AMAP

LITTER AND MICROPLASTICS

MONITORING PLAN

ARCTIC MONITORING & ASSESSMENT PROGRAMME

ARCTIC COUNCIL

AMAP

CONTENTS

Sisimiut, Greenland. *Photo: Jakob Strand*

Background **4**

Arctic Monitoring and Assessment Programme (AMAP) 4

Context and rationale for a pan-Arctic litter and microplastics Monitoring Plan 5

Objectives of the Monitoring Plan 7

Monitoring recommendations **8**

Types of monitoring 9

Recommendations for monitoring litter and microplastics in the Arctic environment 11

Implementation of monitoring programs 16

Focal regions and ecosystems with current data gaps 16

Recommendations for source and surveillance monitoring 18

Monitoring to provide data for future Arctic-specific modeling scenarios 18

Future monitoring of biological effects of litter and microplastics 19

Data reporting **20**

Future directions **23**

BACKGROUND

Arctic Monitoring and Assessment Programme (AMAP)

The Arctic Monitoring and Assessment Programme (AMAP) is a Working Group of the Arctic Council. AMAP's mission is to monitor and assess the status of the Arctic region with respect to pollution and climate change issues by (i) facilitating and advancing the coordinated implementation of relevant circumpolar monitoring and research, (ii) documenting levels and trends, pathways and processes, and effects on ecosystems and humans, (iii) distinguishing human-induced changes from changes caused by natural phenomena, and (iv) proposing actions to reduce associated threats for consideration by governments and relevant organizations.

This *AMAP Litter and Microplastics Monitoring Plan* (the *Monitoring Plan*) has been prepared by the AMAP Litter and Microplastics Expert Group (LMEG), established in 2019 to review and assess the status and knowledge of plastic pollution in the Arctic, and to provide recommendations for developing coordinated pan-Arctic monitoring activities. The *Monitoring Plan* recommends a series of environmental compartments for monitoring, for consideration by national and regional institutions when implementing their respective plastics monitoring initiatives, recognizing that it is these institutions' decision, if specific recommendations are implemented.

Sampling beach sand for microplastics beneath Kittiwake colony. Kongsfjorden, Svalbard. *Photo: Maria Granberg*

Collecting microplastics from seawater on a filter using a submerged pumping devise. Kongsfjorden, Svalbard. *Photo: Ingrid Gabrielsen*

Context and rationale for a pan-Arctic litter and microplastics Monitoring Plan

Plastic pollution has been increasing globally over the last several decades. Although this form of pollution has become an issue of growing concern, leading to many recent local, regional, and international initiatives aiming to better understand and address it, there is limited information on the state of plastic pollution in the Arctic. In particular, there are limited data to identify levels and trends in the environment, or to assess how litter and microplastics may affect the environment and the ecosystems in the Arctic region. The Arctic may be particularly vulnerable to plastic pollution, and many of the species in the region are of high cultural and nutritional importance, therefore, it is important to develop an understanding of the particular threat of plastic pollution in the region, and to monitor changes over time. Plastics may accumulate in the Arctic from multiple sources.

The declaration from the Arctic Council Ministerial (2017) notes "(…) growing concerns relating to the increasing levels of microplastics in the Arctic and potential effects on ecosystems and human health." The issue of plastic pollution in the Arctic was addressed by the Arctic Council in the AMAP assessment *Chemicals of Emerging Arctic Concern* (AMAP 2016), and subsequently the PAME (Protection of the Arctic Marine Environment) *Desktop Study on Marine Litter, including Microplastics in the Arctic* (PAME 2019) provided the first overview of plastic pollution in the Arctic. The study called for more work to address the transport, fate, and effects of plastic in the Arctic marine environment.

Monitoring the Arctic environment for the presence of litter and microplastics is needed to understand the extent and types of sources, transportation patterns, as well as the effects this global pollutant may have on the region. Importantly, monitoring of litter and microplastics can inform mitigation efforts aimed at reducing the inputs and effects, and can help to evaluate the effectiveness of different mitigation actions. Given both the local and distant sources of litter and microplastics in the Arctic, it is critical that monitoring in the Arctic be aligned with global efforts to facilitate regional and global comparisons. To promote a harmonized monitoring approach and standard of reporting for litter in the Arctic, AMAP has developed the *AMAP Litter and Microplastics Monitoring Guidelines* (the *Monitoring Guidelines* (AMAP 2021)[1]. This is a technical document, covering the methodologies for sampling and analysis of litter and microplastics in abiotic and biotic compartments, including air (via atmospheric deposition), snow/ice, water, seabed, marine sediments, beaches/shorelines, terrestrial soils, invertebrates, fish, birds, and mammals. The guidelines include a description of state-of-the-art methods and their possibilities and limitations in the context of an Arctic monitoring program.

Given that the field of monitoring litter and microplastics is relatively young, standardized approaches are limited. A number of international programs aim to develop monitoring standards for litter and microplastics, but these are often limited to one or two environmental compartments (i.e., water), and do not take a holistic ecosystem approach. It is important to use comparable and reliable methods for the sampling and characterization of litter and microplastics in the Arctic (i.e., number, size, shape, mass, and types of material) to generate data that are comparable in time and space and will thus enable circumpolar assessments.

[1] The *Monitoring Plan* and the *Monitoring Guidelines* are available at https://litterandmicroplastics.amap.no/

Plastic in fulmar from West Greenland. *Photo: Jakob Strand*

Although some current initiatives aimed at tracking litter and microplastics in the environment include the Arctic within their scope, there are some Arctic-specific aspects of litter and microplastics monitoring that should be considered in the context of monitoring plans, besides the general logistic challenges. First, the presence of ice and snow in the region for extended periods of time may be an obstacle for monthly or seasonal surveys of beaches/shoreline monitoring, which global recommendations often call for, but this is not possible in many regions in the Arctic due to ice cover. Second, the presence of litter and microplastics in snow and ice samples is an area in which the Arctic regions may focus efforts specific to the region. These environmental compartments are of particular interest in polar, alpine, and regions where snow and ice are common, and their monitoring could enhance the understanding of the transport and fate of microplastics in particular.

Plastic pollution can have a wide range of effects on biota and the environment, ranging from the physical impacts of large litter pieces entangling mammals, to chemicals leaching from ingested microplastics in the guts of biota. This *Monitoring Plan* only considers approaches for monitoring the physical presence of litter and microplastics in the Arctic environment; considerations for monitoring the effects of litter and microplastics, including those of their associated chemicals, will be addressed at a later stage.

For the purposes of this *Monitoring Plan*, the terms *litter and microplastics* are used as follows:

- *Litter* is used to describe any object that is persistent, manufactured or processed solid material discarded, disposed of, lost, or abandoned in the environment. This may include plastic, machined wood, textiles, metal, glass, ceramics, rubber, and other persistent man-made materials. These products often are worn down over time, but do not entirely biodegrade and are therefore persistent in the environment. This is consistent with the US National Oceanic and Atmosphere Administration's (NOAA) definition of marine debris, OSPAR's (Convention for the Protection of the Marine Environment of the North-East Atlantic) marine litter definition, and is also used by PAME.

