Arctic Science

OPEN ACCESS | Article

Monitoring litter on Arctic and subarctic shorelines: current status and next steps for monitoring programs

Ingrid L. Pollet[a], Julia E. Baak[b], Louise Feld[c], Bjørn E. Grøsvik[d], Max Liboiron[e], Mark L. Mallory[a], Jennifer F. Provencher[f], and Jakob Strand[c]

[a]Biology Department, Acadia University, Wolfville, NS B4P 2R6, Canada; [b]McGill University, Montreal, QC H3A 0G4, Canada; [c]Department of Ecoscience, Aarhus University, Roskilde, 4000, Denmark; [d]Institute of Marine Research, Bergen, 5817, Norway; [e]Department of Geography, Memorial University, St. John's, NL A1C 5S7, Canada; [f]Environment and Climate Change Canada, Ottawa, ON K1A 0H3, Canada

Corresponding author: **Jennifer F. Provencher** (email: jennifer.provencher@canada.ca)

Abstract

Plastic pollution is ubiquitous, and the Arctic is no exception. One important step to understand the extent of the problem, and to monitor its impact is to have repeatable, comparable, and relevant measures across time and space that allow for the detection of marine litter trends. Arctic shorelines are a critical part of monitoring efforts. Pan-Arctic monitoring of litter on shorelines is also an essential component to examine global trends. Based on previous work examining litter in some regions of the Arctic, we suggest steps towards more harmonized protocols that include community-based monitoring, crowdsourced science programs, and science team-based surveys that are specific for the Arctic. Specifically, we recommend that shoreline survey sites for long-term monitoring be established where possible and be at least 50 m and surveys carried out at regular intervals of at least twice a year by any type of research team. Criteria for the selection of sites should be grounded in Indigenous and other local community and regional priorities, and should result in representation of both remote shorelines impacted by distant-source marine litter and shorelines impacted by more local sources. Results of any Arctic shoreline litter surveys should be made regularly available either through publications which include data sets, and/or accessible databases to promote regional comparisons and trend analysis across the pan-Arctic.

Key words: Arctic, beaches, marine litter, debris, plastic, harmonization, monitoring

1. Introduction

Plastic pollution is a global issue, affecting all environments from mountaintops to deep oceans (MacLeod et al. 2021; Padha et al. 2022). The presence and accumulation of litter, including plastic litter is not recent (Scott 1971; Cundell 1973; Merrell 1980), but the exponential increase in the level of litter gained scientific interest in the recent decade (Serra-Gonçalves et al. 2019; Cesarano et al. 2021; Ansari and Farzadkia 2022). Litter is defined as any persistent, manufactured, or processed solid materials directly or indirectly, intentionally or unintentionally, discarded, disposed of, abandoned, or lost in the environment. This also includes marine litter entering the marine environment via rivers, sewage outlets, storm water outlets, or winds (OSPAR 2010, 2020; Opfer et al. 2012). Here, we use the term "litter" to refer to all plastic items or fragments (litter, debris, garbage) larger than 2.5 cm in size. However, some types of smaller mesoplastic particles within the size range of 0.5–2.5 cm, such as industrial pellets, different specific small items, as well as fragments, can in some cases also be registered during surveys, although not always in the same manner. Microplastics can also be monitored on shorelines (see Chapter 6.3 of GESAMP 2019, for a more detailed description of those methods), but in this discussion, we focus on macroplastic litter items (>2.5 cm), as microplastics monitoring in the Arctic is covered in other papers included in this special collection (e.g., Martin et al. 2022). The most common types of plastic litter vary among regions but often include single-use items such as plastic bags and cigarette filters (Novotny and Slaughter 2014; Addamo et al. 2017). Marine litter items from packaging or transportation such as strapping bands, nets, and rope from fishery-related activities have been documented for decades at high latitudes (Walker et al. 1997).

While there is, currently, a focus on microplastics in many regions, macroplastics also have negative impacts on wildlife and economies. Wildlife, including marine mammals, turtles, fish, and seabirds, can suffer from macroplastics in many ways, including entanglement/confinement at sea or at the nest sites, ingestion during foraging, or ingestion by chicks being fed macroplastic pieces by adults (Kühn and van Franeker 2020). Following exposure in the environment, macroplastics will also eventually break down into microplastics, making the pollution more accessible to a larger number of taxa (Lavers et al. 2014; O'Hanlon et al. 2017;

Blettler and Mitchell 2021). In addition to the damages caused to wildlife, macroplastics also have a large negative impact on global economies with an increase in clean-up costs, potential damage to shipping or fishery equipment, and a decline in tourism (Fadeeva and Van Berkel 2021; McIlgorm et al. 2022).

Monitoring of litter can be used to identify important litter sources and thereby inform relevant actions for effective mitigating measures to reduce plastics, and to evaluate the effectiveness of existing legislation and regulations (Galgani et al. 2013; Grelaud and Ziveri 2020; Chassignet et al. 2021). Assessment of litter on shorelines provides data for spatial and temporal assessments, such as amounts, composition, and pathways of plastic accumulation (Moriarty et al. 2015; Tekman et al. 2017; Alomar et al. 2020). For example, examination of litter from an uninhabited island in the central South Atlantic Ocean has demonstrated that vessel traffic may be the source of the island's litter as opposed to local or long-range transport (Ryan et al. 2019).

Shorelines are an important environmental compartment for monitoring marine litter (GESAMP 2019), because they (i) are where marine litter is often present in high densities, (ii) offer a measurable gradient from land-based sources compared to monitoring the seafloor or sea surface, shoreline monitoring, (iii) are more accessible, and (iv) have lower technological requirements and environmental impacts. As a result, shorelines are typically the first environmental compartment considered for quantifying marine litter, and surveys of plastics on shorelines are also part of many citizen science projects worldwide (e.g., Serra-Gonçalves et al. 2019; Kawabe et al. 2022).

Shorelines, at the confluence of the terrestrial and aquatic environments, may accumulate plastic items from local land- and sea-based sources as well as stranded plastic items from long-distance marine transport (Lebreton et al. 2019; Strand et al. 2021). As such, monitoring marine litter on shorelines is a widely used indicator of local, regional, and national litter amounts and composition of litter (Lebreton et al. 2019; OSPAR 2020; HELCOM 2021). For example, oceanic backtracking simulations for seven OSPAR beaches in Norway and Svalbard have demonstrated drift time, the possible origins of plastic, and whether it is possible for plastic from a particular source to reach a particular beach. The results show that it is highly probable that most of the litter observed on the Arctic OSPAR beaches in the study originated from regional fishing areas (Strand et al. 2021).

Litter on some shorelines has been monitored and reported on for decades, but not in a uniform manner. Sandy beaches are the most commonly monitored type of shoreline, and only 4% of shoreline studies worldwide monitor plastics in coarse, gravel sediments, or vegetated shores (Melvin et al. 2021). Virtually no study systematically sampled the zone of natural accumulation of organic material, encompassing the wrack line, or strand line (Melvin et al. 2021). Long-term data sets have been published that examine trends in shoreline litter over several decades from some areas (Rees and Pond 1995; Schulz et al. 2013), while other areas received little to no attention regarding the amount of litter on shorelines, and global reviews of shoreline monitoring revealed that between one quarter and two-thirds of the sampled shorelines have only been surveyed in single events, and thus may be impacted by the accumulation of litter for longer times (Serra-Gonçalves et al. 2019; Melvin et al. 2021). It is also important to note that in many regions, shoreline surveys for litter are often performed in combination with wider clean-up activities through different organizations that may have different metric and categories for data (e.g., the Great Canadian Shoreline Cleanup, Clean Up Australia, Keep Norway Beautiful; Konecny et al. 2018), usually with the help of volunteers (Jorgensen et al. 2021). There are also examples of involvement of local groups in citizen science-driven data generation, such as involving school children in a nationwide realm in Denmark covering also several Arctic sites in Greenland and Faroe Islands (Syberg et al. 2020). Even recently published peer-reviewed studies can present beach litter data that are difficult to compare. Some studies focus on sharing data that are single visits to remote sites and represent the first available data for a region (Andrades et al. 2020; Mallory et al. 2021), while other studies track data over 6 years of monitoring via monthly surveys (Watts et al. 2017). This wide array of collection methods and frequency can render any temporal or spatial comparisons difficult. Yet, protocols for such surveys should match as best as possible other monitoring efforts to have more comparable data across spatial or temporal scales. Mitigating the tensions between harmonized methods and often necessary variations in landscapes and practices is one goal of this article.

Here, we summarize the current status regarding litter shoreline monitoring in the Arctic, with the aim to provide suggestions for future monitoring programs across the pan-Arctic to facilitate comparisons among surveys and establish trends. The long-term goal is to offer a systematic monitoring scheme specific to the Arctic that answers the requirements of the international scientific community, Indigenous and other local Arctic communities, and different levels of government.

2. State of knowledge on monitoring litter on shorelines, globally, and in the Arctic

Many countries across different continents have implemented regular monitoring programs for litter on shorelines (GESAMP 2019), and there are several papers and reports that cover these extensively. We briefly discuss some of these programs to compare and contrast them with Arctic programs. Coordination of these programs occurs at different governmental and organizational levels through frameworks such as the multinational European Marine Strategy Framework Directive (MSFD), the NOAA Marine Debris Program in the United States, and the United Nations Environment Programme Regional Sea Conventions (EU 2021; Galgani et al. 2013; Lippiatt et al. 2013; OSPAR 2020; Burgess et al. 2021; Fleet et al. 2021; HELCOM 2021). In Australia, the Commonwealth Scientific and Industrial Research Organisation conducts nationwide coastal litter surveys (Willis et al. 2022), while in regions of India work is done primarily by

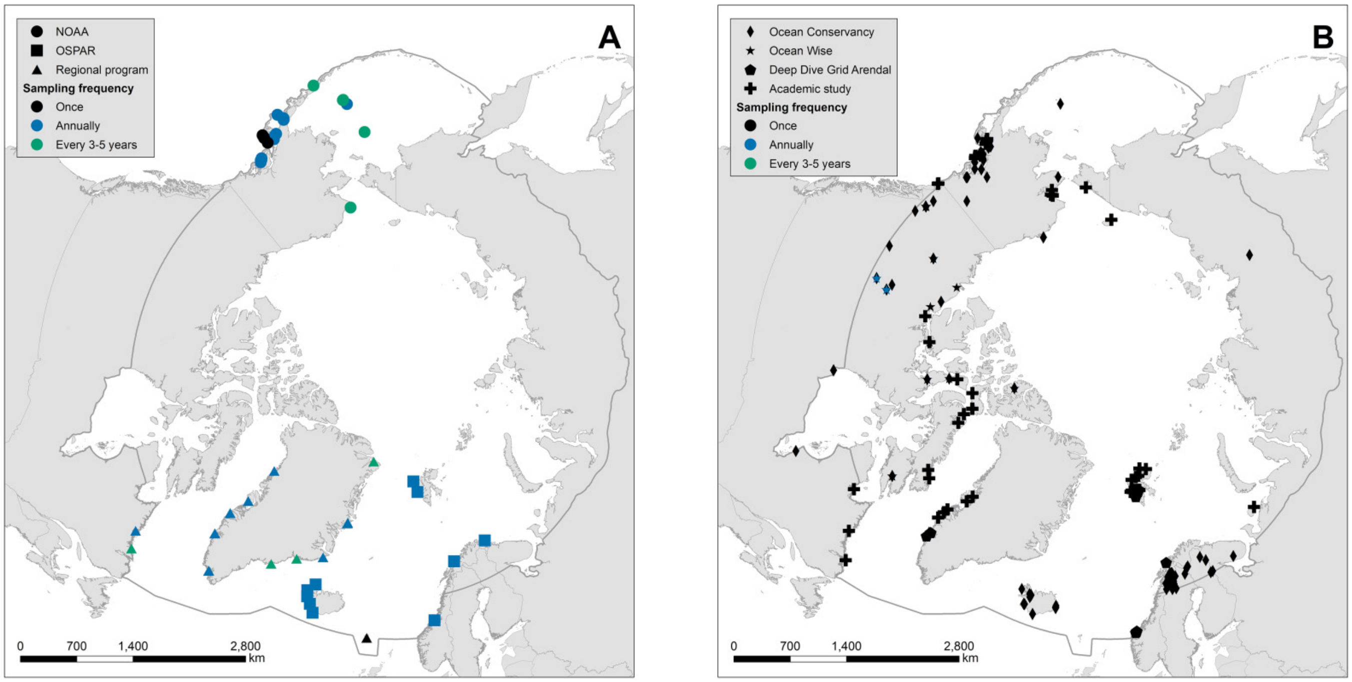


Fig. 1. Locations and sampling frequency of existing monitoring programs (A) and opportunistic surveys (B) of marine litter on shorelines of oceans, rivers, and lakes in the Arctic and subarctic regions (excluding Norwegian "Rydde" and "Rent Hav" portals). Base map: https://gadm.org/, projection: North Pole Lambert Azimuthal Equal Area 1288, and coordinate system: GCS WGS 198. Ocean Conservancy information include data from 1 January 2015 to present, exported on 23 August 2022 (https://www.coastalcleanupdata.org/reports). Deep Dive Grid Arendal locations were manually imported based on approximate locations.

research institutions (Perumal et al. 2021). The Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) has also published suggested guidelines for the monitoring and assessment of macro- and microplastics in the marine environment (GESAMP 2019). In addition, efforts are ongoing to harmonize surveys and obtain data on marine litter pollution that are comparable at larger scales (González-Fernández and Hanke 2017; Fleet et al. 2021; https://www.euroqcharm.eu/en/). This implies that those large global frameworks for monitoring of litter on shorelines (GESAMP, MSFD, NOAA, OSPAR) are relatively standardized, yet some national and regional variations in protocols exist, and those guidelines have to be widely adopted and used to reach broad-scale standardization. Over time, these shoreline monitoring activities are necessary to create a baseline, identify priority areas, and assess if there are changes in conditions that need to be addressed through management or policy (see Linnebjerg et al. 2020 for a list of regional and international policy frameworks pertaining to Arctic countries). This could, for instance, involve implementation or adjustments to Indigenous-led, local, national, or regional action plans to reduce plastic pollution.

