach of northern fulmars has develpped to an extent that allows temporal and geographic comparison and to which seafloor data and microplastics on sediments are nowadays being added. The compilation of information on this desktop study makes it obvious that there is quite a lot to learn from monitoring surface water and sea ice presence of plastics, a consideration to be made when further developing monitoring strategies aimed towards assessing progress in tacking marine litter and plastic pollution.

Finally monitoring strategies and programmes should be developed in an adaptive manner. Actions to combat this challenge are being designed continuously based often on the precautionary principle and addressing specific geographic or value chain hot spots which may bring the need to develop specific indicators to assess progress towards the objective pursued by the action.

### 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 and reduction and impact mitigation. If enough documentation is identified in each of these categories a subsection will be devoted to each of them.]

The literature search and review has not turned in any references dealing specifically with actions to address marine litter and plastic pollution in the Arctic. Specific actions to address marine litter within the Arctic that are looking into pollution prevetion and reduction are addressing sea-based sources and have resulted from research projects focused on understanding the drivers and release mechanisms linked mostly to fisheries which is one of the sectors of activity identified as a major local contributor.

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 Clean 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 as a result of inadequate waste management (Nashoug, 2017). This led to enhanced awareness among the fisherman operating in the Barents Sea. The Norwegian Fishermen’s Association, the Fishing Industry Union of the North, the Association of coastal Fishermen and Fish Farmers in Murmansk, and Fisheries Iceland produced a [joint statement](https://fiskeribladet.no/nyheter/?artikkel=55648) condemning the disposal of nets and other fishing equipment from any member vessel.

Representatives of the Saami Council proposed a new project, Clean-up of the Saami territory in the Murmansk Region, for consideration at the April 2018 meeting of the Arctic Contaminants Action Programme. The project, which is expected to begin following conclusion of the formal ACAP project approval process, will involve both the inventory and eventual collection and proper disposal of land-based waste in this part of the Saami territory. There may be possibilities for conducting comparable work in the territories and remote settlements of other Arctic Council Permanent Participants and indigenous peoples of Arctic nations. There also may be value in promoting coordination among the leads for this ACAP project and researchers interested in learning more about possible marine litter sources in particular geographic areas.

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

Moving towards more end of the pipe, a major course of action towards mitigating the effects of marine litter 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 1994 running volunteer cleanups. 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).

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

The project “Hreinsum Ísland” is a coastal cleanup project that is managed by Landvernd the Icelandic Environment Association in association with the Blue Army. The objective with the project is to draw attention to the problem with marine litter pollution and get individuals, groups and enterprises involved by signing up for voluntary beach cleanups at [hreinsumisland.is](http://hreinsumisland.is/).

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

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, 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 an increasing focus on addressing marine plastic pollution from a preventive perspective through avoiding the leakage of plastic in the environment and avoiding the unsustainable use of plastic where possible. Arctic 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.

## 5. Gap Analysis

[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 Arctic (Trevail et al., 2015b; Hallanger and Gabrielsen, 2018) or for larger regions like the Nordic region including part of the Arctic (Strand et al., 2015).

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 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, resource exploration and exploitation, and shipping activities based information reported by the operators within the sector is not exisiting and would be fundamental in understanding the relative importance of local sourced pollution versus pollution brought to the Arctic by currents. Assessment with high spatial and temporal resolution of the distribution of fishing, aquaculture, resource exploration and exploitation, 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. This regional assessment for sea-based sources would certainly benefit from reporting from the different sectors regarding discharge of wastewater and comminuted food waste. To complete the picture of potential drivers of input of litter and plastic in the marine environment a map of the distribution of oil and gas instalations in the Arctic could point at point source hot spots in case a contribution from this sector would be identified.

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. Similarly the coverage (or lack of coverage) of populations centers by sewage systems, and the location, capacity and degree of treatment of wastewater treatment plants should also be mapped to gauge potential input linked to deficient wastewater treatment. 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 plastics 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 unknown.

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 Chukchi 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 in 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 ice 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 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, Chukchi 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 available information on interactions with biota only covers certain groups of organisms that are known to interact with plastic pollution and some additional due to anecdotical records. Information on ingestion is well developed for seabirds as they are known to interact and be impacted at the individual level. Knowledge on ingestion by seabirds has led to the identification of 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 kittiwakes, 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) review the gaps regarding Nordic marine biota, which are extensive to the Arctic and highlight the lack of broad understanding of plastic and microplastic ingestion and effects on fish, organisms lower on the trophic chain like zooplankton and the urgent need for understanding 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 efforts 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 efforts should be placed on researching the incidence 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 the further reaching ecological impacts of marine plastic pollution in Arctic.

Future models and experimental settings must be constructed and designed in a way to determine whether populations are declining because of marine plastic pollution and if so which parts of the life cycle are affected.

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

Besides this, also the understanding of the final fate of plastic pollution in the Arctic and for example the influence that it has on the formation of aggregates, the sinking velocity of these aggregates and 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.