- *Microplastics* includes synthetic polymers, such as polypropylene (PP), polyethylene (PE), as well as anthropogenic particles, such as acrylic paints, rubber, silicones, and tire abrasion rubber-blend particles. Thus, *microplastics* can be harmonized with microlitter for methods and reporting purposes because the methods employed targeting microplastics yield results on a wide range of anthropogenic particles. This is consistent with the definitions of the Marine Strategy Framework Directive (MSFD) of the European Union (Directive 2008/56/EC). For particle size, the use of the term "litter and microplastics" is specifically designed to encompass all the size classes found in the environment. This is consistent with the EU MSFD by defining microlitter particles as < 5 mm, without a lower size limit definition in the Commission Decision 2017/848/EU. In the practical work with microplastics analysis, operationally defined size classes above and below 1 mm are often used (Table 1).

The *Monitoring Plan* builds on existing regional and global monitoring programs and their protocols and allows for national alignment with these, including the EU Marine Strategy Framework Directive (MSFD), the Regional Sea Conventions (e.g., Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the Baltic Marine Environment Protection Commission (HELCOM)), and monitoring in Antarctic waters (e.g., efforts under the Scientific Committee on Antarctic Research's (SCAR) Plastic Advisory Group). It also supports contributions to global regulation and effectiveness evaluation efforts (e.g., UN Environment Assembly (UNEA), Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP)) and the *UN Sustainable Development Goal* indicator 14.1.1b on plastic debris density. It should be noted that although several of these initiatives mainly deal with litter and microplastics in the marine environment, AMAP's work on litter and microplastics is broader and includes marine, freshwater, terrestrial, and atmospheric compartments. The *Monitoring Plan* also includes considerations on how to gather information on the effectiveness of the *Marine Litter Regional Action Plan* (ML-RAP), developed by PAME in relation to their work on marine litter.

Objectives of the *Monitoring Plan*

The main purpose of the *Monitoring Plan* is to identify key elements and considerations for a coordinated environmental monitoring program for litter and microplastics across the Arctic. It includes recommendations on environmental matrices and indicators, locations as well as times, and frequency of sampling. The specific objectives are to:

1. Promote a standardized approach for baseline mapping of litter and microplastics across a wide range of environmental compartments in the Arctic that will enable more robust spatial and temporal comparisons in the coming years;

2. Initiate trend monitoring that will generate data to assess temporal and spatial trends for litter and microplastics in the Arctic;

3. Provide guidance to Arctic nations, Permanent Participants, and the Arctic Council Observers to consider in the development and implementation of litter and microplastics monitoring and research via national initiatives, community-based programs, and other mechanisms in the context of a pan-Arctic program;

4. Identify key datasets that can be used in association with the *Marine Litter Regional Action Plan* (ML-RAP);

5. Act as a catalyst for future work in the field of litter and microplastics in the Arctic, for example, effects on biota, including determining environmentally relevant concentrations, with a view to cumulative effect assessments; and

6. Enhance the ability of the Arctic Council to assess the state of the Arctic region with respect to plastic pollution and to contribute Arctic regional data and information to future assessments of litter and microplastics in the environment on a broader international scale.

MONITORING RECOMMENDATIONS

Photo: Peter Murphy

Types of monitoring

Monitoring types can complement one another in the sense that the same observation and sampling strategy can be applied for different purposes. It is important to recognize that monitoring activities can be led and implemented by a variety of partners including researchers, community groups, and Indigenous communities.

At present, AMAP recommends baseline mapping, trend monitoring, and source and surveillance monitoring to meet the objectives outlined in the *Monitoring Plan*:

- **Baseline mapping**: Monitoring actions to establish the benchmark levels for specific areas at a given time, which can be a starting point for studying spatial and temporal trends. Although the true background environmental level of litter and microplastics in the environment is zero, the term benchmark level is used to describe the most historic state of litter and microplastics in the environment.

- **Trend monitoring**: Monitoring actions designed to detect changes across temporal and/or spatial scales.

- **Source and surveillance monitoring**: Monitoring actions to monitor potential point sources/specific pressures, including monitoring for determining local sources (e.g., melting sea ice, rivers, dumping sites, wastewater outlets etc.), or the transportation of litter and microplastics into the Arctic via long-range transport.

In the future, when target environmental values are defined, (e.g., threshold values as in EU MSFD and OSPAR assessments) additional types of monitoring might become useful or existing monitoring initiatives can have additional purposes, including:

- **Compliance monitoring**: Monitoring of environmental parameters to ensure that regulatory requirements/standards are being met.

- **Effects monitoring:** Monitoring of environmental parameters that are sentinels for effects caused by plastic pollution and related contaminants.

- **Risk based monitoring**: Monitoring actions aim to assess the status of contamination levels critical for certain species, human health, or food safety.

At the beginning of any monitoring operation, it is important to establish a benchmark level at selected sites that can be visited regularly. The results of subsequent surveys can be compared with the benchmark levels to see whether there has been a change in quantities, perhaps as the result of policy interventions, or as a result of an event (e.g., storm event or large-scale spill of litter or plastics). Over time, this can result in systematic trend monitoring or allow for the assessment of the impacts on litter and microplastics from a specific event. Because of the inherent variability in the abundance of litter and microplastics in all environmental compartments, high numbers of replicates and several years of sampling or observations may be required to detect a temporal trend with a sufficient statistical power. The inherent variability – and resulting statistical power - has to be considered in the sampling strategy, with regard to sampling frequencies. Better knowledge of variability is an area of ongoing research. Therefore, in the absence of consolidated knowledge of variability, annual monitoring is recommended for those environmental compartments that are being prioritized across the pan-Arctic, whereas the frequency of monitoring in other compartments should be tailored depending on the questions to be addressed. Variability and statistical power should then be assessed after some years of monitoring.

Snow sampling, Yukon, Canada. *Photo: Liisa Jantunen*

The data available on litter and microplastics in different environmental compartments are unevenly distributed across the Arctic (Figure 1). One obvious reason for this is the cost of sampling, and it is recommended that sampling for litter and microplastics be done in the context of existing national monitoring efforts (Figure 2).