More specific to the Arctic, knowledge of amounts, distribution, composition, and sources of litter on shorelines do exist (e.g., Bergmann et al. 2017; Halsband and Herzke 2019; Mallory et al. 2021), but this knowledge is relatively scarce and fragmented, and to a large extent based on noncoordinated efforts (Melvin et al. 2021). Within the Arctic Monitoring and Assessment Programme (AMAP) boundary, which has its own guidelines (AMAP 2021), the NOAA and OSPAR programs, perform their own monitoring (specifically in Alaska for NOAA, and in northern Norway, Svalbard, Iceland, and East Greenland for OSPAR; Fig. 1). Continuing to use these existing monitoring frameworks for litter monitoring will be advantageous for time series consistency and data comparability (Table 1). However, these two frameworks can also be challenging to harmonize and more detailed comparisons at a larger Arctic scale, as the historical data are generated with different monitoring methods and to date pan-Arctic assessments are lacking.

There are also other programs that have been collecting information on shoreline litter in the Arctic region. Several programs and national databases have information gathered from surveys carried out by researchers, institutions, or dedicated crowdsourcing communities. This information ranges from single assessments of macroplastics and litter items collected opportunistically by volunteers, to regular coastal clean-up campaigns; data are collected using platforms such as the Debris Tracker (formerly known as the Marine Debris Tracker) or the Ocean Wise Shoreline Cleanup (https://debristracker.org; www.shorelinecleanup.ca). According to the online tracking tool of Debris Tracker, data on shoreline litter are very heterogeneous within the AMAP Arctic boundary. For example, there are over 5000 entries for coastal Nunatsiavut, and 2000 entries for in Alaska, but less than 300 entries for coastal northern Norway and less than 100 entries

Table 1. Summary of the OSPAR and NOAA protocols for shoreline litter monitoring.

Characteristics	OSPAR Protocol (OSPAR 2020)	NOAA Protocol (Burgess et al. 2021)
Beach type	Sand, gravel, or pebble and exposed to the open sea Accessible all year-round Accessible for litter removal Preferably, the survey sites are not subject to other cleaning	Sand or pebble Not necessarily accessible all year-round
Sample unit	100 m (minimum 50 m)	4 (or more) × 5 m transects in a 100 m length of shoreline
Litter size	>5 mm*	>2.5 cm
Frequency	Four times a year, if possible	Not specified
Collection	Recording counts by litter category Removal and disposal of litter Marking litter if removal not possible	Recording counts by litter category Removal optional but encouraged and documented

*Only items >2.5 cm were used for assessment.

for coastal Iceland (from 2010 until 15 July 2022). One consideration of these entries is that many of them are for litter that are not on shorelines, but in coastal cities, and occasionally inland freshwater rivers and lakes, and data are often collected during single clean-ups rather than continuous monitoring efforts. Thus, the type of data collected needs to be carefully considered before being used in global analysis.

To complement the monitoring guidelines set by AMAP (AMAP 2021), a desktop study (PAME 2019) reviewed the experiences and results of Arctic shoreline macroplastics assessments. The PAME (2019) concluded that there was a paucity of current available data, with insufficient timeline and geographical coverage to assess any patterns. Importantly, the incomparability of shoreline litter survey data in the Arctic precludes statistical analysis of trends in amounts, distribution, and composition of litter in Arctic areas at the time of publication. This is important to consider in that Arctic shoreline litter data often have more data points and a longer history of data collection than any other plastic pollution compartment (e.g., water, biota; Provencher et al. 2022).

For some years now, several Arctic countries have initiated monitoring activities for marine litter on shorelines according to either recommended monitoring protocols (OSPAR and NOAA; Fig. 1). In addition, Canadian data generated within the Nunatsiavut Government monitoring program (M. Liboiron, Memorial University, personal communication (2023)) can provide other relevant Arctic data that can be compared with the NOAA Marine Debris Monitoring and Assessment Project (MDMAP) and OSPAR data. Within the AMAP region shoreline litter data have been collected using several different frameworks (Fig. 1), as well as using several different methods, resulting in data in several different databases (Fig. 2). While data for Arctic shoreline litter are housed in at least six databases (Fig. 3), it also ranges in start dates from 2002 (i.e., OSPAR), to the most recent program starting in 2018 (i.e., GRID-Arendal).

3. Methods for shoreline surveys

3.1. Benefits

There are several benefits of monitoring litter on shorelines. First, macrolitter can give a good indication of sources, origins, and pathways of plastics and other types of litter in the environment because identification of macrolitter is relatively easy compared to microplastics (Cashman et al. 2020; Woo et al. 2021). In addition, the geography of the Arctic is rich in shorelines, and data can be collected with relatively time- and cost-effective efforts (Haseler et al. 2019) that do not require expensive laboratory equipment and can also be performed through both nationally coordinated support of local teams and networks, community programs, and crowdsourcing projects by nonacademic personnel following basic instructions and quality assessment/quality control (QA/QC) procedures (Falk-Andersson et al. 2019; GESAMP 2019). Finally, shoreline surveys have lower environmental impacts than seafloor, water column, or surface surveys, that require boats and either trawls or remotely operated vehicles (Maes et al. 2018; Choy et al. 2019).

3.2. Challenges

Arctic shorelines are often located in remote areas with difficult access because of the rugged nature of the landscape. In some areas, sandy shorelines do not exist, but rather shorelines comprise rocks and pebbles. Morphology of shorelines can vary and affect surveys and the detection of litter (Convey et al. 2002; Aguilera et al. 2016). Moreover, shorelines in the Arctic can be covered by ice and snow during long periods of the year, thus preventing survey activities from taking place consistently over time.

Different monitoring protocols are currently applied to shoreline litter monitoring (e.g., OSPAR and NOAA MDMAP protocols), which can be challenging or impossible to follow in a rigorous manner in the Arctic based on local conditions and seasonality, or can require additional effort when combining data for circumpolar assessments. In addition, some litter items relevant to the Arctic may currently be included in a broader category from the existing protocols. For example, in the NOAA protocol, shotgun cartridges are lumped with other plastic and animals and aquaculture feed bags are lumped with all other bags (see Supplementary material). In Greenland, shotgun cartridges are one of the most common pieces of nonfishing debris found on the shorelines (Kirkfeldt 2016); in Alaska, strapping bands are items of specific inter-

 Arctic Science 9: 807–824 (2023) | dx.doi.org/10.1139/as-2022-0047

Fig. 2. Sampling method (A) and data storage location (B) of marine litter on shorelines of oceans, rivers, and lakes in the Arctic and subarctic regions. Base map: https://gadm.org/, projection: North Pole Lambert Azimuthal Equal Area 1288, and coordinate system: GCS WGS 198.

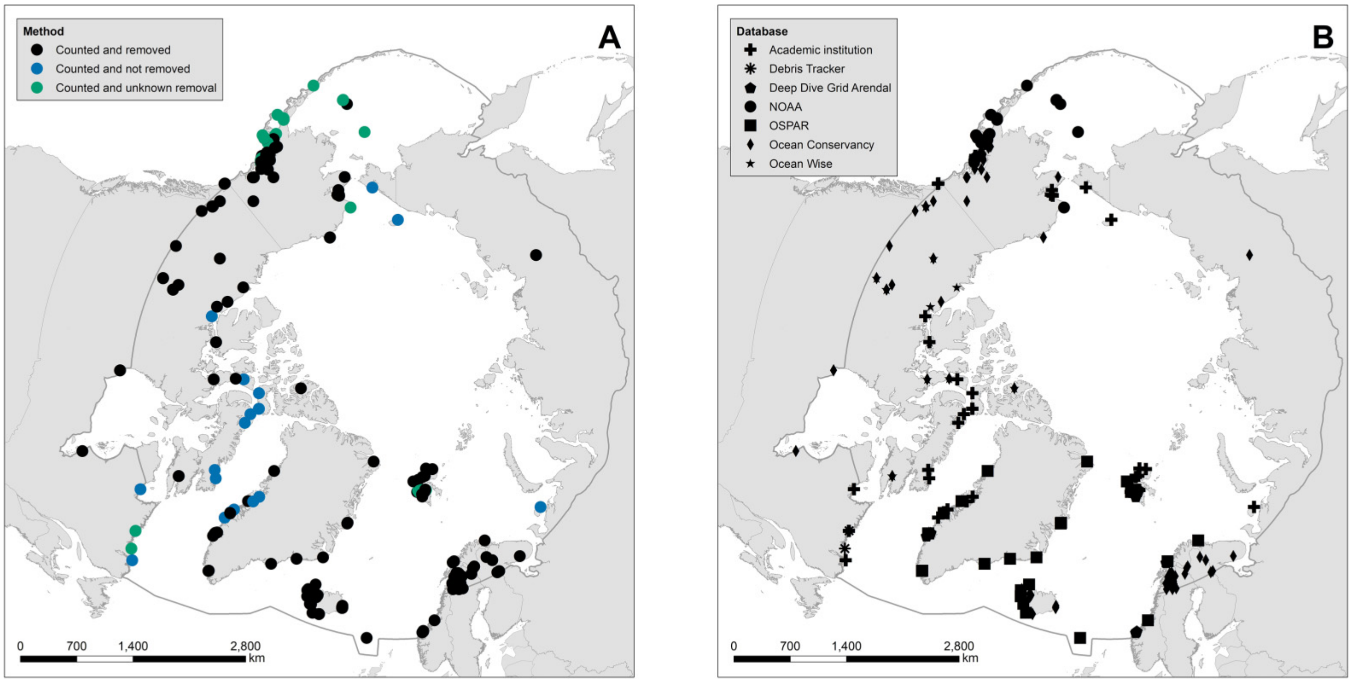
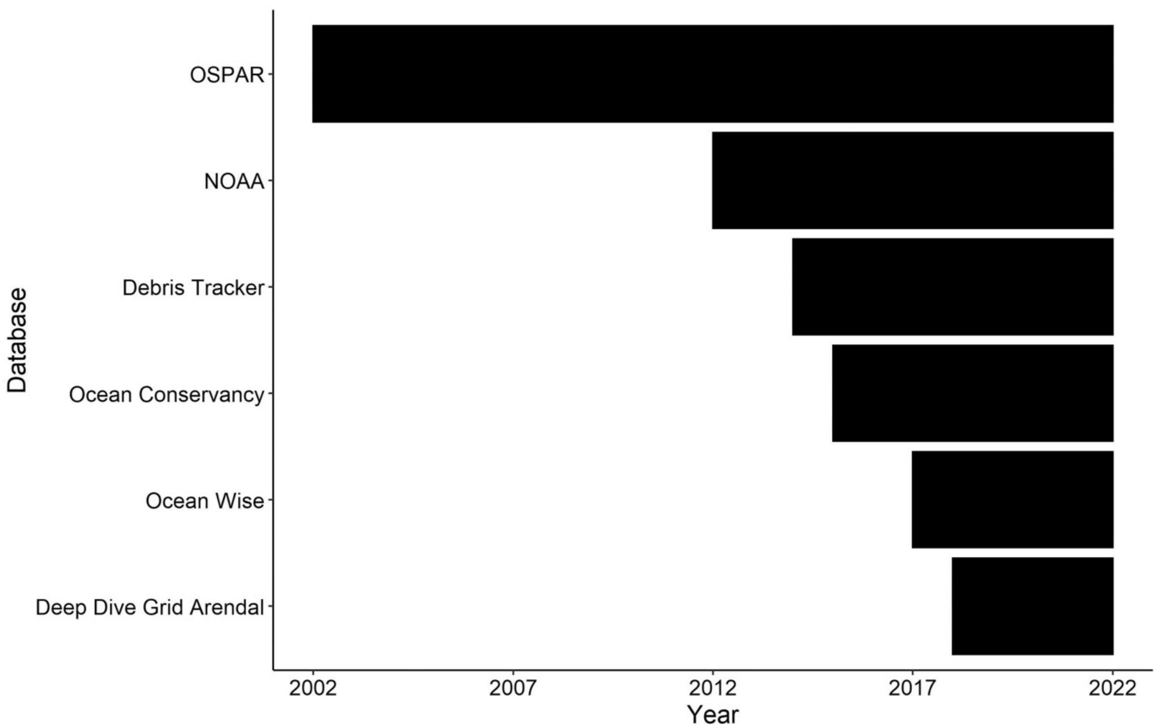