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 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.

When considering the knowledge gaps highlighted in here and what is necessary in order to fill them up it is very important to keep in mind the additional logistical and practical challenges of conducting research in the Arctic as incorporating those in the early planning stage may lead to more realistic expectations on the capacity to resolve some of the unanswered questions.

# Section IV: Recommendations on Next Steps

[Introductory paragraphs to the recommendations]

The review of information on the previous section documents the ubiquitous presence of marine litter, including plastic debris and microplastics, across the different regions and compartments of the Arctic marine environment. The documented impacts on organisms, leading towards impacts at the assemblage and population levels, the potential substantial disruption of Arctic marine ecosystem functions and services, and, the direct impact that marine litter already has on the maritime sector because of physical mechanical interation with vessels and fishing gear, have been taken into consideration for the elaboration of the following recommendations for PAME’s consideration:

***Develop a regional action plan on marine litter in the Arctic****,* taking into account existing regional action plans, and be structured around the following themes:

* + Actions to combat sea-based sources of marine litter
  + Actions to combat land-based sources of Marine Litter
  + Removal Actions
  + Monitoring/Science
  + Education and Outreach

It was recommended that in developing the outline of a Regional Action Plan to take into account the following issues:

* A Regional approach[, including regional actions, that] amplifies national actions by coordinating efforts.
* Jointly addressing international commitments (e.g. UN, IMO, ~~EU~~, etc.), ~~including the Polar Code, antifouling paints on ship~~s and possible impacts on the Arctic Region, including on sea ice.
* [The importance of close cooperation with relevant entities, e.g. OSPAR as OSPAR has developed and is implementing a regional action plan for marine litter, addressing both land based and sea based sources and removal actions, as well as education and outreach activities. Data sharing and avoidance of duplicating data would be vital.]
* [Coordinate and build on the work of the different Arctic Council working groups dealing with monitoring (AMAP) and biodiversity assessment (CAFF) and their initiatives for example the Arctic Migratory Bird Initiative (AMBI).]
* Including recommendations from FAO on gear marking to identify lost and abandon fishing gear [and involving relevant RFMOs].
* [Developing best practices for the management of old/derelict fishing gear, including evaluation of nets, recycling of nets (e.g. list of suppliers), passively fished waste, the use and disposal of plastics, disposal of fisheries and aquaculture waste, and waste from shipping. These measures should look both at prevention of waste, [easy and feasible waste management onboard,] as well as delivery of waste to adequate [and practical] port reception facilities through an effective mix of incentives and enforcement.]
* [Developing best practices for recycling and disposing of waste from fishing vessels.]
* [Developing best practices for the management of land-based waste.]
* [Common local community concerns and priorities for addressing marine pollution.]
* [Engage with marine litter projects throughout the region, including MARP, the Arctic Marine Litter Project, etc.]

***Develop a monitoring program*** parallel to the development of a regional action plan on marine litter in the Arctic and considering the following issues:

* Establish an advisory group on monitoring within the Arctic Council working groups working on this topic and seek guidance, as relevant, from Regional Sea Conventions (e.g. OSPAR that is an Arctic Council Observer) [and other relevant bodies such as the EU Technical Group on Marine Litter], that already have monitoring programs in place. Such an advisory group should develop a Terms of Reference for their work and could consider the following:

***Other recommendations on next steps*** that could be considered either as a standalone activity or as a part of the development of a regional action plan on marine litter in the Arctic

* Developing waste management best practices for port reception facilities [in line with IMO and EU guidance].

[Asses the costs of developing local waste management facilities and landfills. These should include the burden of managing marine debris collected in cleanup actions.]

* Developing best practices for waste management and management of sludge [and stormwater].
* Considering end of the line solution regarding sludge.
* Assessing sewage treatment systems in the Arctic.
* Assessing atmospheric inputs to the Arctic.
* Assessing sea-ice input and oceanic input.
* Describing impact types, debris type, geography (Arctic sub-region, LME’s or country)
* Building an economic incentivized model for evaluating impacts.
* Consider establishing of a best practice forum to discuss the impact of marine litter for the industry to gain an overview of production, retail and tourism industries for the Arctic Region.
* Develop case studies: Degradation of plastics in the Arctic, How the cold influences the break-down of plastic (e.g. is it more brittle?), evidence of microplastics accumulating in humans, socio-economic studies of the impact of marine litter, fishing and Litter.
* Develop a risk assessment for food security and food safety.
* Assess micro vs. nano ecotoxicology.

# 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. See, e.g., G.A. Res. 59/24 at para. 92(b) (17 Nov. 2004) (requesting that the Secretary-General convene the sixth meeting of the Consultative Process for Oceans and Law of the Sea the following June and recommending that it focus on two topics: fisheries and marine debris). See also G.A. Res. 60/30, paras. 65 and 66 (29 Nov. 2005) (encouraging States to raise awareness of impacts of marine debris and “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.”). [↑](#footnote-ref-6)
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