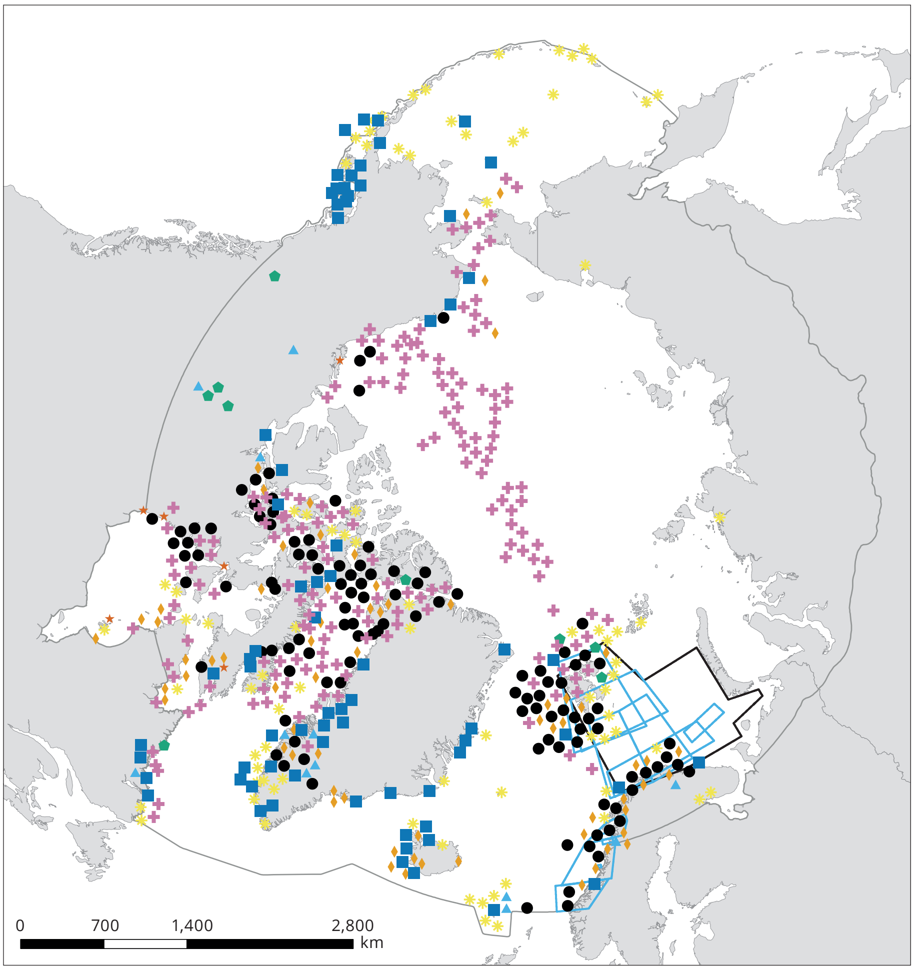

Figure 1. A sub-set of the distribution of the types and locations of existing data on litter and microplastics in the AMAP region. Data are from national reports, as well as the peer-reviewed literature. Points are jittered to prevent overlap and make the symbols visible to demonstrate the spread of the data. See the AMAP *Litter and Microplastics Monitoring Guidelines* for more detailed information on each environmental compartment.

- Aquatic sediments
- Beaches
- Fish
- Ice and snow
- Invertebrates
- Mammals
- Seabirds
- Water
- Fish
- Aquatic sediments
- AMAP Region

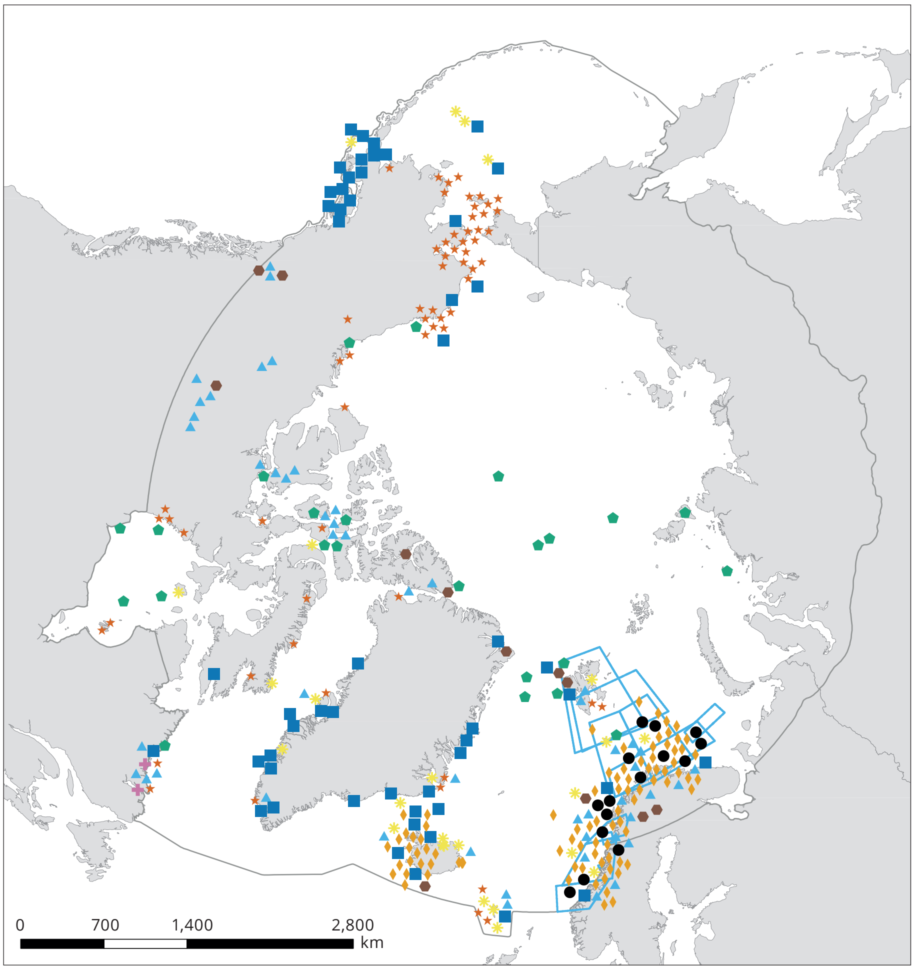

Figure 2. Locations of current monitoring for chemical contaminants (atmosphere deposition, ice and snow, sediments, water, invertebrates, seabirds, fish, and mammals), litter (via beaches), and populations (seabirds, fish, and mammals) in the environmental compartments examined in the *AMAP Litter and Microplastics Monitoring Guidelines.* These monitoring programs could be augmented to include additional metrics to collect information on litter and microplastics alongside existing monitoring. Points are jittered to prevent overlap and make the symbols visible to demonstrate the spread of the data.

- Atmospheric deposition
- Aquatic sediments
- Beaches
- Fish
- Ice and snow
- Invertebrates
- Mammals
- Seabirds
- Water
- Fish
- AMAP Region

Recommendations for monitoring litter and microplastics in the Arctic environment

The *AMAP Litter and Microplastics Monitoring Guidelines* cover eleven environmental compartments: air, ice/snow, terrestrial soils, marine sediments, beaches/shorelines, water, seabed litter, invertebrates, fish, seabirds, and mammals. These compartments span several Arctic ecosystems (e.g., tundra, lakes, rivers, coastlines, sub-tidal). Data from these compartments can be used to document the presence of a range of size classes of litter and microplastics in the environment and to improve the understanding of underlying processes (Table 1).

Environmental compartment	Particles > 1 mm	Particles < 1 mm
Beaches/shorelines	X	
Water	X	X
Sediments	X	X
Seabirds	X	
Atmospheric deposition		X
Seabed	X	
Invertebrates		X
Fish		X
Snow/ice		X
Terrestrial soil		X
Mammals	X	X

Table 1. Size classes of plastic particles that are typically reported in the eleven Arctic environmental compartments addressed in the *AMAP Litter and Microplastics Monitoring Guidelines*. 1 mm is a typical cut-off value in the methodological approaches.