Fig. 3. Public databases that store monitoring program and opportunistic survey data of marine litter on shorelines of oceans, rivers, and lakes in the Arctic and subarctic regions and the years for which these data are available.



est (Merrell 1980; Raum-Suryan et al. 2009). As such, both shotgun cartridges and strapping bands are important items in Arctic litter, and should be singled out, and targeted for management. Globally, one of the greatest challenges is the harmonization of data to make them comparable across different studies (Serra-Gonçalves et al. 2019; Uhrin et al. 2022), and this currently applies to existing data sets from the Arctic shoreline litter data as well.

Shoreline clean-ups are an important component to engaging with the public on plastic pollution issues, but specific site selection of clean-ups and their overrepresentation in data sets can result in a misrepresentation of the amount of litter on the shoreline during surveys (Baak et al. 2022). While shoreline counts are an essential part of tracking litter patterns, the public engagement of cleaning beaches in highly used areas may cause a skew in composition of litter types and litter estimates if targeted sites are within proximity of communities (Rees and Pond 1995; Asensio-Montesinos et al. 2019). The physical characteristics of the shoreline (gradient, substrate, exposition) are also responsible for the retention and amount of litter present (Haarr et al. 2019). Clean-up data are not easily comparable across clean-up or among organized monitoring data sets, and a large number of clean-up data are required for meaningful analysis. This becomes particularly challenging when trying to compare litter data on shorelines across large geographic areas that have different levels of human use. Representation of remote shorelines in the monitoring program is, thus, important to obtain data of amounts, composition, and trends of litter primarily washed ashore from the sea and subsequently more indicative of environmental reference levels in the sea. Furthermore, categorization of the investigated shorelines according to the level of human use (e.g., urban, suburban, or remote/natural), as recommended for instance in the HELCOM guidelines for monitoring beach litter (HELCOM 2021), is also an important prerequisite to try to accommodate the skewing of litter data and to perform reliable assessments.

3.3. Monitoring strategies

The Arctic region is characterized by a low human population density, a less developed infrastructure, and cold climatic conditions. These special conditions call for particular attention in the design and establishment of shoreline litter monitoring programs. Some shoreline litter surveys have been conducted in different Arctic regions using the internationally recommended OSPAR (OSPAR 2010, 2020) or NOAA (Burgess et al. 2021) protocols, although often with some modifications (Mallory et al. 2021). In the NOAA protocol, litter is counted, and removal is optional, while under the OSPAR protocol the litter is removed from a site, which is monitored four times a year, if snow cover allows it (Table 1). A previous NOAA protocol (Lippiatt et al. 2013) distinguished between "accumulation surveys" in which all litter items falling within a 100 m shoreline segment were removed and "standing-stock surveys" in which all litter items were recorded but not collected from within subsampled transects. These two methods are now phased out after several iterations of project evaluation, as measuring accumulation versus standing stock really depends on the frequency of removal, frequency of surveys, and whether or not one can control the incidence of clean-up activities between surveys (Lippiatt et al. 2013). Differing survey protocols pose challenges for a wider pan-Arctic survey strategy because it would complicate data comparisons (Fig. 2).

Different monitoring strategies for litter on shorelines are outlined in GESAMP (2019). The work by GESAMP focuses on several additional components that should be included in shoreline surveys with a focus at the global scale. This includes assessing litter in different substrates of shorelines and how they may influence the retention of macroplastics, and the effects of the direction of the prevailing winds on the macroplastics accumulation on shorelines.

Given the advantages and limitations for the adaptation of predetermined criteria in the OSPAR and NOAA monitoring guidelines, along with other relevant criteria, with regard to implementation of an Arctic monitoring strategy, there are several Arctic-specific characteristics to consider. These include

- the shoreline typography and location (e.g., urban/populated versus remote/reference),
- survey frequencies and the importance of continuity in monitoring surveys on selected shorelines,
- the expertise of the monitoring personnel,
- categories used for the registration of the different predefined litter items,
- the presence of ice or snow,
- units for reporting data, and
- the quality assurance of the surveys.

These criteria can be important for data comparison in wider regional assessments of shoreline litter, where establishment of continuous monitoring efforts are required, and, therefore, also need to be considered within the context of the Arctic environment. Given the global experience, and building on those surveys that have been carried out in the Arctic, we make several recommendations for shoreline litter monitoring specific to Arctic programs seeking to contribute to large-scale monitoring objectives (Table 2).

3.4. Where to monitor

Several criteria are necessary to allow for surveys to contribute to region-wide comparisons and trends assessment. The first criterion for the selection of a survey location is coastal morphology. Beach-like shorelines, to a large extent, receive marine litter washed ashore from the sea and are easier and safer to thoroughly examine than rocky shores. However, in many parts of the Arctic shorelines are dominated by rocks and cliffs, and beach-like coastal segments are dominated by pebbles or different-sized stones will only occur in smaller bays. Rocky shores are known to retain more plastics of different sizes than their sandy counterparts (McWilliams et al. 2018). The occurrence of sandy beaches, which are often preferred for international beach litter monitoring programs, are scarce in much of the Arctic, although they do occur in some areas (e.g., Mallory et al. 2021). In addition, these beach-like segments are often delimited by rocky shores and therefore not always a full 100 m in length. Therefore, shorter shoreline segments should be accepted for Arctic shoreline monitoring even though a 100 m segment is the recommended length in both the OSPAR and NOAA guidelines. Linear length of the survey should be noted in the database for future statistical work. As data become more available, we will need to consider the statistical implications of representativity and probability that come with site selections. Pro-

Table 2. Summary of recommended monitoring criteria for site selection and conduction of marine litter surveys on Arctic shorelines.

Criteria	Recommended site selection criteria and survey parameters
Coastal morphology	Beach-like shoreline with sand, gravel, pebbles, or stones of different sizes, but not shorelines with cliffs; preferably with clear depositional wash-up lines from both normal tidal conditions and more extreme weather conditions.
Length of survey segment	100 m defined by start and end GPS positions, but shorter segments as low as 50 m can be accepted, if limited by rocky shores.
Type of shorelines	Remote shorelines, preferably located at an outer coastline (not inner fjords) and pointing toward the open sea.
	Urban or semi-urban shorelines, located in or close to town or settlements and receiving litter from local activities.
Definition of survey area	From the waterline to the back of the beach including the zone deposited during high-water levels caused by storms. Slippery areas due to wrack on stones below the normal waterline in the tidal zone can be excluded because of unsafe conditions for litter collection. A consistent and well-defined survey area of the shoreline should be identified for temporal monitoring.
Accessibility	The coastline should be accessible from land or by a boat.
Survey frequency	At least one to two seasonal surveys should be performed per year per location, i.e., summer (May–July) and/or autumn (August–October).
The presence of ice and snow	Ice and snow act as temporary sink for litter, which is released as ice and snow melt (Scopetani et al. 2019), and the presence and coverage of ice and snow should be noted.
Collection and registration of litter items	When possible, all manmade litter items sized >2.5 cm should be collected and identified according to categories of litter described in either the NOAA or OSPAR guidelines.
Removal of litter items	Litter items should be removed from the shoreline when possible, and status of removal indicated in all litter reporting. Regional guidelines need to be adhered to, which may prohibit picking up older manmade items in some remote locations (Griebel 2014).
	Larger litter items that cannot be transported to an appropriate waste disposal site, might be moved inland away from the shoreline, so the items are not registered again during the next survey. Items too large to move should be marked on site in a way that they would not be registered again.

grams should undertake regular reviews in the design and site selection procedures. Those program reviews are necessary for them to evolve alongside the policy needs.

The second criterion is the selection of a survey location based on the expected relative impact from different litter sources. The location can be chosen because the shoreline predominantly receives litter washed ashore from the open sea (reference or remote shoreline), or because the shoreline is impacted by contributions from local sources (urban or semi-urban shoreline; Cheshire et al. 2009). Hence, the amounts and composition of marine litter can depend on both the geographical location relative to marine and land-based activities occurring in close proximity (Storrier et al. 2007), and the dominant hydrological conditions and wind regimes that will transport litter from the sea (Cunningham and Wilson 2003). This implies that the selection of the survey locations can determine the marine litter data that are collected. In the design of a monitoring program for shoreline marine litter, the type of information preferred or required from the effort (i.e., hours, counters) should therefore be considered.

An appropriate shoreline used for long-term monitoring is ideally located in an uninhabited area with minimal visible human activity nearby, preferably on an outer coastline and pointing toward the open sea. This means it will principally reflect the pressures from long-range transport, sea-based activities, and a more diffuse distribution of litter from land-based local sources. These characteristics allow for a reference value of litter deposition that does not receive an overrepresentative amount of litter from local sources.

In contrast to this, the selection of so-called urban or semi-urban shoreline located in the vicinity of towns and smaller settlements, including harbors, sewage effluents, and open dump sites, will more notably reflect the impact of local litter sources. The ability and precision in the identification of either local or regional/international sources of litter to the marine environment can, thus, be influenced from the types and locations of beaches included in the monitoring program. Identification of litter sources is a prerequisite for implementation of targeted actions toward their reduction. Determination of the efficiency of mitigation actions also requires measures of the amounts of litter released from the source or trends of the amounts and composition observed in the marine environment.

Another criterion is that the shoreline should be accessible from land or by a boat (or other common form of transportation), so litter items can be easily removed from the shoreline, and it can be revisited for future surveys on a yearly basis. This may or may not be achievable in some regions of the Arctic given both the location of the sites, and the amount and nature of pollution that is deposited. For example, in some regions of Alaska discarded fishing nets weighing several tons have been recovered from beaches, or the quantity of debris encountered has required significant logistical support (Young 2009). As such, removal transport, and disposal of this marine litter often requires a coordinated effort and significant external resources.

The removal of any items should respect the Indigenous and other local authorities and communities, especially regarding the protection of archaeological artifacts. For example, in Nunavut, "any tangible evidence of human activity that is more than 50 years old" is defined as an archaeological artifact (Griebel 2014). Personnel should be instructed on the potential presence of any expected or possible archaeological artifacts and best practices on how to avoid impacting them during monitoring and removal activities; this may require an archaeology permit.

3.5. Definition of survey area

A clear definition of the survey area and the units used for registration of shoreline litter are essential to make the data comparable among surveys using standardized approaches (i.e., OSPAR and NOAA protocols). The survey area should preferably be 100 m sections parallel to the waterline (see monitoring type, below), but an adaptation for Arctic conditions could include lengths 50–100 m based on accessibility and availability.

Defining the survey area is also important for opportunistic sampling. Some studies have implemented the 100 m section using portable transects during visits to beaches from vessels (Mallory et al. 2021). That project also used shorter transects in some cases, and then used a normalization factor, demonstrating how such protocols can be implemented on beaches even when the protocol must be adapted.

