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Anthropogenic litter in marine waters and coastlines of Arctic Canada and West Greenland

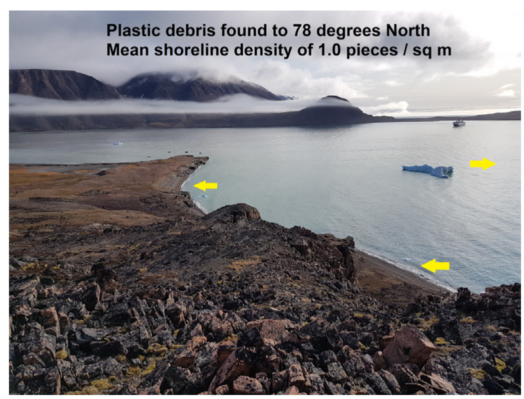
Mark L. Mallory [a,*], Julia Baak [a], Carina Gjerdrum [b], Olivia E. Mallory [a], Brittany Manley [c], Cedar Swan [c], Jennifer F. Provencher [d]

[a] Biology, Acadia University, 15 University Avenue, Wolfville, Nova Scotia B4P 2R6, Canada
[b] Canadian Wildlife Service, 45 Alderney Drive, Dartmouth, Nova Scotia B2Y 2N6, Canada
[c] Adventure Canada, 55 Woodlawn Avenue, Mississauga, Ontario L5G 3K7, Canada
[d] Environment and Climate Change Canada, National Wildlife Research Centre, Raven Road, Carleton University, Ottawa, Ontario K1A 0H3, Canada

HIGHLIGHTS

- Surveyed macroplastic litter at sea and coast of Arctic Canada and West Greenland
- Litter was found to 78°N and 83°W, and at 21 of 22 coastal landing locations.
- Litter densities averaged 1 item/m^2.
- More litter within 5 km of communities, suggests local and long-range sources

GRAPHICAL ABSTRACT



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ABSTRACT

Despite much interest and research into marine litter (including plastic debris) on beaches globally, relatively little is known about the density and distribution of this pollutant in Arctic environments, particularly Arctic Canada and West Greenland. We used two sources of data, observations of floating litter from vessels at sea, and quadrat surveys of litter on low slope beaches, to establish the first measures of anthropogenic litter densities in this region. Most litter observed (73%) was plastic, predominantly fragments, threads and sheets, with a mean density of 1.0 ± 1.7 (SD) items·m^{-2} along sandy/gravel beaches (median 1), and items were observed on the ocean surface as far as 78°N. Litter densities were significantly greater for sites within 5 km of communities, and much of the litter near remote communities was clearly from local sources. However, contrary to our predictions, we did not find that litter densities decreased with increasing latitude. Collectively, our results confirm that this global pollutant is distributed around much of this portion of the Arctic, and that better waste management strategies in a number of sectors may help reduce its occurrence in this remote region.

* Corresponding author.
E-mail address: mark.mallory@acadiau.ca (M.L. Mallory).

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1. Introduction

Marine litter has become one of the most topical environmental issues of the early 21st century (UNEP, 2016). Plastic debris (a subset of marine litter with deleterious health consequences) has been found in almost 700 wildlife species, notably those in the marine environment, but increasingly on land as well (Gall and Thompson, 2015). For several decades, ingestion of plastic pollution by wildlife, particularly seabirds, has been recognized as an increasing problem even in remote or isolated areas, such as the Arctic and sub-Arctic (Battisti et al., 2019; Mallory et al., 2006; Provencher et al., 2009). Marine litter can enter these areas through ocean currents, wind, sea ice or biotransport by seabirds (Mallory, 2008; Obbard, 2018). Indeed, marine litter has been found in diverse Arctic regions and environmental compartments, notably in sea ice (Peeken et al., 2018), snow (Bergmann et al., 2019) and water (Bergmann et al., 2016; Lusher et al., 2015). With increasing human populations, and associated increasing industrial and shipping activity in the resource-rich Arctic, expectations are that marine litter, notably plastic pollution, will increase here as well (Provencher et al., 2010; Smith and Stephenson, 2013).

Although recent studies have identified microplastics as being prevalent in the Arctic (e.g., Huntington et al., 2020), few studies have examined the prevalence or density of macro- and mesoplastics along Arctic coastlines (except for Svalbard; see Halsband and Herzke, 2019). This is somewhat surprising, because densities of larger plastic debris have been well-reported from many locations around the world (Serra-Gonçalves et al., 2019), often due to high public interest, outcry or costs of cleanup (Rodríguez et al., 2020), and consequent citizen involvement in assessing plastic densities (e.g., Bravo et al., 2009). Liboiron et al. (2020) recently completed a large study at the southernmost part of our range (Newfoundland and Labrador), but had only three sites for coastal beach data in Labrador. Presumably the high cost and challenging logistics of working in the Arctic (Mallory et al., 2018) compared to warmer regions have precluded similar assessments at higher latitudes. However, Arctic expedition (cruise) and research ships offer a suitable method to access and assess pollution of Arctic coastlines because they cover extensive distances (thousands of kilometres on some voyages; Dawson et al., 2018), travel to many locations, some close to remote communities, and most are keen to undertake activities aimed at preserving a healthy Arctic environment (Bergmann et al., 2017; Stewart et al., 2011).