For each of these environmental compartments, the *Monitoring Guidelines* list a suite of primary and secondary monitoring indicators that have been described in relation to (i) the current state of methodologies (in each compartment) and (ii) the feasibility for their use in monitoring initiatives across the Arctic (summarized in Appendix A). Primary monitoring indicators are those within each compartment that can be implemented immediately with current protocols and technologies to inform future litter and microplastics assessments in the Arctic. For example, examination of stomach contents in northern fulmars is the primary indicator identified in the seabird section for immediate implementation where possible. Secondary monitoring indicators are those within each compartment that are viewed as needed for a holistic understanding of litter and microplastics in Arctic ecosystems but need further efforts to develop methodologies before being implemented at the pan-Arctic level. In the seabird compartment, gut analysis of other species, as well as nest incorporation of litter are listed as secondary indicators that require more development before widespread implementation. Some secondary monitoring indicators may also serve specific other monitoring purposes, for example effect monitoring in relation to chemicals associated with plastic pollution.

The primary and secondary monitoring indicators are thus linked to different types of monitoring with the main focus on baseline establishment, trend monitoring, and source/surveillance monitoring. These primary and secondary monitoring indicators also address the actions outlined in the *Marine Litter Regional Action Plan* (ML-RAP). Some indicators may be used in concert to better understand sources and transport of litter and microplastics.

In addition to the primary and secondary monitoring indicators within each of the eleven environmental compartments, a suite of environmental compartments was identified as Priority 1 and Priority 2 monitoring recommendations.

Priority 1 recommendations are those that should be implemented, when possible and where relevant, immediately, across all regions in the pan-Arctic to facilitate *trend monitoring*, i.e. spatial and temporal trends. The Priority 1 recommendations include the primary monitoring indicators of water (freshwater and marine), sediments (freshwater and marine), beaches/shorelines, and seabirds (Table 2). Specifically, these recommendations include measuring microplastics in surface water using nets in inshore waters and pumps in offshore waters, microplastics in sediments (including freshwater inputs, estuaries, and marine zones), litter surveys on beaches/shorelines, and plastic ingestion in northern fulmars (Table 2). The aim of this approach is to focus monitoring efforts on obtaining spatially and temporally comparable data across the Arctic.

The four compartments in the Priority 1 recommended indicators meet the following criteria, which are critical for widespread immediate implementation:

1. Standardized or harmonized protocols have been developed and implemented in several regions (e.g., seabirds with OSPAR, shorelines with OSPAR and NOAA);
2. Litter and/or microplastics are known to accumulate in these compartments, indicating they can be used to better understand litter and/or microplastics in the Arctic (compared to compartments where little litter and/or microplastics have been recorded to date);
3. Data are available in several Arctic regions;
4. Future sampling can be carried out in collaboration with existing programs that are already in place (Figure 2);
5. Sampling (i.e., collection method or species) can be implemented across most of the Arctic without additional need for infrastructure or technology development (Figure 2); and
6. Approaches can be aligned with litter and microplastics monitoring outside the Arctic, ensuring that Arctic data can be used in future broader international or global assessments.

In addition to the above criteria, the combination of water, sediments, beaches/shoreline, and seabird monitoring covers a range of size classes of litter and microplastics (Table 1). Sampling from sediment and water samples commonly produces data for size classes varying between 100 µm (but some as low as 10 µm) and 1 mm and above, typically defined by the selected methodology, i.e., mesh and filter sizes. Seabirds, specifically those that feed in the open ocean, can be used to study litter particles between 1 and 25 mm. Beach/shoreline surveys focus mostly on litter, and largely on particles greater than 25 mm. Thus, combining these compartments yields information on an overlapping and wide range of litter and microplastics (Table 1). Different Priority 1 compartments may also be targeted based on regional priorities to monitor different size classes of plastic pollution or specific matrices or species. If larger size classes of plastic pollution (> 1 mm) are the main interest in a region, then beach/shoreline surveys and seabirds (i.e., northern fulmars) should be prioritized for monitoring efforts. If smaller size classes of plastic pollution (< 1 mm) are of regional concern, water and sediment sampling should be prioritized.

It is recommended that monitoring programs consider a joint water and sediment approach, where possible. The rationale for this recommendation is that water and sediment sampling can often be carried out in the same sampling campaign and provide complementary, but not overlapping, information on the status and trends of plastic contamination. When water and sediment sampling are combined, they provide the most complete picture of microplastics contamination of aquatic environments including potential exposure of organisms, from the benthic to the pelagic. Furthermore, water and sediment sampling provides different temporal perspectives on plastic pollution. Sediments provide a more spatially and temporally integrated signal of plastic contamination, whereas water samples can possibly track more rapid fluctuations such as what might occur with increased shipping in the Arctic or if communities alter their wastewater treatment processes. However, capturing the target water mass can be challenging, thus hydrodynamic processes in the area need to be well-known in order to interpret the results. It is also important to note that although plastics in the sediment have moved through the water column, it is difficult to draw a direct relationship between plastic concentration and composition in the water and sediment.

All Arctic nations should aim to implement monitoring at one site or more for each of the four Priority 1 compartments or according to the national capacity and applicability. Arctic nations should consider implementation of monitoring in the most relevant compartments for the nation within selected Large Marine Ecosystems (LMEs) within their jurisdiction (Figure 3). This will allow for future spatial trend monitoring across large scale areas that experience similar oceanographic conditions.

Table 2. Summary of the Priority 1 and 2 recommendations for monitoring of litter and microplastics in the Arctic. More information on the individual environmental compartments can be found in the *AMAP Litter and Microplastics Monitoring Guidelines*.