The width of the monitoring area is from the edge of the high tide water level to the back of the beach/shoreline, characterized by the first presence of dunes, rocks, or a vegetation line (back barrier). Vegetation past the back barrier often acts as a litter sink, so debris from within an additional 2 m (as per Olivelli et al. 2020) into the back barrier can be counted, separately from the main beach, if the back barrier is permeable to wind and water, and, thus, capable of trapping debris. For Arctic beaches, a clear shift in the primary substrate or the presence of a barrier is often less visible. Therefore, the width could be the part of the beach directly affected by marine water fluctuations including the zone deposited as a result of storms. Being familiar with the beach being surveyed is important and much information could be acquired from local and Indigenous knowledge.

3.6. Frequency of monitoring surveys

The NOAA protocol does not specify a monitoring frequency, and the OSPAR guidelines recommend four annual monitoring surveys per beach (winter, spring, summer, and autumn), and recognize that snow, ice, and personal presence may limit surveys to summer months (Table 1; Fig. 1A). In the Arctic, climatic conditions shorten the feasible period for beach litter monitoring, as do often high costs and logistic constraints (Mallory et al. 2018). Hence, during winter and spring, access to the beaches, particularly the remote beaches, can be very difficult or even impossible. Furthermore, ice and snow cover can render monitoring impossible or difficult. These challenges may limit the monitoring frequency, as demonstrated in the frequency of past sampling efforts in the region (Fig. 1B). The feasible number of surveys under Arctic conditions may only be one to two surveys per beach per year. Allowing fewer monitoring surveys per year will affect the confidence in deriving baseline levels and assessing trends for the Arctic. For instance, it has recently been recommended for monitoring under the EU MSFD that national and subregional baseline levels be based on median values of data from a minimum of 40 monitoring surveys within a 6 year monitoring period because this constitutes an optimum point for achieving a reasonable confidence interval (van Loon et al. 2020). The median assessment value is robust against extreme values, which frequently occur in shoreline litter monitoring. However, this level of survey on shorelines in many regions of the Arctic is not possible or practical and must be modified. Further analyses are, therefore, needed to assess the implications of fewer available AMAP-relevant survey data on the statistical power of trend analyses (Smith and Markic 2013). This should be considered when designing monitoring strategies for litter on shorelines in Arctic and subarctic regions.

When ice and snow are present, it will almost certainly influence findings, with the number of litter items being underestimated in the presence of ice and snow. Therefore, presence of ice and snow and potentially the date of the last snow storm must be noted in the survey forms and ensuing database. Scopetani et al. (2019) conducted surveys focused on microplastics on shorelines in sediment, ice, and snow, and noted acute differences between the matrices. Even while it presents challenges, some areas of the Arctic are covered by ice and snow nearly year-round and these areas cannot necessarily be left out of monitoring activities. Moreover, some research questions about land use and seasonality can only be answered with sampling during seasons with ice and snow coverage. Thus, in addition to the measures introduced above, consideration of harmonized sampling practices that include shorelines partly covered by ice and snow are nonexistent so far (Melvin et al. 2021), but should be considered. At the least, the percentage of the shoreline covered in snow should be reported.

3.7. Litter registration

For shoreline litter surveys in the Arctic, recording of litter items has predominantly been performed according to the OSPAR guidelines (e.g., data from Norway, Greenland, and Iceland) and the NOAA guidelines (e.g., data from Alaska and Canada). These two guidelines provide different litter item lists (Supplementary material). The NOAA guidelines include descriptions of 44 different litter types divided into six material categories whereas the OSPAR list gradually has been appended over time to include 126 different litter types divided into 11 material categories.

Subsequently, the description of litter items in the OSPAR and NOAA guidelines do not match and used separately, the two guidelines will generate different information on the composition of different types of litter items including, for example, generation of a top 10 list of the most often registered litter items. Therefore, if wider Arctic assessments are to include and compare marine litter data generated with both guidelines, some level of aggregation of litter types is needed to obtain a more comparable data set. We propose a resolution to this data challenge on how such an aggregation of litter items particularly relevant to the Arctic could be performed across multiple survey types to ensure inclusion of categories that are common in Arctic data sets (Table 3).

In addition to the proposed list of aggregated litter items useful for pan-Arctic assessments, it may also be worthwhile to add some other more specific litter items that are relevant to the Arctic because of local uses or frequency of occurrence in the Arctic. This could include items related to cruise ships, fishing activities, or items typically found in local communities and dump sites. Information of littering of these specific items may also be relevant for future regional action plans to combat marine litter in the Arctic. Litter codes for these items could be introduced by subgrouping of existing litter types in the OSPAR and NOAA lists.

Another key parameter to follow in Arctic shoreline litter monitoring will be source characterization (Uhrin et al. 2022), as warming conditions and changing sea ice regimes may bring differing types, sources, and amounts of plastic to the Arctic (Bergmann et al. 2022). Thus, in addition to grouping the items according to the material categories, the litter types can potentially also be grouped according to their sources and uses. For instance, OSPAR (2010) has previously proposed a division of the litter items with the main focus on sea-based sources, i.e., resulting specifically from fishery and aquaculture, or from shipping operation.

- Fishery and aquaculture,
- Ship galley waste, and shipping operational waste,
- Sanitary waste,
- Public littering (e.g., tourism),
- No source characterized.

For the Arctic, it would be important to differentiate litter from local communities versus long-range litter. In addition, litter originating from construction and mining activities, hunting, and land-based waste handling can also be relevant to consider as part of a source assessment to the marine litter from an Arctic perspective.

The assignment of shoreline litter items to the different source categories can also be refined with the help of Arctic communities which can identify common waste items that are more likely locally derived versus those that come ashore via long-range transport. Community members often have detailed knowledge of local source patterns and pathways, e.g., by a Matrix Scoring Technique based on the likelihood that the litter items recorded originated from specific types of characterized sources (Tudor and Williams 2004; Schäfer et al. 2019).

Further developments in methods to perform source characterizations from shoreline litter data are currently being assessed in different national and international frameworks. For instance, for the European MSFD monitoring, a new protocol has recently been developed as part of the Joint List of Litter Categories for Marine Macrolitter Monitoring (Fleet et al. 2021) with a more detailed source characterization of litter items to better address most of the relevant litter items targeted in the OSPAR and HELCOM regional action plan for marine litter, the European single-use plastic directive. As such, this may also be relevant for other regions, such as the US states and regional action plans for marine litter.

The general unit for reporting data should be the number of litter items recorded per survey, corresponding to a 100 m shoreline. Ideally the monitored shoreline length should be 100 m (see Section 3.4 "Where to monitor" and Table 2), but if a different length is surveyed, data should be normalized to the number of items per 100 m. Considering the process of fragmentation undertaken by plastic, we recognize that the number of litter items is not the only unit that can be used to report litter items. When feasible, weight is also a valuable method to report litter and can reveal varying contributions of the different litter categories (Smith and Turrell 2021).

3.8. Logistics

Preferably, trained personnel should conduct repeated surveys at specifically selected shorelines, revisited with regular frequency. This setup ensures high-quality monitoring data and more easily enables trend analyses and comparison of surveys. Because access and surveying are difficult for Arctic remote shorelines, the establishment of cross-linking networks with both local people and external scientific personnel involved in other field activities in these remote areas may be valuable. For example, in High Arctic Canada, seabird population monitoring (Gutowsky et al. 2022) is often paired with contaminant or plastic ingestion monitoring (Provencher et al. 2009; Bianchini et al. 2022), maximizing use of logistic and financial resources (Mallory et al. 2018). The regularity of other field activities in specific remote areas may vary. This may, therefore, imply a trade-off between the total number of shoreline surveys and the consistency in the selected shorelines and monitoring personnel. We recommend that the shoreline litter monitoring program is mainly based on trained personnel revisiting the same shoreline locations. However, less experienced personnel can be a valuable resource to ensure a continued monitoring at remote stations that will otherwise not be covered.

Community-based survey programs allow greater capacity for regular and even continuous monitoring as well as providing locally relevant research questions and data interpretation, including identification of likely local sources of marine litter (Falk-Andersson 2021). The Arctic Marine Litter Project based at Wageningen University in the Netherlands actively involves local stakeholders and experts in identifying shoreline litter, as it leads to more robust interpretation (Strietman et al. 2021). When outside researchers respect local knowledge and capacities it can increase the number and success of partnerships, including partnerships where communities can lead and implement shoreline litter surveys that are specific to the region and contribute to globally comparable data sets.

3.9. Safety

Monitoring should begin 1 h after high tide to prevent surveyors being cutoff by incoming tide, and activities be undertaken by a minimum of two people on remote shorelines.

Table 3. Examples of marine litter items with higher Arctic relevance because of local uses and sources.

Description	OSPAR code	NOAA category	Material category
Melted plastic pieces, e.g., from outdoor incinerations	46, 47, 117	Other	Plastic
Detonating cords for explosives including fragmented pieces	46	Other	Plastic
Aquaculture and animal feed bags	23	Other	Plastic
Strapping bands	39	Other	Plastic
Plastic sanitary bags	102	Personal care products	Plastic
Trawl nets and gill nets including pieces	115, 116	Ropes and nets	Plastic
Shotgun cartridges	43	Shotgun shells and wads	Plastic

Note: If included, separate reporting codes need to be defined. The list can be modified or expanded over time based on inputs, e.g., from local stakeholder and rightsholder communities or from the process of developing the Arctic regional action plan.

This is particularly important in some areas of the Arctic, where some of the largest tides globally can be found (e.g., Frobisher Bay). While approaching and monitoring shorelines, individuals should be mindful of their surroundings, especially in regard to wildlife, such as polar bears (Ursus maritimus, Phillips 1774). Dangerous or suspicious looking items, such as ammunition, chemicals, fuel, and medicine should not be removed. Instead, photos of the items should be taken and sent to the relevant authorities.

4. Quality assurance/quality control

4.1. Quality assurance

Hands-on training for field workers is generally recommended for conducting harmonized monitoring surveys on the shorelines, registration of the specific litter items according to the specifications in monitoring guidelines, and reporting the data to relevant databases. An online monitoring toolbox (https://marinedebris.noaa.gov/monitoring-toolbox) for NOAA MDMAP provides access to video tutorials, shoreline survey protocols, and item categorization guides, field datasheets, and examples of data uses. A link to the MDMAP database where data visualizations may be viewed is also available. All of the above are useful resources for training shoreline surveyors in the Arctic.

Trained and experienced surveyors can be established within research programs or long-term, community-led programs that perform coordinated monitoring continuously, or volunteers/crowdsourcing science doing single clean-ups. Wider coordination of teams and networks monitoring different sites can here benefit the general knowledge sharing of how to perform the surveys, how to identify litter items, and how to submit data to databases, by more harmonized and quality-assured means. Detailed photo documentation of all collected litter for each survey can be useful for later identification and confirmation (Bergmann et al. 2017). In many cases, photo documentation of every item may not be possible. We recommend items that are difficult to categorize or specifically notable for their low or high frequency should be the priority, for documentation purposes. Alternatively, for Arctic shorelines where access may be time-limited, survey coordinators may consider photographing sections of shorelines transects to survey a larger number of sites in a short time period (Mallory et al. 2021). This method should only be used under time-restricted situations and if the litter items cannot be collected. A correction factor may be applied to consider detection limitation.

4.2. Quality control

Data collected during beach surveys should go through a process of validation. This process can involve recounting the number of plastic items found during the survey and having several people agreeing on the type of litter found. Photo documentation might be helpful for this purpose. In addition, the possibilities for QA/QC steps should also be considered on data submitted to the monitoring databases prior to data assessments, e.g., by outlier controls and being able to have later contact with the actual data originators of the data sets. Under regional sea conventions, the OSPAR supporting scientific expert group (Intersessional Correspondence Group on Marine Litter (ICG-ML)) has been appointed national QC coordinators, responsible for assuring the quality of the submitted data on beach litter into the OSPAR monitoring database.

4.3. Data management and reporting formats for databases

To perform thorough spatial and temporal trend analyses of the amount and composition of marine litter on Arctic shorelines, the availability of quality-assured monitoring data stored and secured in long-term databases is necessary. These databases are most useful when they are easily accessed, and the data they contain can be easily queried or exported in readily usable formats. The OSPAR beach litter database (https://beachlitter.ospar.org) stores and secures marine litter data generated according to OSPAR beach litter guidelines and collected at reference beaches in the Northeast Atlantic region, which includes some parts of the Arctic Sea. The reported data need to be normalized to 100 m beach segments. Currently, the database contains some AMAP relevant data from Arctic and subarctic parts of Norway, Iceland, Faroe Islands, East Greenland, and West Greenland. However, OSPAR is considering not hosting data from locations outside the OSPAR maritime area, even though they are generated using comparable data formats. This may affect the long-term storage of the monitoring data from some locations, such as West Greenland or Arctic Canada. Subsequently, the use of another database must be considered, even though a wider OSPAR database would be a better platform for the standardization and harmonization of monitoring efforts and data assessments in these neighboring regional seas (Fig. 2B).

Monitoring data generated according to the NOAA MDMAP guidelines can be reported to NOAA's public database: https://mdmap.orr.noaa.gov/, which covers data from both maritime areas and the Great Lakes in the USA. A search shows data from 34 shoreline locations in Alaska, although only two of these are in the AMAP region. The International Council for the Exploration of the Sea (ICES) Database on Oceanography and Marine Ecosystems database (https://www.ices.dk/data/data-portals/Pages/DOME.aspx) can potentially also host these types of beach litter databases for specific types of litter. However, as of this writing, this database is yet to host significant relevant data, to our knowledge.

4.4. Data generated by crowdsourcing

Crowdsourcing refers to coordinated but usually ad hoc mobilization of local and tourist individuals for large-scale clean-ups and/or in-depth data collection and later analysis. Crowdsourcing activities have a strong component of public engagement in the scientific and policy-making process, and can act as an important removal action for combatting plastic pollution in the environment. There are several examples of crowdsourcing and clean-up activities in the Arctic that generate data for assessing amounts and composition of litter items on shorelines, including Canada (e.g., https://civiclaboratory.nl/2015/07/25/beach-clean-ups/; Liboiron et al. 2020; https://shorelinecleanup.org/), Alaska (Polasek et al. 2017), and Norway, where the nongovernmental organization Keep Norway Beautiful (https://ryddenorge.no/) is coordinating and mapping clean-up activities in cooperation with other groups and with the Norwegian Centre against Marine Litter (https://www.marfo.no/). The crowdsourcing data collected in Norway, which also include many AMAP-relevant locations, are of sufficient quality to identify the main sources of marine litter in Norway on a broad scale but do have some limitations (Falk-Andersson et al. 2019). In these projects, professional scientists typically accompany the volunteer participants to ensure data quality and comparability (GESAMP 2019), and in some cases, they can address temporal trends (Haarr et al. 2020). Comparable assessments on the usefulness of crowdsourcing-generated data have also been performed in Europe by the European Environmental Agency, which hosts the database for the European Marine Litter Watch (https://www.eea.europa.eu/publications/marine-litter-watch). The wide range of protocols and structures within crowdsourcing efforts create uncertainty in how to integrate them with assessments based on monitoring.

For cleanup-related crowdsourcing science, data can be sent to and retrieved from a public data set at the Debris Tracker website (https://debristracker.org/), the Norwegian citizen science database "Rydde" hosted by MARFO (https://www.marfo.no/artikkel/rydde/), or the Marine Litter Watch developed by the European Environmental Agency (https://marinelitterwatch.discomap.eea.europa.eu). These platforms can provide data frames, and sometimes produce quantitative data on litter (e.g., total litter items per unit area (m^2) or per unit length (m) of a shoreline transect). One challenge with these platforms is that they often lack information on effort; the denominator is unknown. This hampers the comparability of this type of data to more standardized surveys. One solution is for these online tracking tools to incorporate a unit of effort in relation to observations as has been done with online bird observation tools (e.g., eBird; https://ebird.org). These listed platforms or apps are examples, and it is recognized that additional apps or platforms will be developed over time, although the specific internet connectivity challenges of the Arctic may continue to make them difficult to use there. New apps or platforms should be evaluated for potential utility as part of monitoring efforts on a case-by-case basis, and importantly, consider how the data will be harmonized with existing data during the idea development stage. Crowdsourcing projects and their resulting data are valuable in themselves, but if data generated can be used in a comparative way with data from more systematic and continuous monitoring efforts for marine litter on shorelines (e.g., for identifying sources and/or wider spatial and temporal trend assessments in the Arctic), they could have significantly more value.

4.5. Data from community-based monitoring

Unlike crowdsourcing science, community-based monitoring is driven by Indigenous and other local researchers who are also stakeholders and rightsholders in monitoring plastics and other contaminants in a way that answers local research questions and policy needs (Linnebjerg et al. 2020). This approach ties together producers and end users of the data at the local scale. This can be done with or without outside researchers, but for the sake of an interest in comparable data, partnerships with outside researchers or research organizations can be a valuable source of long-term monitoring and harmonized data sets. Examples of partnered community-based plastic monitoring programs in the Arctic include Oceans North and Ocean Wise's Arctic Community Ocean Plastics Initiative (Canada, https://www.oceansnorth.org/en/blog/2018/08/monitoring-microplastics-in-an-arctic-community/), The Saami Council's Kola Waste Project (Russia, ACAP 2021), and Nunatsiavut Government's "Nunalinni kamatsianik palastikkinik igitauKattatunik Nunatsiavummi/Community-based monitoring of plastic pollution in Nunatsiavut" project (Canada; Pijogge and Liboiron 2021).

5. Other considerations for litter monitoring in the Arctic

As a supplement to basic NOAA and OSPAR adjusted monitoring described above, other survey types can be relevant for studying amounts and composition of litter on shorelines, and these can provide additional information on sources and trends. These survey types are, at the moment, either only applied on smaller geographical scales, need further research and development, or are too time-consuming or expensive to be implemented for monitoring on a wider scale.

5.1. In-depth clean-ups' analyses

An alternative survey based on more detailed, in-depth analyses (in some studies called "deep dives") has been developed for analyzing large amounts of litter collected from large-scale clean-ups (Falk-Andersson 2021). This method can be a way to more efficiently provide detailed insights on sources and origin of marine litter at local or even (sub) regional scales, because this type of study includes a more detailed focus on the origin of different types of litter, for example, fishery-related items (see GRID Arendal website for an example of deep dive; https://deepdive.grida.no/). In addition, the framework for this type of survey can act as a useful tool when communicating with specific groups of stakeholders by involving them more directly. Such in-depth studies of marine litter on shorelines have been performed in different areas of northern Norway and Svalbard (Falk-Andersson et al. 2018; Falk-Andersson and Strietman 2019) and have recently been expanded to Greenland and Iceland (Strietman et al. 2020, 2021; Strietman 2021). These surveys require both the collection of significantly larger amounts of litter and a more detailed registration of several of the litter items surveys than is currently described in the NOAA and OSPAR monitoring guidelines.

5.2. Large-scale aerial surveys

Aerial surveys using drones or small manned aircrafts can be very helpful for carrying out rapid assessments of the distribution of macroplastic over larger geographical scales by relying on the analyses of photo images (e.g., following major natural events, such as storms and tsunamis, or following accidents at sea; Martin et al. 2018; GESAMP 2019; Andriolo et al. 2022). Aerial surveys also have the potential to identify coastlines that are prone to accumulation, with high densities of accumulated plastic and other litter on the shorelines with difficult access. This information can be used to optimize the efforts of clean-up actions (Deidun et al. 2018). Furthermore, aerial surveys, such as those carried over Hawaiian Islands can be particularly valuable for assessing marine litter in remote areas and could potentially be applied in monitoring programs (Moy et al. 2018). However, recognition of specific sizes of groups and types of marine litter will depend on image resolution, development of artificial machine learning algorithms for recognizing litter items, and amounts and types of other natural material on the shorelines that can interfere with identification (Deidun et al. 2018; Lo et al. 2020).

5.3. Modeling transport and identification of vulnerable coastlines

Hydrodynamic modeling can provide information on the importance of long-range transport with the North Atlantic or Pacific Ocean currents and can identify coastlines that are vulnerable to receiving larger amounts of litter from the open sea, both on larger and more local geographical scales (Jalón-Rojas et al. 2019; Uzun et al. 2022). For instance, in Norway, oceanographic models for transport of floating litter and probability of stranding along the coast have been developed along the entire coastline (Strand et al. 2021; Mats Huserbråten, Institute of Marine Research, unpublished data). The model will be validated with clean-up data from the NGO Keep Norway Beautiful (https://holdnorgerent.no/). Another Norwegian study has tested a GIS-based predictive model to identify marine litter hotspots in northern Norway that could predict a more effective site selection for maximizing removal of litter during organized coastal clean-up actions (Haarr et al. 2019). Modeling efforts should focus on understanding where accumulation of plastic litter may occur in the Arctic, and where regions with high levels of accumulation may need targeted efforts to survey and contribute a more holistic perspective on shorelines levels of litter at the pan-Arctic level. The expansion of this type of work to the broader pan-Arctic will greatly inform future shoreline litter assessments.

5.4. Surveys of riverine litter inputs

In addition to marine shorelines, freshwater shorelines are also an important environment to monitor (van Emmerik et al. 2022). Rivers are natural pathways for litter, and the human density along rivers will influence the amount of litter, which then accumulates in lakes and can ultimately end up on marine shorelines (Rech et al. 2014; Hoellein et al. 2015; Schwarz et al. 2019). Yet, litter monitoring on freshwater shorelines has received less attention than marine coastal habitats (González-Fernández and Hanke 2017), and more effort is required to sample freshwater shorelines to better assess the potential input of plastic pollution to the Arctic Ocean (Blettler et al. 2018; Blettler and Wantzen 2019; Melvin et al. 2021).

5.5. Weathering and fate of litter in the Arctic marine environment

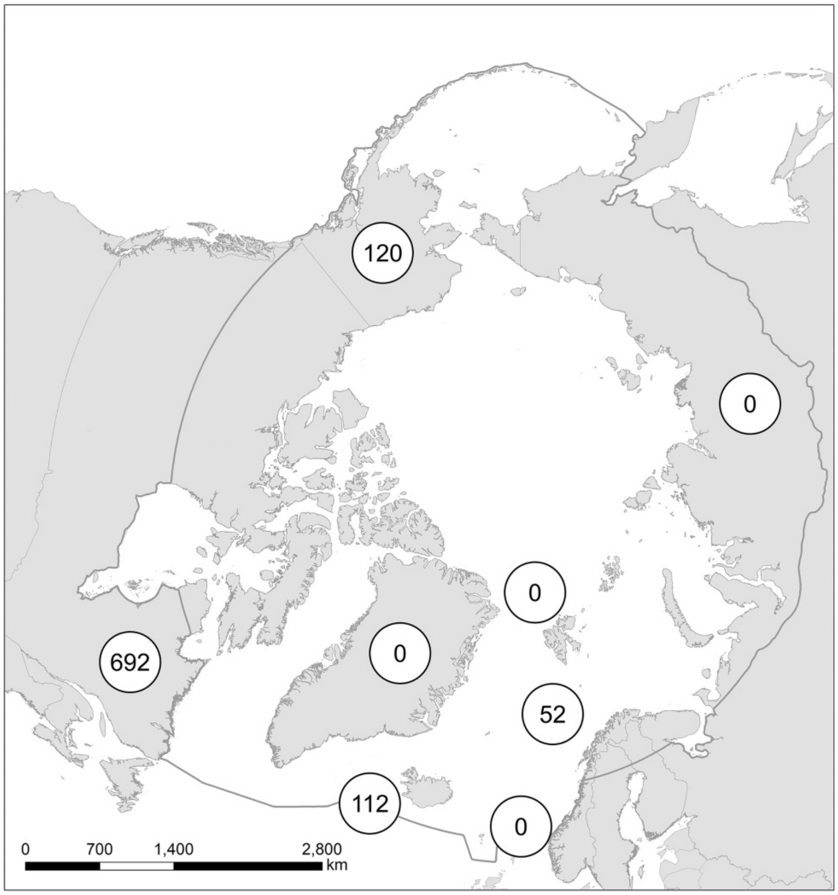
Research on litter weathering and fate on shorelines should be carried out to better understand the process of disintegration from macroplastics to microplastics (MacLeod et al. 2021). Over time, the weathering and fragmentation will decrease the particle size of litter items. This will render the detection and the identification of the source of pollution more difficult. Shorelines are ideal environments to promote the chemical and mechanical weathering process (Arp et al. 2021; Dąbrowska 2021) with the abrasion from the sand and wave action, the exposure to solar ultraviolet (UV) radiation, and the thermal and chemical actions (Corcoran et al. 2009). These processes might be slightly different in the Arctic environment and represent a knowledge gap (Halsband and Herzke 2019).