Environmental Compartment	Possible applications for monitoring
Priority 1 Recommendations –	
Beaches/ shorelines	Beach/shoreline surveys focus on litter and can be done via a variety of groups but should use a harmonized approach and standardized reporting methods. Given that one of the most abundant litter items in several Arctic regions is lost, discarded, and abandoned fishing gear, implementing widespread beach/shoreline monitoring for litter will greatly improve the assessment of current levels, will identify hotspots, and inform mitigation actions. Beach/shoreline monitoring can be implemented through various programs, including community-based monitoring. Surveys should be done at least once during the ice-free seasons.
Water (surface)	Water sampling can be performed using harmonized methods and standard reporting, via existing monitoring programs and can be done quite readily at other sites, at least in coastal regions. Water sampling can include litter and microplastics. Water samples in inshore regions should be done using nets with ca. 300 µm mesh size (but can go as low as 10 µm). Sample volumes will depend on local sampling conditions. Offshore water samples should use pumps, target water 1-7 m below the surface and use sequential filtration reporting 1 mm, 300 µm and 100 µm mesh. Sampling in rivers and estuarine ecosystems should be included for source monitoring, i.e., establish baseline levels of litter and microplastics across the Arctic entering via riverine input.
Sediments	Sampling of aquatic and shoreline sediments primarily focuses on microplastics. A variety of polymers can be found in sediment samples from beaches, whereas sampling in the sublittoral zone will target particles with a higher sinking rate with densities greater than seawater (e.g., PVC). Sampling of marine sediments allows for the detection and tracking of microplastics with a higher density than what is found in other compartments. It also allows for the detection of particles with changed density or settling properties resulting from biofouling. Microplastics in sediments should be monitored and reported in size categories 300 µm – 1 mm and 1 – 5 mm. Lower size classes can provide additional data in areas where this is of interest. Sediments near rivers and estuarine ecosystems can improve the understanding of historic and current levels of deposition.
Seabirds	Several species of seabirds have been assessed for ingestion of litter > 1 mm, as well as for entanglement. Nest incorporation data can provide information on larger litter. Data show that microplastics accumulated in seabird stomachs can vary in size depending on the feeding mode of the specific species, therefore species ecology is important for interpreting results. Initial efforts should focus on expanding existing data. Fulmars should be an initial focus of program developed through harvested birds, bycatch specimens, or beached birds. This species is recognized as a bioindicator of plastic pollution because fulmars directly ingest plastic at the surface of the water and accumulate plastics in their stomachs. Future work could be extended to secondary indicators, i.e., other species across the Arctic. Although the use of seabirds as samplers of litter and macroplastics is limited in some regions due to the species abundance or because of the conservation status of the species, seabirds are a well-established indicator in e.g., OSPAR.
Priority 2 Recommendations –	
Air via atmospheric deposition	Sampling of microplastics in air can be done via atmospheric deposition using existing infrastructure and sampling efforts in several regions of the Arctic (i.e., the existing atmospheric monitoring stations in the Arctic). Studies in urban areas at temperate latitudes have shown airborne plastic pollution deposition, but there is little information from remote regions to assess the long-range atmospheric transport of microplastics. Microplastics that are likely subjected to atmospheric transport are mainly < 300 µm and consist of mostly microfibers (< 5 mm). Plastic particles as small as 10 µm can be detected in atmospheric deposition samples.
Invertebrates	Most invertebrates have demonstrated a capacity to ingest and accumulate microplastics, but current collections of invertebrates in the Arctic are limited. Studies show that microplastics detected in invertebrates vary in densities and size depending on the feeding mode of the species examined. It is critical to have detailed knowledge on the ecology and feeding behavior of the sampled species to correctly interpret microplastics data. It is also important to have insight into particle feeding dynamics in the specific species under the specific sampling conditions, because feeding rates and particle selectivity are highly circumstantial. Analyzing a range of different invertebrate species, can lead to a better understanding of the fate of microplastics in the benthic and pelagic environments, as well as answer questions related to trophic transfer. This can provide important information relating to effects and human exposure to microplastics when combined with the assessment of the health of the organisms and critical levels for human ingestion if species consumed by people are included in the monitoring programs.
Fish	Studies on microplastics accumulation in fish from the Arctic region show highly variable results with relatively low incidence compared to other taxa. However, that is probably related to the size range and the part of the fish investigated as well as methods applied. Most studies only investigated the fish stomach content for plastic larger than 300 µm, whereas new studies show occurrence of plastic below that size in fillet and liver. Several species of fish are regularly sampled throughout much of the Arctic for various purposes, including chemical contaminant studies. The existing programs could include microplastics studies as part of ongoing projects. Different fish species can provide information on microplastics in the benthic and pelagic environments. This can result in data on microplastics of varying densities and size classes given that fish have different types of feeding habits. Thus, as with other species, it is critical to have a detailed knowledge about the feeding behavior of the sampled species to correctly interpret microplastics data. Sampling of fish tissues can also provide important information needed for questions relating to effects on Arctic ecosystems and human exposure when combined with the assessment of the condition of the organisms and critical levels for human ingestion.

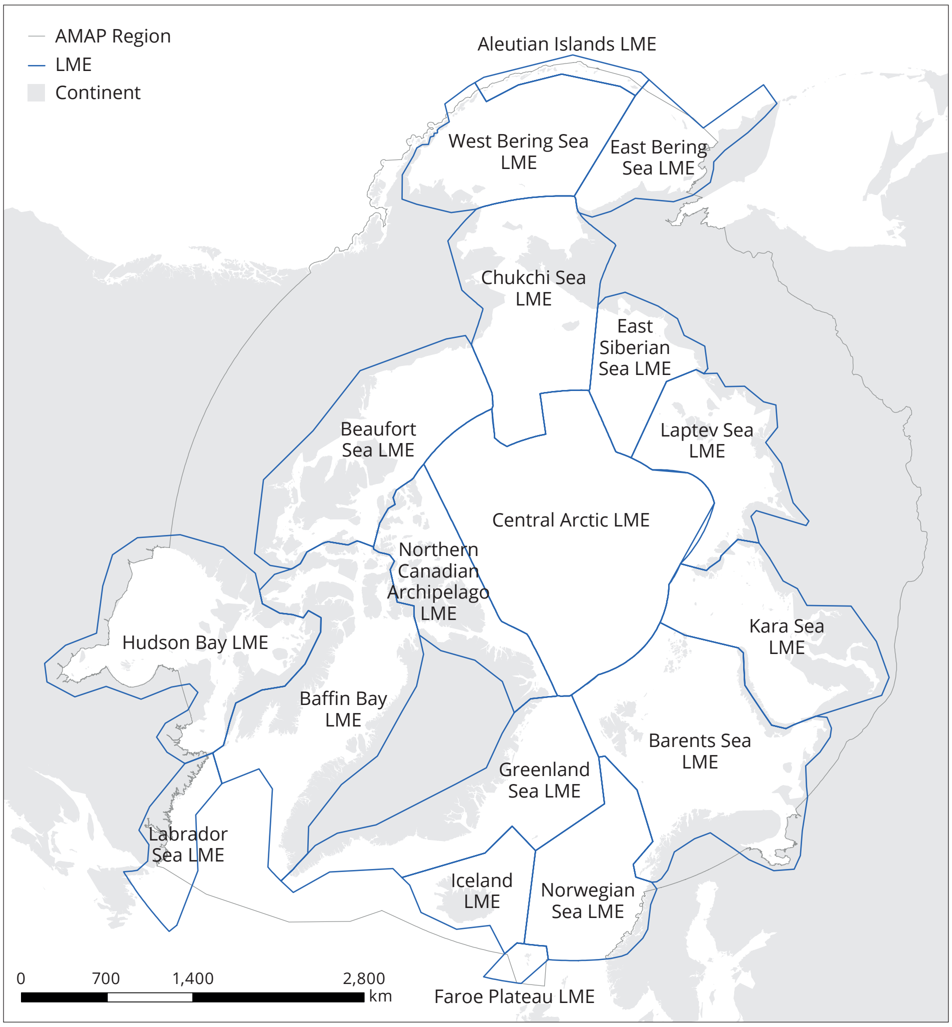

Figure 3. The Large Marine Ecosystems (LMEs) within the AMAP boundary. It is recommended that the Priority 1 recommendations for monitoring litter and microplastics are implemented in at least one location across all the Arctic LMEs where possible.

Given that individual Arctic nations may wish to explore litter and microplastics monitoring in additional environmental compartments because of regionally or locally relevant questions, or because they are transitioning from research to monitoring, **Priority 2 recommendations** are also presented (Table 2).

The Priority 2 recommendations include the primary indicators for air (atmospheric deposition), invertebrates, and fish. These compartments should be considered for further development because:

1. Standardized or harmonized protocols are in place, but need to be further refined through implementation and a greater community of practice;
2. Data may not be available in most regions of the Arctic, but the compartments can now be widely sampled with coordinated efforts;
3. Program development in some regions is needed to ensure greater geographical coverage of the Arctic; and
4. Additional monitoring efforts will support developments in infrastructure or technologies.