5.6. Data consolidation considerations

There is a need to recognize that shoreline litter data sets are among the richest data sets on plastic pollution globally, including the Arctic region. However, we still lack both large-scale regional and global assessments due to the absence of harmonized methods. There is a multitude of programs collecting data on litter in the Arctic, potentially providing essential information. However, those databases or reports are sometimes difficult to query and hinder the use of their valuable data to the wider community. Some groups do regional reports that only use one method/database en-

 Arctic Science **9:** 807–824 (2023) | dx.doi.org/10.1139/as-2022-0047

Fig. 4. Individual pieces count for each region from the Debris Tracker database in the year 2021 .



tries (e.g., NOAA, OSPAR), but there is a challenge in bringing together multiple data sets (as discussed above). The litter types described by NOAA and OSPAR guidelines could be comparable, with some harmonization (Supplementary material). Some reports are only available in not widely read languages, and therefore accessible to a limited public (see https://holdnorgerent.no/wp-content/uploads/2022/09/Rydderapporten-2021-komp.pdf for an example). Some programs are victims of their own success and they have so much data that it is impossible to query the database for a meaningful period of time. For example, we found it difficult to extract meaningful data from the Debris Tracker database (Fig. 4), as query by country, region, or year is not possible.

Given the massive efforts to reduce plastic pollution in the environment, and the need for evidence-based decision-making, there is a need to prioritize efforts on shoreline litter data to examine pan-Arctic data sets together and start to develop methods to reconcile different databases to understand temporal and spatial trends. Similar discussions are taking place globally, aligning and examining the comparability of databases (Hapich et al. 2022), but more of these types of efforts are needed in the Arctic before any pan-Arctic regional assessment can be carried out. This includes the need to create accessible databases to promote regional comparisons and trend analysis across the pan-Arctic. Beyond the Arctic, tracking marine debris trends globally is still a large challenge, with for example, the lack of interoperability for database platforms (Walker et al. 2021).

6. Recommendations for Arctic shoreline monitoring

Being able to assess trends of either amount, composition, or distribution of macroplastics requires a large number of sampling points to achieve statistical power. Determining such trends on Arctic shorelines requires the establishment of a coordinated monitoring effort, which should comprise more comparable harmonized surveys carried out throughout the Arctic as performed within other Regional Seas Conventions (e.g., OSPAR 2010 and HELCOM 2021). Furthermore, past and future data should be shared with the different stakeholders, rightsholders, government agencies, and the scientific community through peer-reviewed publications and/or plain-language reports, supported with easily accessible databases. This is critical even for data not collected in a standardized way, as researchers can begin to apply meta-analysis techniques that can account for such differences.

Given that shoreline litter monitoring is carried out globally and is a major component of several plastic pollution initiatives, we recommend several actions be the focus in the Arctic region for shoreline litter assessments. Alignment of the OSPAR and NOAA protocols are most relevant when it comes to data assessments that combine data sets generated with the two protocols.

1. Where possible surveys of shoreline litter be carried out using existing protocols (OSPAR or NOAA), ideally using a designated 100 m shoreline section, and no less than a 50 m section.
   The choice of which protocol to use will be region-dependent.
2. In addition to the standard litter item lists used, we recommend that all surveys use an extended list that includes items that are commonly found in the Arctic (see Table 3).
3. Full descriptions of shorelines, including geomorphology, substrates, wind patterns, seasonality, and presence of ice and snow should be included in data.
4. Surveys should target remote shorelines that will reflect long-range transport via water currents, and also shorelines that will inform questions related to potential local sources of shoreline litter.
5. Training of the monitoring personnel should be prioritized preferably by side-learning or alternatively by use of detailed tutorials to achieve consistent data collection.
6. Indigenous and other Arctic communities and their existing knowledge should be respected and partnered with to increase capacity for long-term, regular data collection and locally relevant analysis.
7. Establishment of shoreline locations for long-term continuous litter monitoring should be prioritized to obtain high-quality data for trend assessment.
8. All shoreline data should be made available as soon as possible through the use of open, accessible, and easy to query databases.

7. Conclusions

Shoreline litter surveys are among the most common recordings carried out and highly recommended type of plastic pollution monitoring in the world, and programs for shoreline litter data collection in the Arctic have been in place for several years. Unfortunately, no pan-Arctic, widespread trend assessment can currently take place (PAME 2019), due to differences in monitoring strategies and protocols employed, and limitations in the spatial and temporal extent of existing data. Therefore, efforts for plastic pollution monitoring should consider when, where, and how to implement shoreline litter monitoring as part of the primary tools. But to use this type of data to inform policies, action plans, and mitigation strategies, an equal amount of effort is needed to ensure that data on amounts and as well as litter composition are harmonized and available for trend analysis, including regional assessments, on a regular basis. Optimization and also development of new potential methods and tools should be limited to those that are fulfilling a specific data gap or community need, as the proliferation of databases and methods are currently hampering data synthesis. Data management, accessibility, and trend analysis must be primary components of any shoreline litter monitoring program to facilitate future Arctic assessments on shoreline litter.

Acknowledgements

We thank Hillary K. Burgess, Amy V. Uhrin, and Peter Murphy for their comments in earlier versions of this manuscript. We also thank three reviewers for their valuable feedback that greatly improved the manuscript.

Article information

History dates

Received: 16 November 2022
Accepted: 20 March 2023
Accepted manuscript online: 22 June 2023
Version of record online: 1 August 2023

Notes

This paper is part of a collection entitled Litter and Microplastics Monitoring in the Arctic.

Copyright

Data availability

We have included a supplemental file with the metadata and decisions on analyses.

Author information

Author ORCIDs

Bjørn E. Grøsvik https://orcid.org/0000-0003-0794-2212
Mark L. Mallory https://orcid.org/0000-0003-2744-3437
Jennifer F. Provencher https://orcid.org/0000-0002-4972-2034

Author notes

Jennifer Provencher and Mark Mallory served as Associate Editors at the time of manuscript review and acceptance and did not handle peer review and editorial decisions regarding this manuscript.

Author contributions

Conceptualization: LF, BEG, ML, JFP, JS
Data curation: JEB, JFP
Formal analysis: ILP, MLM
Funding acquisition: JFP
Methodology: JEB, LF, BEG, ML, MLM, JFP, JS
Project administration: MLM, JFP
Supervision: MLM

Validation: LF, BEG, JFP, JS
Visualization: ILP, JEB, BEG, MLM, JFP, JS
Writing – original draft: ILP, LF, BEG, ML, MLM, JFP, JS
Writing – review & editing: ILP, JEB, LF, BEG, ML, MLM, JFP, JS

Competing interests

We know of no competing interests for this work.

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/as-2022-0047.

References

Addamo, A.M., Laroche, P., and Hanke, G. 2017. Top Marine Beach Litter Items in Europe. EUR 29249 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-79-87711-7. doi:10.2760/496717, JRC108181.

Aguilera, M.A., Broitman, B.R., and Thiel, M. 2016. Artificial breakwaters as garbage bins: structural complexity enhances anthropogenic litter accumulation in marine intertidal habitats. Environmental Pollution, **214**: 737–747. doi:10.1016/j.envpol.2016.04.058.

Alomar, C., Compa, M., Deudero, S., and Guijarro, B. 2020. Spatial and temporal distribution of marine litter on the seafloor of the Balearic Islands (western Mediterranean Sea). Deep-Sea Research Part I, **155**: 103178. doi:10.1016/j.dsr.2019.103178.

Andrades, R., Pedago, T., Godoy, B.S., Reis-Filho, J.A., Nunes, J.L.S., Grillo, A.C., et al. 2020. Anthropogenic litter on Brazilian beaches: baseline, trends and recommendations for future approaches. Marine Pollution Bulletin, **151**: 110842. doi:10.1016/j.marpolbul.2019.110842.

Andriolo, U., Garcia-Garin, O., Vighi, M., Borrell, A., and Gonçalves, G. 2022. Beached and floating litter surveys by unmanned aerial vehicles: Operational analogies and differences. Remote Sensing (Basel), **14**: 1336. doi:10.3390/rs14061336.

Ansari, M., and Farzadkia, M. 2022. Beach debris quantity and composition around the world: a bibliometric and systematic review. Marine Pollution Bulletin, **178**: 113637. doi:10.1016/j.marpolbul.2022.113637.

Arctic Contaminants Action Program (ACAP). 2021. Kola Waste Project: Cleaning of the Sámi Territory in the Murmansk Region (2018–2020). Arctic Contaminants Action Program (ACAP). pp. 16.

Arctic Monitoring and Assessment Programme (AMAP). 2021. AMAP litter and microplastics monitoring guidelines. Version 1.0. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway. pp. 257.

Arp, H.P.H., Kühnel, D., Rummel., C., MacLeod, M., Potthoff, A., Reichelt, S., et al. 2021. Weathering plastics as a planetary boundary threat: Exposure, fate, and hazards. Environmental Science & Technology, **55**: 7246–7255. doi:10.1021/acs/est/1c1512.

Asensio-Montesinos, F., Anfuso, G., and Williams, A.T. 2019. Beach litter distribution along the western Mediterranean coast of Spain. Marine Pollution Bulletin, **141**: 119–126. doi:10.1016/j.marpolbul.2019.02.031.

Baak, J., Brown, Z.O., Provencher, J.F., and Mallory, M.L. 2022. A rapid assessment technique for coastal plastic debris sampling: applications for remote regions and community science. Marine Pollution Bulletin, **178**: 113641. doi:10.1016/j.marpolbul.2022.113641.

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G.W., Provencher, J.F., Rochman, C.M., et al. 2022. Plastic pollution in the Arctic. Nature Reviews Earth & Environment, **3**: 323–337. doi:10.1038/s43017-022-00279-8.

Bergmann, M., Lutz, B., Tekman, M.B., and Gutow, L. 2017. Citizen scientists reveal: marine litter pollutes Arctic beaches and affects wildlife. Marine Pollution Bulletin, **125**: 535–540. doi:10.1016/j.marpolbul.2017.09.055.

Bianchini, K., Mallory, M.L., Braune, B.M., Muir, D.C.G., and Provencher, J.F. 2022. Why do we monitor? Using seabird eggs to track trends in Arctic environmental contamination. Environmental Reviews, **30**: 245–267. doi:10.1139/er-2021-0078.

Blettler, M.C.M., Abrial, E., Khan, F.R., Sivri, N., and Espinola, L.A. 2018. Freshwater plastic pollution: recognizing research biases and identifying knowledge gaps. Water Research, **143**: 416–424. doi:10.1016/j.watres.2018.06.015.

Blettler, M.C.M., and Mitchell, C. 2021. Dangerous traps: macroplastics encounters affecting freshwater and terrestrial wildlife. Science of the Total Environment, **798**: 149317. doi:10.1016/j.scitotenv.2021.149317.

Blettler, M.C.M., and Wantzen, K.M. 2019. Threats underestimated in freshwater plastic pollution: mini-review. Water, Air, & Soil Pollution, **230**: 174. doi:10.1007/s11270-019-4220-z.

Burgess, H.K., Herring, C.E., Lippiatt, S., Lowe, S., and Uhrin, A.V. 2021. NOAA Marine Debris Monitoring and Assessment Project Shoreline Survey Guide. NOAA Technical Memorandum NOSOR&R 56. p. 20. doi:10.25923/g720-2n18 .

Cashman, M.A., Ho, K.T., Boving, T.B., Russo, S., Robinson, S., and Burgess, R.M. 2020. Comparison of microplastic isolation and extraction procedures from marine sediments. Marine Pollution Bulletin, **159**: 111507. doi:10.1016/j.marpolbul.2020.111507.

Cesarano, C., Aulicino, G., Cerrano, C., Ponti, M., and Puce, S. 2021. Scientific knowledge on marine beach litter: a bibliometric analysis. Marine Pollution Bulletin, **173**: 113102. doi:10.1016/j.marpolbul.2021.113102.

Chassignet, E.P., Xu, X., and Zavala-Romero, O. 2021. Tracking marine litter with a global ocean model: where does it go? Where does it come from? Frontiers in Marine Science, **8**: 667591. doi:10.3389/fmars.2021.667591.

Cheshire, A., Adler, E., Barbière, J., Cohen, Y., Evans, S., Jarayabhand, S., et al. 2009. UNPE/IOC Guidelines on survey and monitoring of marine litter. UNEP Regional Seas Reports and Studies No. 186. IOC Technical Series No. 83. p. 120.

Choy, C.A., Robison, B.H., Gagne, T.O., Erwin, B., Firl, E., Halden, R.U., et al. 2019. The vertical distribution and biological transport of marine microplastics across the epipelagic and mesopelagic water column. Scientific Reports, **9**: 7843. doi:10.1038/s45198-019-44117-2.

Convey, P., Barnes, D.K.A., and Morton, A. 2002. Debris accumulation on oceanic island shores of the Scotia Arc, Antarctica. Polar Biology, **25**: 612–617. doi:10.1007/s00300-002-0391-x.

Corcoran, P.L., Biesinger, M.C., and Grifi, M. 2009. Plastics and beaches: a degrading relationship. Marine Pollution Bulletin, **58**: 80–84. doi:10.1016/j.marpolbul.2008.08.022.

Cundell, A.M. 1973. Plastic materials accumulating in Narragansett Bay. Marine Pollution Bulletin, **4**: 187–188. doi:10.1016/0025-326X(73)90226-9.

Cunningham, D.J., and Wilson, S.P. 2003. Marine debris on beaches of the Greater Sydney Region. Journal of Coastal Research, **19**: 421–430.

Dąbrowska, A. 2021. Marine microplastics in polar region – a Spitsbergen case study. Water, Air, & Soil Pollution, **232**: 393. doi:10.1007/s11270-021-05346-2.

Deidun, A., Gauci, A., Lagorio, S., and Galgani, F. 2018. Optimising beached litter monitoring protocols through aerial imagery. Marine Pollution Bulletin, **131**: 212–217. doi:10.1016/j.marpolbul.2018.04.033.

European Union (EU). 2021. MSFD Technical Group on Marine Litter. *In* Current work items of the TG litter. European Union, Brussels, Belgium. [online]. Available from https://mcc.jrc.ec.europa.eu/main/dev.py?N=41&O=434&titre_chap=TG%2520Marine%2520Litter [accessed May 2023].

Fadeeva, Z., and Van Berkel, R. 2021. Unlocking circular economy for prevention of marine plastic pollution: an exploration of G20 policy and initiatives. Journal of Environmental Management, **277**: 111457. doi:10.1016/j.jenvman.2020.111457.

Falk-Andersson, J. 2021. Beach litter deep dives – A method for improved understanding of sources of and behaviour behind littering. Marine Pollution Bulletin, **167**: 112346. doi:10.1016/j.marpolbul.2021.112346 R.

Falk-Andersson, J., and Strietman, W.J. 2019. Svalbard beach litter deep dive [online]. SALT Report, No. 1033. p. 57. Available from https://salt.nu/en/projects/svalbard-beach-litter-deep-dives [accessed May 2023].

Falk-Andersson, J., Berkhout, B.W., and Abate, T.G. 2019. Citizen science for better management: lessons learned from three Norwegian beach litter data sets. Marine Pollution Bulletin, **138**: 364–375. doi:10.1016/j.marpolbul.2018.11.021.

Falk-Andersson, J., Olaussen, E.D., and Macintyre, C. 2018. Strandsøppel dypdykk for forebygging av marin forsøpling [Beach litter deep dive for prevention of marine littering] [online]. SALT Report, No. 1024. p. 53. Available from https://salt.nu/prosjekter/strandsoppel-dypdykk-for-forebygging-av-marin-forsopling-rapport [accessed May 2023].

Fleet, D., Vlachogianni, T., and Hanke, G. 2021. A joint list of litter categories for marine macrolitter monitoring: manual for the application of the classification system. EUR 30348 EN, Publications Office of the European Union, Luxembourg. doi:10.2760/127473.

Galgani, F., Hanke, G., Werner, S., and De Vrees, L. 2013. Marine litter within the European Marine Strategy Framework Directive. ICES Journal of Marine Science, **70**: 1055–1064. doi:10.1093/icesjms/fst122.

González-Fernández, D., and Hanke, G. 2017. Towards a harmonized approach for monitoring of riverine floating macro litter inputs to the marine environment. Frontiers in Marine Science, **4**: 86. doi:10.3389/fmars.2017.00086.

Grelaud, M., and Ziveri, P. 2020. The generation of marine litter in Mediterranean island beaches as an effect of tourism and its mitigation. Scientific Reports, **10**: 20326. doi:10.1038/s41598-020-77225-5.

Griebel, B. 2014. A guide to Nunavut archaeology and artifacts for northern communities. Inuit Heritage Trust Inc. Available from http://www.ihti.ca/eng/IHT-Archaelogy-Artifacts-Guidebook-Communities-English-Web-Opt.pdf [accessed July 2023].

Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP). 2019. Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean [online]. GESAMP, London, UK. Available from http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean.

Gutowsky, S.E., Baak, J.E., Gaston, A.J., and Mallory, M.L. 2022. Sea ice extent and phenology influences breeding of High Arctic seabirds: four decades of monitoring in Nunavut, Canada. Oecologia, **198**: 393–406. doi:10.1007/s00442-022-05117-8.

Haarr, M.L., Pantalos, M., Hartviksen, M.K., and Gressetvold, M. 2020. Citizen science data indicate a reduction in beach litter in the Lofoten archipelago in the Norwegian Sea. Marine Pollution Bulletin, **153**: 111000. doi:10.1016/j.marpolbul.2020.111000.

Haarr, M.L., Westerveld, I., Fabres, J., Iversen, K.R., and Busch, K.E.T. 2019. A novel GIS-based tool for predicting coastal litter accumulation and optimising coastal cleanup actions. Marine Pollution Bulletin, **139**: 117–126. doi:10.1016/j.marpolbul.2018.12.025.

Halsband, C., and Herzke, D. 2019. Plastic litter in the European Arctic: what do we know? Emerging Contaminants, **5**: 308–318. doi:10.1016/j.emcon.2019.11.001.

Hapich, H., Cowger, W., Gray, A., Tangri, N., Hale, T., Magdy, A., et al. 2022. Trash Taxonomy Tool: harmonizing classification systems used to describe trash in environments. Microplastics and Nanoplastics, **2**: 15. doi:10.1186/s43591-022-00035-1.

Haseler, M., Weder, C., Buschbeck, L., Wesnigk, S., and Schernewski, G. 2019. Cost-effective monitoring of large micro- and meso-litter in tidal and flood accumulation zones at south-western Baltic Sea beaches. Marine Pollution Bulletin, **149**: 110544. doi:10.1016/j.marpolbul.2019.110544.

HELCOM. 2021. Guidelines for monitoring beach litter. Available from https://helcom.fi/wp-content/uploads/2021/03/HELCOM-guidelines-for-monitoring-beach-litter.pdf [accessed July 2023].

Hoellein, T.J., Westhoven, M., Lyandres, O., and Cross, J. 2015. Abundance and environmental drivers of anthropogenic litter on 5 Lake Michigan beaches: a study facilitated by citizen science data collection. Journal of Great Lakes Research, **41**: 78–86. doi:10.1016/j.jglr.2014.12.015.

Jalón-Rojas, I., Wang, X.H., and Fredj, E. 2019. A 3D numerical model to Track Marine Plastic Debris (TrackMPD): sensitivity of microplastic trajectories and fates to particle dynamical properties and physical processes. Marine Pollution Bulletin, **141**: 256–272. doi:10.1016/j.marpolbul.2019.02.052.

Jorgensen, B., Krasny, M., and Bazten, J. 2021. Volunteer beach cleanups: civic environmental stewardship combating global plastic pollution. Sustainability Science, **16**: 153–167. doi:10.1007/s11625-020-00841-7.

Kawabe, L.A., Ghilardi-Lopes, N.P., Turra, A., and Wyles, K.J. 2022. Citizen science in marine litter research: a review. Marine Pollution Bulletin, **182**: 114011. doi:10.1016/j.marpolbul.2022.104011.

Kirkfeldt, T.S. 2016. Marine Litter in Greenland. Masters' thesis, Aalborg University, Denmark.

Konecny, C., Fladmark, V., and De la Puente, S. 2018. Towards cleaner shores: assessing the Great Canadian Shoreline Cleanup most recent data on volunteer engagement and litter removal along the coast of British Columbia, Canada. Marine Pollution Bulletin, **135**: 411–417. doi:10.1016/j.marpolbul.2018.07.036.

Kühn, S., and van Franeker, J.A. 2020. Quantitative overview of marine debris ingested by marine megafauna. Marine Pollution Bulletin, **151**: 110858. doi:10.1016/j.marpolbul.2019.110858.

Lavers, J.L., Bond, A.L., and Hutton, I. 2014. Plastic ingestion by Flesh-footed Shearwaters (*Puffinus carneipes*): implications for fledgling body condition and the accumulation of plastic-derived chemicals. Environmental Pollution, **187**: 124–129. doi:10.1016/j.envpol.2013.12.020.

Lebreton, L., Egger, M., and Slat, B. 2019. A global mass budget for positively buoyant macroplastic debris in the ocean. Scientific Reports, **9**: 12922. doi:10.1038/s41598-019-49413-5.

Liboiron, M., Duman, N., Bond, A.L., Liboiron, F., Ammendolia, J., Hawkins, K., et al. 2020. Regional report on plastic pollution in Newfoundland and Labrador, 1962–2019. Civic Laboratory for Environmental Action Research (CLEAR). Memorial University, St. John's.

Linnebjerg, J.F., Baak, J.E., Barry, T., Gavrilo, M.V., Mallory, M.L., Merkel, F.R., et al. 2020. Review of plastic pollution policies of Arctic countries in relation to seabirds. FACETS, **6**: 1–25. doi:10.1139/facets-2020-0052.

Lippiatt, S., Opfer, S., and Arthur, C. 2013. Recommendations for monitoring debris trends in the marine environment. NOAA Technical Memorandum NOS-OR&R-46.

Lo, H-S., Wong, L-C., Kwok, S-H., Lee, Y-K., Po, B.H-K., Wong, C-Y., et al. 2020. Field test of beach litter assessment by commercial aerial drone. Marine Pollution Bulletin, **151**: 110823. doi:10.1016/j.marpolbul.2019.110823.

MacLeod, M., Arp, H.P.H., Tekman, M.B., and Jahnke, A. 2021. The global threat from plastic pollution. Science, **373**: 611–665. doi:10.1126/science.abg5433.

Maes, T., Barry, J., Leslie, H.A., Vethaak, A.D., Nicolaus, E.E.M., Law, R.J., et al. 2018. Below the surface: Twenty-five years of seafloor litter monitoring in coastal seas of North West Europe. Science of the Total Environment, **630**: 790–798. doi:10.1016/j.scitotenv.2018.02.245.

Mallory, M.L., Baak, J., Gjerdrum, C., Mallory, O.E., Manley, B., Swan, C., and Provencher, J.F. 2021. Anthropogenic litter in marine waters and coastlines of Arctic Canada and West Greenland. Science of the Total Environment, **783**: 146971. doi:10.1016/j.scitotenv.2021.146971.

Mallory, M.L., Gilchrist, H.G., Janssen, M., Major, H.L., Merkel, F., Provencher, J.F., and Strøm, H. 2018. Financial costs of conducting science in the Arctic: examples from seabird research. Arctic Science, **4**: 624–633. doi:10.1139/as-2017-0019.

Martin, C., Parkes, S., Zhang, Q., Zhang, X., McCabe, M.F., and Duarte, C.M. 2018. Use of unmanned aerial vehicles for efficient beach litter monitoring. Marine Pollution Bulletin, **131**: 662–673. doi:10.1016/j.marpolbul.2018.04.045.

Martin, J., Granberg, M., Provencher, J.F., Liborion, M., Pijogge, L., Magnusson, K., et al. 2022. The power of multi-matrix monitoring in the Pan-Arctic region: plastics in water and sediment. Arctic Science. e-First. doi:10.1139/as-2021-0056.

McIlgorm, A., Raubenheimer, K., McIlgorm, D.E., and Nichols, R. 2022. The cost of marine litter damage to the global marine economy: insights from the Asia-Pacific into prevention and the cost of inaction. Marine Pollution Bulletin, **174**: 113167. doi:10.1016/j.marpolbul.2021.113167.

McWilliams, M., Liboiron, M., and Wiersma, Y., 2018. Rocky shoreline protocols miss microplastics in marine debris surveys (Fogo Island, Newfoundland and Labrador). Marine Pollution Bulletin, **129**: 480–486. doi:10.1016/j.marpolbul.2017.10.018.

Melvin, J., Bury, M., Ammendolia, J., Mather, C., and Liboiron, M. 2021. Critical gaps in shoreline plastics pollution research. Frontiers in Marine Science, **8**: 689108. doi:10.3389/fmars.2021.689108.

Merrell, T., Jr. 1980. Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Marine Environment Research, **3**: 171–184. doi:10.1016/0141-1136(80)90025-2.