In addition to the Priority 1 compartments, the Priority 2 recommended compartments should be considered for implementation throughout the pan-Arctic region to meet objectives related to filling in the gaps in baseline monitoring, as well as spatial and effects monitoring (Figure 4), co-developed with Indigenous and local communities. Given the ongoing developments in the field of litter and microplastics research and monitoring, the goal in the coming years should be to further develop the techniques and capacities that would lead to future recommendations of these compartments for baseline mapping and future trend monitoring efforts. Table 3 gives an overview of the monitoring questions that can be addressed by litter and microplastics monitoring via the eleven environmental compartments.

Dumping site. Sisimiut, Greenland. *Photo: Maria Granberg*

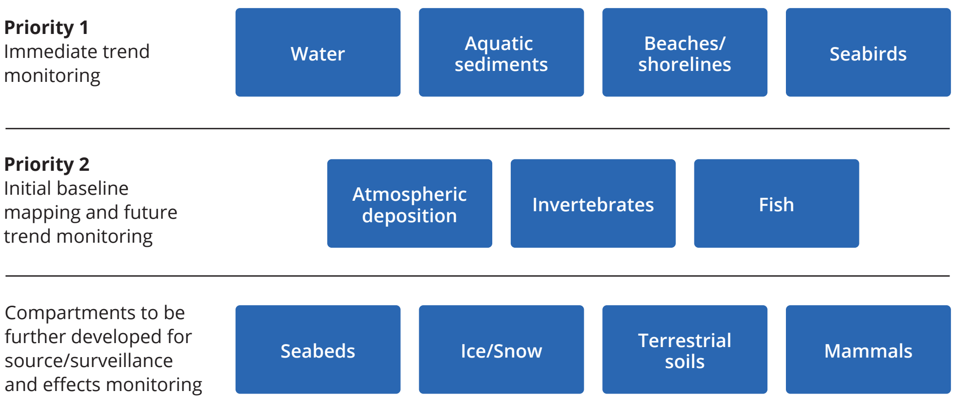

Figure 4. Overview of the environmental compartments recommended for trend, baseline, source/surveillance and effects monitoring for litter in the Arctic.

Table 3. Summary of the types of monitoring questions that can be addressed by litter and microplastics monitoring via the eleven environmental compartments.

Compartment	Immediate trend monitoring *)	Initial baseline mapping and future trend monitoring	Source/Surveillance monitoring	Effects monitoring
Priority 1				
Beaches/shorelines	X		X	
Water	X		X	
Sediments	X		X	
Seabirds	X			X
Priority 2				
Air		X		
Invertebrates		X		X
Fish		X	X	X
Other compartments				
Snow/ice			X	
Seabed		X	X	
Terrestrial soils			X	
Mammals				X

*) Referring to spatial and trend monitoring, with the exception of water, which is less suited for temporal trend monitoring.

Implementation of monitoring programs

Monitoring programs can be implemented in a variety of ways, including nationally-led and community-based. Monitoring programs often involve infrastructure for observations and sampling, e.g., research stations and observatories, but increasingly include community-based and citizen science initiatives, for example, locally organized sampling campaigns or large-scale collections of observations reported via online platforms. Sampling strategies can include species-specific and opportunistic sampling, and a combination of both. As Arctic nations (and others) design monitoring approaches for litter and microplastics, a variety of monitoring programs should be considered to ensure feasibility and engagement with partners.

An example of an existing monitoring project in the Arctic is the mapping of marine litter in the Norwegian and Russian Arctic Seas (MALINOR), a multi-national project funded by the Norwegian Research Council. The goal of this project is to map areas of marine litter in the Norwegian and Russian Arctic through coordination among several institutes.

More than 100 research stations and observatories in the Arctic, some of which are designed to be permanent or semi-permanent, can provide important support to litter and microplastics monitoring projects. One example of how these research stations can contribute to litter and microplastics monitoring is demonstrated by the work at the long-term ecological research observatory HAUSGARTEN, established by the Alfred Wegener Institut (Germany). Since 2002, the HAUSGARTEN observatory in the Arctic has conducted marine plastic monitoring on the seafloor using towed seafloor photography.

Community-based monitoring includes projects that are created, led, and carried out by community groups, as well as projects that are co-developed and those that are created and facilitated by outside principal investigators but led and carried out by communities. The main benefits of these programs are that they concretely address community concerns about plastics and tend to focus on local needs, methods, and goals. An example of a community-based project is “Community Monitoring of Plastic Pollution in Wild Food and Environments in Nunatsiavut”, an Inuit-led project of the Nunatsiavut Government, funded by Canada’s Northern Contaminants Program (NCP). The program focuses on plastic pollution in traditional food webs and culturally important ecosystems for Inuit hunters and fishers and employs local Inuit to carry out research on their own land.

Citizen science is the collection of scientific information and observations carried out by the general public and is often part of a collaborative project led by a team of researchers. These efforts are usually opportunistic, though can be more regular if groups return to the same places over time. An example of citizen science being carried out in the Arctic to monitor plastic litter pollution is the use of the *Marine Debris Tracker App*. This is a free phone application that has been created through a partnership with the US’s NOAA Marine Debris Program and the Southeast Atlantic Marine Debris Initiative (SEA-MDI) at the University of Georgia. The app geotags plastic debris and uploads the data to a centralized website for public use. Data have been collected in the Arctic in Canada, Norway, Finland, and the USA (Alaska).

When Arctic nations are considering the implementation of the Priority 1 and 2 monitoring recommendations, a variety of approaches should be included in the planning to ensure that Indigenous and local concerns and capacities are taken into consideration and planned for.

Focal regions and ecosystems with current data gaps

The data available on litter and microplastics in different environmental compartments are unevenly distributed across the Arctic (Figure 1). The Pacific region of the Arctic has very limited information on litter and microplastics beyond beach litter and plastic ingestion in seabirds (Figure 1). The Russian Arctic is another region where there are limited data on plastic pollution, although several ongoing projects are aiming to explore and collect data on litter and microplastics in the region.

Given the number of large rivers that flow into the Arctic, there are several important waterways and their basins in the Arctic for which only few data are available. Importantly, the basins of several large rivers span the Arctic and the sub-Arctic regions, and thus could be a route for litter and microplastics from the south to more northern latitudes. Source and surveillance monitoring should include large riverine systems and their watersheds to track the transport and fate of litter and microplastics. Monitoring of these riverine systems should include sampling along the flow of the river, and specifically above and below major potential sources of litter and microplastics. To collect data relevant to modeling the riverine input of litter and microplastics to the Arctic marine environment, monitoring in water and sediments should also be focused around the estuaries of large rivers.

Generally, litter and microplastics have been studied in the marine environment to a greater extent than in the freshwater and terrestrial environments. The understanding of the fate, transport to, and accumulation of, litter and microplastics in the terrestrial and aquatic ecosystems of the Arctic, and their potential effects on species in these areas is limited. Additionally, seabirds have been reported to move marine litter back to the terrestrial environment. Therefore, where terrestrial ecosystems may be highly exposed to litter and microplastics, highly sensitive to pollution, or of importance to subsistence species, monitoring should be established to map the levels and trends of litter and microplastics and to generate data for a better understanding of the fate, transport, and potential effects. In addition, the atmospheric environment as a transport pathway of microplastics to the Arctic is not well-studied.

Photo: Peter Murphy

Table 4. Summary of source and surveillance monitoring that may be undertaken in environmental compartments for litter and microplastics.

Environmental compartment	Possible applications for source and surveillance monitoring
Air via atmospheric deposition	Local samples around point sources can be used to detect microplastics in relation to specific waste management tools and implemented actions. More widespread and remote sampling can inform how and which type of microplastics is deposited on the larger pan-Arctic scale by long-range transport including remobilization processes (i.e., useful for creating Arctic specific circulation models).
Snow/ice	Local samples around point sources can be used to detect microplastics in relation to specific waste management tools and implemented actions. More widespread sampling can inform how litter and microplastics are deposited at the larger pan-Arctic scale (i.e., useful for creating Arctic specific circulation models).
Water	Sampling of both fresh- and seawater can be used to track sources of litter entering the Arctic aquatic environment. It can be difficult to target the specific site in which microplastics originating from a land-based source will concentrate; therefore, an understanding of local currents is needed. The best place for sampling is thus as close to the point of entry as possible whether the source is an effluent or an ice front.
Sediments	Sampling of sediments at the littoral and the subtidal zones for microplastics can be a useful tool for surveillance monitoring for litter and microplastics. Paired with beach surveys for litter, marine sediments can inform how local sources may influence microplastics levels and types in the surrounding areas.
Terrestrial soils	Although terrestrial soil sampling is not often considered in addressing marine litter and microplastics, in many regions the largest source of litter and microplastics is land-based. Monitoring terrestrial soils for microplastics can inform how microplastics move from the land to the marine environment, and how this may be altered under different management scenarios.
Seabed	Seabed surveys for litter can serve as a useful tool to track sources of litter. This type of monitoring should be employed in regions where lost, abandoned, and discarded fishing gear may be concentrated.
Beaches/ shorelines	Beach/shoreline surveys for litter are likely to be one of the main tools for surveillance monitoring of litter. Paired with marine sediment monitoring for microplastics and accountability methods, beach surveys can indicate sources of pollution. Areas susceptible to lost, abandoned, and discarded fishing gear should be considered for this type of monitoring.
Invertebrates	Invertebrates with known ecology and functional group identity can be used around local sites to examine how microplastics enter the biological compartments and food chains.
Fish	Litter and microplastics assessments in fish with known ecology and migration patterns (or landlocked species), can provide information on local sources of pollution.
Seabirds	Bird species that regurgitate (i.e., gulls, skuas) can be used to track local sources of litter and microplastics because obtained samples are non-lethal and reflect the diet of the birds in the hours before collection. Nest incorporation of litter by black-legged kittiwakes can also be used to track local sources of litter and can be tracked over time easily via community-based monitoring.

Recommendations for source and surveillance monitoring

In addition to trend monitoring, baseline mapping, and source monitoring of riverine inputs, as described above, there is a need for surveillance monitoring around point sources and a need to support assessments of the effectiveness of the actions and measures in the *Marine Litter Regional Action Plan* (ML-RAP). Baseline mapping followed by trend monitoring will support such assessments, but more focused efforts around potential sources of litter and microplastics will be needed. For this type of monitoring a different suite of monitoring tools can be used, and the monitoring frequency should consider potential seasonal and inter-annual patterns (Table 4). These can be useful tools in addition to the monitoring of non-natural components (e.g., monitoring in wastewater outputs) and modeling applications (e.g., DPSIR model).

As discussed in the *Marine Litter Regional Action Plan* (ML-RAP), a suite of monitoring tools is recommended that can be used to track the effectiveness of the actions. Many actions within the *Marine Litter Regional Action Plan* (ML-RAP) are based on discarded, lost, and abandoned fishing gear because this is a large component of the litter on many Arctic coastlines. For these actions monitoring the seabed and beaches for litter is recommended.

For those actions that are examining the sources of plastic pollution via waste and wastewater handling, depending on the location, shorelines, freshwater, terrestrial soils, seawater, sediments, and marine birds via gull boluses could be considered. When considering source monitoring, sampling stations located upstream from contamination pathways as close to sources as possible are recommended.

Monitoring to provide data for future Arctic-specific modeling scenarios

Currently there are several models that examine plastic pollution sources, circulation, and sinks in the oceanic environment, but there are no Arctic specific models. Arctic data are needed for development and validation of these models; for example, to quantify riverine inputs and other sources of litter and microplastics in the Arctic, and thus obtain information on where reduction actions may be needed.

River systems have been identified as one of the key conduits of plastics from terrestrial environments to the world's oceans transporting millions of tonnes of plastic annually to marine ecosystems. In general, little information is available on litter and microplastics in freshwater systems, and more research is needed to add to the understanding of freshwater sources, sinks, and circulation of litter and microplastics.

Atmospheric transport models are an important tool to further the understanding of the role of local sources and long-range transport of microplastics to the Arctic. Especially because the small particles, with a size range below 10 µm are expected to travel by air, a close interlinkage with monitoring data is vital, using state of the art methodology. A combined effort is necessary to ensure the parallel development of robust and sensitive monitoring methods and model estimates.

Plastic litter collected on the Adventfjord beach. Svalbard. *Photo: Lisa Winberg von Friesen*

Future monitoring of biological effects of litter and microplastics

In addition to the other types of monitoring described above, effects and risk-based monitoring approaches are also relevant to consider in relation to litter and microplastics at the pan-Arctic level. Therefore, any planning of monitoring programs undertaken now should also consider methods and collections for potential future efforts to assess the effects of litter and microplastics, as well as plastic contaminants in Arctic biota. More specifically, although this *Monitoring Plan* focuses on detecting and reporting the physical litter and microplastics in environmental compartments, the effects these may have on species that accumulate them, including effects of plastic-derived and plastic-associated chemicals, should be considered.

Effects monitoring studies may use the same species (e.g., northern fulmars) but examine different tissues (e.g., microplastics assessments in stomachs while plastic additives are assessed in liver tissue). Tissues that are known to be target organs for plastic-derived and -associated contaminants and/or that are consumed by humans, such as liver, blubber, and muscle/fillet (depending on the species) should be prioritized for effects monitoring alongside ingested litter and microplastics examination. This notion is corroborated by pilot studies showing that Arctic animals can contain microplastics of smaller size classes, such as between 10 and 200 µm, as has been shown in some marine mammals.

Although Priority 1 and 2 recommendations are the focus of baseline mapping and trend monitoring, some Arctic nations (and others) may wish to implement monitoring in other compartments and with other purposes, e.g., effect monitoring because of regional concerns relating to species that are culturally important to Indigenous and local communities through subsistence harvests, for instance birds, seals, whales, and polar bears. In several regions marine mammals have been shown to ingest litter and microplastics, and monitoring in this group will add to the understanding of litter and microplastics and associated contaminants across the food web and contribute to future effects research and monitoring efforts.