Moriarty, M., Pedreschi, D., Stiokes, D., Dransfeld, L., and Reid, D.G. 2015. Spatial and temporal analysis of litter on the Celtic Sea from Groundfish Survey data: lessons for monitoring. Marine Pollution Bulletin, **103**: 195–205. doi:10.1016/j.marpolbul.2015.12.019.

Moy, K., Neilson, B., Chung, A., Meadows, A., Castrence, M., Ambagis, S., and Davidson, K. 2018. Mapping coastal marine debris using aerial imagery and spatial analysis. Marine Pollution Bulletin, **132**: 52–59. doi:01.1016/j.marpolbul.2017.11.045.

Novotny, T.E., and Slaughter, E. 2014. Tobacco product waste: an environmental approach to reduce tobacco consumption. Current Environmental Health Reports, **1**: 208–216. doi:10.1007/s40572-014-0016-x.

O'Hanlon, N.J., James, N.A., Masden, E.A., and Bond, A.L. 2017. Seabirds and marine plastic debris in the northeastern Atlantic: a synthesis and recommendations for monitoring and research. Environmental Pollution, **231**: 1291–1301. doi:10.1016/j.envpol.2017.08.101.

Olivelli, A., Hardesty, B.D., and Wilcox, C. 2020. Coastal margins and backshores represent a major sink for marine debris: insights from a continental-scale analysis. Environmental Research Letters, **15**: 074037. doi:10.1088/1748-9326/ab7836.

Opfer, S., Arthur, C., and Lippiatt, S. 2012. NOAA Marine Debris Shoreline Survey Field Guide, National Oceanic and Atmospheric Administration (NOAA), Marine Debris Program [online]. p. 19. Available from https://marinedebris.noaa.gov/sites/default/files/ShorelineFieldGuide2012.pdf [accessed March 2023].

OSPAR. 2010. Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area [online]. OSPAR, London, UK. p. 84. Available from https://www.ospar.org/ospar-data/10-02e_beachlitter%20guideline_english%20only.pdf [accessed March 2023].

OSPAR. 2020. CEMP Guidelines for marine monitoring and assessment of beach litter. EIHA(2) WP 20/01/04-Add.1. Available from https://www.ospar.org/documents?v=44122 [accessed March 2023].

Padha, S., Kumar, R., Dhar, A., and Sharma, P. 2022. Microplastic pollution in mountain terrains and foothills: a review on source, extraction, and distribution of microplastics in remote areas. Environmental Research, **207**: 112232. doi:10.1016/j.envres.2021.112232.

Perumal, K., Boopathi, V., Chellaiyan, S., Muthuramalingam, S., and Raja, P. 2021. Sources, spatial distribution, and abundance of marine debris on Thondi coast, Pal Bay, Southeast coast of India. Environmental Sciences Europe, **33**: 136. doi:10.1186/s12302-021-00576-x.

Pijogge, L., and Liboiron, M. 2021. Nunalinni kamatsianik palastikkinik igitau Kattatunik Nunatsiavummi/Community-based monitoring of plastic pollution in Nunatsiavut. Northern Contaminants Program Results Workshop, online [accessed March 2023].

Polasek, L., Bering, J.J., Kim, H., Neitlich, P., Pister, B., Terwilliger, M., et al. 2017. Marine debris in five national parks in Alaska. Marine Pollution Bulletin, **117**: 371–379. doi:10.1016/j.marpolbul.2017.01.085.

Protection of the Arctic Marine Environment (PAME). 2019. Desktop study on marine litter including microplastics in the Arctic. 11th Arctic Council Ministerial Meeting, Rovaniemi, Finland, 7 May 2019 [online]. PAME, Akureyri, Iceland. Available from https://www.pame.is/images/03_Projects/Arctic_Marine_Pollution/Litter/Desktop_study/Desktop_Study_on_marine_litter.pdf [accessed October 2022].

Provencher, J., Kögel, T., Lusher, A., Vorkamp, K., Gomiero, A., Peeken, I., et al. 2022. An ecosystem-scale litter and microplastics monitoring plan under the Arctic Monitoring and Assessment Programme (AMAP). Arctic Science. doi:10.1139/as-2021-0059.

Provencher, J.F., Gaston, A.J., and Mallory, M.L. 2009. Evidence for increased ingestion of plastics by northern fulmars (*Fulmarus glacialis*) in the Canadian Arctic. Marine Pollution Bulletin, **58**: 1092–1095. doi:10.1016/j.marpolbul.2009.04.002.

Raum-Suryan, K., Jemison, L.A., and Pitcher, K.W. 2009. Entanglement of Steller sea lions (*Eumetopias jubatus*) in marine debris: Identifying causes and finding solutions. Marine Pollution Bulletin, **58**: 1487–1495. doi:10.1016/j.marpolbul.2009.06.004.

Rech, S., Macaya-Caquilpán, V., Pantoja, J.F., Rivadeneira, M.M., Madariaga, D.J., and Thiel, M. 2014. Rivers as a source of marine litter – a study from the SE Pacific. Marine Pollution Bulletin, **82**: 66–75. doi:10.1016/j.marpolbul.2014.03.019.

Rees, G., and Pond, K. 1995. Marine litter monitoring programmes – a review of methods with special reference to national surveys. Marine Pollution Bulletin, **30**: 103–108. doi:10.1016/0025-326X(94)00192-C.

Ryan, P.G., Dilley, B.J., Ronconi, R.A., and Connan, M. 2019. Rapid increase in Asian bottles in the South Atlantic Ocean indicates major debris inputs from ships. Proceedings of the National Academy of Sciences of the United States of America, **116**: 20892–20897. doi:10.1073/pnas.1909816116.

Schäfer, E., Scheele, U., and Papenjohann, M. 2019. Identifying Sources of Marine Litter: Application of the Matrix Scoring Technique to the German North Sea Region. Report of behalf of Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN) and Schleswig-Holstein Agency for Coastal Defence, National Park and Marine Conservation (LKN.SH). doi:10.13140/RG.2.2.34106.85441.

Schulz, M., Neumann, D., Fleet, D.M., and Mathies, M. 2013. A multi-criteria evaluation system for marine litter pollution based on statistical analyses of OSPAR beach litter monitoring time series. Marine Environment Research, **92**: 61–70. doi:10.1016/j.marenvres.2013.08.013.

Schwarz, A.E., Ligthart, T.N., Boukris, E., and van Harmelen, T. 2019. Sources, transport, and accumulation of different types of plastic litter in aquatic environments: a review study. Marine Pollution Bulletin, **143**: 92–100. doi:10.1016/j.marpolbul.2019.04.029.

Scopetani, C., Chelazzi, D., Cincinelli, A., and Esterhuizen-Londt, M. 2019. Assessment of microplastic pollution: occurrence and characterisation in Vesijärvi lake and Pikku Vesijärvi pond, Finland. Environmental Monitoring and Assessment, **191**: 652. doi:10.1007/s10661-019-7843-z.

Scott, G. 1971. Plastics packaging and coastal pollution. International Journal of Environmental Studies, **3**: 35–36. doi:10.1080/00207237208709489.

Serra-Gonçalves, C., Lavers, J.L, and Bond, A.L. 2019. Global review of beach debris monitoring and future recommendations. Environmental Science & Technology, **53**: 12158–12167. doi:10.1021/acs.est.9b01424.

Smith, L., and Turrell, W.R. 2021. Monitoring plastic beach litter by number or by weight: the implications of fragmentation. Frontiers in Marine Science, **8**: 702570. doi:10.3389/fmars.2021.702570.

Smith, S.D.A., and Markic, A. 2013. Estimates of marine debris accumulation on beaches are strongly affected by the temporal scale of sampling. PLoS ONE, **8**: e83694. doi:10.1371/journal.pone.0083694.

Storrier, K.L., McGlasham, D.J., Bonellie, S., and Velander, K. 2007. Beach litter deposition at a selection of beaches in the Firth of Forth, Scotland. Journal of Coastal Research, **23**: 813–822. doi:10.2112/04-0251.1.

Strand, K.O., Huserbråten, M., Dagestad, K-F., Mauritzen, C., Grøsvik, B.E., Nogueira, L.A., et al. 2021. Potential sources of marine plastic from survey beaches in the Arctic and North Atlantic. Science of the Total Environment, **790**: 148009. doi:10.1016/j.scitotenv.2021.148009.

Strietman, W.J. 2021. Fishing nets on the coastline of the Arctic and North-East Atlantic: a source analysis: findings and recommendations based on an in-depth analysis of the sources, origin and pathways of fishing nets collected on beaches in Greenland, Iceland, Jan Mayen, Svalbard, the Netherlands, Norway, and Scotland [online]. doi:10.18174/541335.

Strietman, W.J., van den Heuvel-Greve, M., van den Brink, A., Leemans, E., Strand, J., and Bach, L. 2021. Beach litter in North-West Greenland: a source analysis [online]. doi:10.18174/541149.

Strietman, W.J., van den Heuvel-Greve, M.J., van den Brink, A.M., de Groot, G.A., Skirtun, M., and Bravo-Rebolledo, E. 2020. Resultaten bronanalyse zwerfafval Griend [online]. doi:10.18174/528599.

Syberg, K., Palmqvist, A., Khan, F.R., Strand, J., Vollertsen, J., Westergarrd Clausen, L.P., et al. 2020. A nationwide assessment of plastic pollution in the Danish realm using citizen science. Scientific Reports, **10**: 17773. doi:10.1038/s41598-020-74768-5.

Tekman, M.B., Krumpen, T., and Bergmann, M. 2017. Marine litter on deep Arctic seafloor continues to increase and spreads to the North at the HAUSGARTEN observatory. Deep-Sea Research Part I, **120**: 88–99. doi:10.1016/j.dsr.2016.12.011.

Tudor, D.T., and Williams, A.T. 2004. Development of a 'Matrix Scoring Technique' to determine litter sources at a Bristol Channel beach. Journal of Coastal Conservation, **9**: 119–127. doi:10.1007/bf02818948.

Uhrin, A.V., Hong, S., Burgess, H.K., Lim, S., and Dettloff, K. 2022. Towards a North Pacific long-term monitoring program for ocean plastic pollution: a systematic review and recommendations for shorelines. Environmental Pollution, **310**: 119862. doi:10.1016/j.envpol.2022.119862.

Uzun, P., Farazande, S., and Guven, B. 2022. Matehematical modeling of microplastic abundance, distribution, and transport in water environments: A review. Chemosphere, **288**: 132517. doi:10.1016/j.chemosphere.2021.132517.

van Emmerik, T., Mellink, Y., Hauk, R., Waldschläger, and Schreyers, L. 2022. Rivers as plastic reservoirs. Frontiers in Water, **3**: 786936. doi:10.3389/frwa.0221.786936.

van Loon, W., Hanke, G., Fleet, D., Werner, S., Barry, J., Strand, J., et al. 2020. A european threshold value and assessment method for macro litter on coastlines. EUR 30347 EN. European Union, Luxembourg. doi:10.2760/54369.

Walker, T.R., McGuinty, E., and Hickman, D. 2021. Marine debris database development using international best practices: a case study in Vietnam. Marine Pollution Bulletin, **173**: 112948. doi:10.1216/j.marpolbul.2021.112948.

Walker, T.R., Reid, K., Arnould, J.P.Y., and Croxall, J.P. 1997. Marine debris surveys at Bird Island, South Georgia 1990–1995. Marine Pollution Bulletin, **34**: 61–65. doi:10.1016/S0025-326X(96)00053-7.

Watts, A.J.R., Porter, A., Hembrow, N., Sharpe, J., Galloway, T.S, and Lewis, C. 2017. Through the sands of time: Beach litter trends from nine cleaned north Cornish beaches. Environmental Pollution, **228**: 416–424. doi:10.1016/j.envpol.2017.05.016.

Willis, K., Hardesty, B.D., Vince, J., and Wilcox, C. 2022. Local waste management successfully reduces coastal plastic pollution. One Earth, **5**: 666–676. doi:10.1016/j.oneear.2022.05.008.

Woo, H., Seo, K., Choi, Y., Kim, J., Tanaka, M., Lee, K., and Choi, J. 2021. Methods of analysing microsized plastics in the environment. Applied Sciences, **11**: 10640. doi:10.3390/app112210640.

Young, L. 2009. A tangled web: the mystery, math, and mechanics of net recycling. *In* Marine debris in Alaska: coordinating our efforts. *Edited by* M. Williams and E. Ammann. Alaska Sea Grant College Program, University of Alaska Fairbanks. pp. 71–74.