DATA REPORTING

Photo: Peter Murphy

One of the purposes of formulating standardized monitoring guidelines, is to be able to compare observations over time and space. To produce comparable observational data, it is important to harmonize methodology and standardize data reporting. The use of harmonized terminology and setting of standards at the level of data detail for all observers, along with the measurement of uncertainty, are critical parts of this process.

Existing databases that should be considered for the reporting of litter and microplastics data include the EBAS database hosted by the Norwegian Institute for Air Research (NILU), the Environmental Database (DOME) of the International Council for the Exploration of the Sea (ICES), OSPAR for shoreline and seabird data, the US's NOAA databases for shoreline data, and the Polar Data Catalogue (PDC). Databases already available for atmospheric pollution, like EBAS, can be modified to store and publish monitoring data, linked with other atmospheric data from the same site. ICES, NILU, NOAA, OSPAR, and PDC have developed standard procedures for the reporting of data to their databases and these should be followed. These procedures define the minimum mandatory information that must be reported but need to be adapted specifically for litter and microplastics for most environmental compartments. In addition, the procedures support the reporting of optional information, depending on the monitoring objectives. In the *AMAP Litter and Microplastics Monitoring Guidelines*, each of the compartment sections has defined what information is optional and mandatory under the objectives of each compartment.

FUTURE DIRECTIONS

Future directions in relation to the monitoring and assessments of litter and microplastics in the Arctic

The current *Monitoring Plan* is envisioned as part of a series of phases of work on litter and microplastics to be carried out under the auspices of AMAP. The *Monitoring Plan* was based on best available knowledge at the time of writing, and the intention is to regularly update the technical guidance (*Monitoring Guidelines*) and *Monitoring Plan* to maintain up to date evidence-based decision making.

In the first phase of the work, technical guidance (*Monitoring Guidelines*) and the *Monitoring Plan* have been developed, establishing a framework that allows national and regional bodies to implement monitoring for physical presence of litter and microplastics in the environment. This will allow assessment of spatial and temporal trends of litter and microplastics in future phases.

Future work is planned to address existing knowledge and knowledge gaps about the effects of plastic pollution, both from a physical perspective but also with a focus on chemical contaminants from plastic pollution. This will be the basis for recommendations for the monitoring for effects of litter and microplastics pollution. This monitoring will enable future assessment of the effects of these.

Future work will be detailed through the biennial work plans of AMAP, which are implemented with the approval of the Arctic Council Ministers.

Nuuk, Greenland. *Photo: Jakob Strand*

Appendix A. - Summary of recommendations of primary and secondary monitoring across compartments as described in the *AMAP Litter and Microplastics Monitoring Guidelines*. Important to note that the size limitations presented are those that are recommended as the minimum reported level, and do not necessarily reflect the methodological limitations at this time. Generally, ocular identification can be used for size classes greater than 300 µm, and polymer identification (via one of the accepted methods; see *AMAP Litter and Microplastics Monitoring Guidelines* for more details) is needed for small size classes.

	Primary monitoring indicators	Secondary monitoring indicators
Atmospheric deposition	Bulk deposition wherever possible greater than 300 µm (particles/day/m^2). Wet deposition greater than 300 µm where existing stations and power sources are available (particles/L). Active air sampling greater than 300 µm where existing stations and power sources are available (particles/m^3).	Dry deposition only, greater than 300 µm (particles/day/m^2).
Snow/ice	[Not recommended for primary monitoring currently].	To gain knowledge of current microplastics loads in sea ice. Additional samples for microplastics should be integrated in the normal sea ice monitoring programs (1-3 replicates/site).
Water (marine and freshwater)	Net samples (water surface of coastal, freshwater, and fjords) using 300 µm mesh. Selected large pump offshore locations (sequential filtration, e.g., 1 mm, 300 µm, 100µm) collected sub-surface – 1-7 meters, 1m^3 per sample.	Widespread large volume pump samples volume (sequential filtration e.g., 1 mm, 300 µm, 100µm) collected sub surface – 1-7 meters, 1 m^3 per sample.
Sediments	Ocular analysis of microplastics content in surface sediments preferably from accumulation bottoms. All microplastics should be monitored and reported in size categories 5- ≥ 1 mm and 1000- ≥300 µm (visual determination stereomicroscope or polymer identification).	Studies around potential point sources. Analysis and polymer ID of microplastics particles smaller than 300 µm.
Shoreline/ Beach litter	Accumulation surveys of litter at reference sites of 100 m segments on shorelines following OSPAR or NOAA guidelines.	Accumulation surveys of litter at point source (e.g., urban) impacted shorelines for assessing inputs from local Arctic sources. Implementation of more specific Arctic relevant litter items in an extended monitoring identification list. Standing stock surveys according to NOAA protocol.
Seabed	[Not recommended for primary monitoring currently].	Add litter quantification to all existing ongoing seabed work.
Terrestrial soils	[Not recommended for primary monitoring currently].	Terrestrial soil samples from locations around point sources using methods that focus on size classes greater than 300 µm.
Invertebrates	Suspension feeding bivalve gut analysis (e.g., mussels, clams, cockles) for litter particles greater than 300 μm (visual determination stereomicroscope or polymer identification).	Quantify particles smaller than 300 µm in suspension filters (visual determination stereomicroscope or polymer identification). Develop knowledge to be able to advise on other benthic or pelagic species with different feeding strategies (i.e., scavenger, deposit, or suspension feeder) - candidate species: Gammaridae amphipods, Sea cucumbers (*Holothuroidea*).
Seabirds	Northern fulmar stomachs for all litter particles greater than 1 mm.	*Uria* spp. stomachs for all litter particles greater than 1 mm. Gull boluses around point sources of litter and microplastics. Nest incorporation of plastic pollution by black-legged kittiwakes during colony visits. Common eider duck stomachs for all litter greater than 300 µm, in association with water, sediment and benthic invertebrate sampling in the same region.
Fish	Gut content analysis of salmonids and polar cod for all litter particles with a minimum size of 300 μm (visual determination stereomicroscope or polymer identification). Gut content analysis *Sculpin* spp. for all litter particles greater than 300 μm (visual determination stereomicroscope or polymer identification) in association with benthic sampling.	Gut content analysis for all litter particles greater than 300 μm (visual determination stereomicroscope or polymer identification) for other species: • Capelin • Flounder • Cusk • Identification of a deep-water fish species that can be regularly assessed for plastic ingestion Development of methods to examine fish tissues for pieces of litter less than 300 µm.
Mammals	[Not recommended for a primary monitoring currently].	Polar bear scat collections combined with hunter knowledge surveys for tracking ingested litter and microplastics. Develop pan-Arctic reporting network for mammal (marine and terrestrial) entanglements.

Photo: Mark Mallory

Cover photo: Bo Eide

AMAP, established in 1991 under the eight-country Arctic Environmental Protection Strategy, monitors and assesses the status of the Arctic region with respect to pollution and climate change. AMAP produces science-based policy-relevant assessments and public outreach products to inform policy and decision-making processes. Since 1996, AMAP has served as one of the Arctic Council's six working groups.

AMAP Secretariat
The Fram Centre,
Box 6606 Langnes,
9296 Tromsø, Norway
Tel. +47 21 08 04 80
Fax +47 21 08 04 85
amap@amap.no
www.amap.no

AMAP
Arctic Monitoring and Assessment Programme