We gathered the first data on marine litter along coastlines of Arctic Canada and West Greenland using two methods: observations of litter at sea, and quantifying density of litter in quadrats along low slope beaches. To do this, we made georeferenced recordings of litter observed floating on the ocean while conducting seabird surveys (e.g., Wong et al., 2014) on ships of opportunity (cruise ships, Coast Guard vessels, fishing vessels). As well, we used a novel approach of partnering with a Canadian expedition company to conduct rapid measurement of anthropogenic litter densities on as many landings as possible through this region. Here we describe the density of marine litter on Arctic beaches, the distribution of litter in the high latitude ocean, and the types of litter we encountered. We predicted that densities of litter would be greater at shoreline sites in or close to communities than those farther offshore or distant from communities, and that densities of litter on coastlines would decrease with increasing latitude.

2. Methods

2.1. At-sea surveys

From 2007 to 2019, the Canadian Wildlife Service of Environment and Climate Change Canada (CWS-ECCC) conducted seabird surveys at-sea from ships-of-opportunity in Atlantic Canada and eastern Arctic (Fig. 1), opportunistically documenting the occurrence of anthropogenic litter (Gjerdrum et al., 2012; Wong et al., 2014). This survey is not targeted to plastic pollution like other surveys (e.g., Bergmann et al., 2016; Ryan and Schofield, 2020); for example, one can count seabirds in storm conditions when observing litter would be difficult. Thus, our intent here was to document the distribution of litter, acknowledging that the amount of litter is an underestimate, but represents the first such data for this region. For this reason, we did not estimate densities of litter floating on the ocean using all of our data. However, for transects where litter was observed (i.e., we assumed ocean conditions were suitable and observers were attentive to litter), we compared the litter density$\cdot$km^{-1} for transects north and south of 60°N, as a coarse comparison of marine litter encounter rate in Arctic versus North Atlantic waters. The geographic location of each litter item was recorded as part of the observations database. Identification of litter were provided for 84% of the items, which were classified into eight categories: polystyrene foam (i.e., cups, packaging); paper and cardboard (i.e., boxes); discarded fishing gear (i.e., nets, floats, traps); plastic (i.e., wrappers, tarps, bags); balloons; wood (i.e., lumber, branches); industrial (i.e., oil drums, paint cans); and aluminum cans.

2.2. Coastal surveys

In August and September of 2018 and 2019, we travelled with Adventure Canada aboard the *MS Ocean Endeavour* on three trips that moved along the coast of Labrador and Nunavut, Canada, as well as West Greenland (Fig. 2). At 22 locations (weather and ocean conditions permitting), we went ashore and conducted a survey of anthropogenic litter at low slope coastal locations (sand or gravel beaches; Cheshire et al., 2009). However, our protocol differed in two major ways from other litter survey approaches to accommodate the specific requirements of the expedition objectives. First, landings at shore for these expeditions are generally targeted at visitor experience/tourism or resupply, and vessels are on a strict schedule to embark and/or disembark passengers. Thus, to gather data on densities of anthropogenic litter, our sampling had to be rapid with little equipment. Second, the expedition had a “no touch” policy for any materials on the ground (to minimize the chance that passengers might inadvertently disturb archaeological remains), and the ship had a “no garbage return” policy to minimize introducing or moving foreign materials among landing sites. Consequently, we could not move or remove pieces of anthropogenic litter from their position on the ground.

We focused on anthropogenic litter along the high tide strandline (e.g., wrack line; Tavares et al., 2020), assuming this would provide an index of recent litter deposition, and at low slope beaches to increase detectability of litter (Cheshire et al., 2009). Beaches were almost all a mix of sand and gravel, with more gravel near the high tide mark. We started at one end of the beach, placed a 1×1 m folding wood ruler (~ quadrat) on the wrack line, and then held a cellphone camera directly over the site (~1.5 m above ground), making sure all of the ruler was in the photograph (Fig. 3). Each photo had a relatively high resolution (generally ≥5 Mb) and we recorded a minimum of five photographs (i.e., 5 quadrats) at each landing. Quadrat locations were selected by choosing a number between 1 and 10, walking that many paces from the first quadrat, then setting the quadrat down, taking a photograph, then repeating until 10 sites were completed, or we had exhausted the limit of the beach. Thus, the number of photographs per site was largely determined by the length of available beach, and the short amount of time available before we had to return to regular duties assisting passengers. Most sites had ~10 photographs (range 5–57). For a subset of 10 photographs from different sites, we groundtruthed litter numbers by checking carefully over the area within the quadrat to manually count all pieces of visible anthropogenic litter to assess the accuracy of photo counts (recall that we could not pick up or move material). Consequently, we report litter density in pieces/m^2, the more common metric in most studies (Serra-Gonçalves et al., 2019).

After the field season, one person counted and measured ($\pm$1 mm; hence we did not consider attempt to consider most microplastics) all

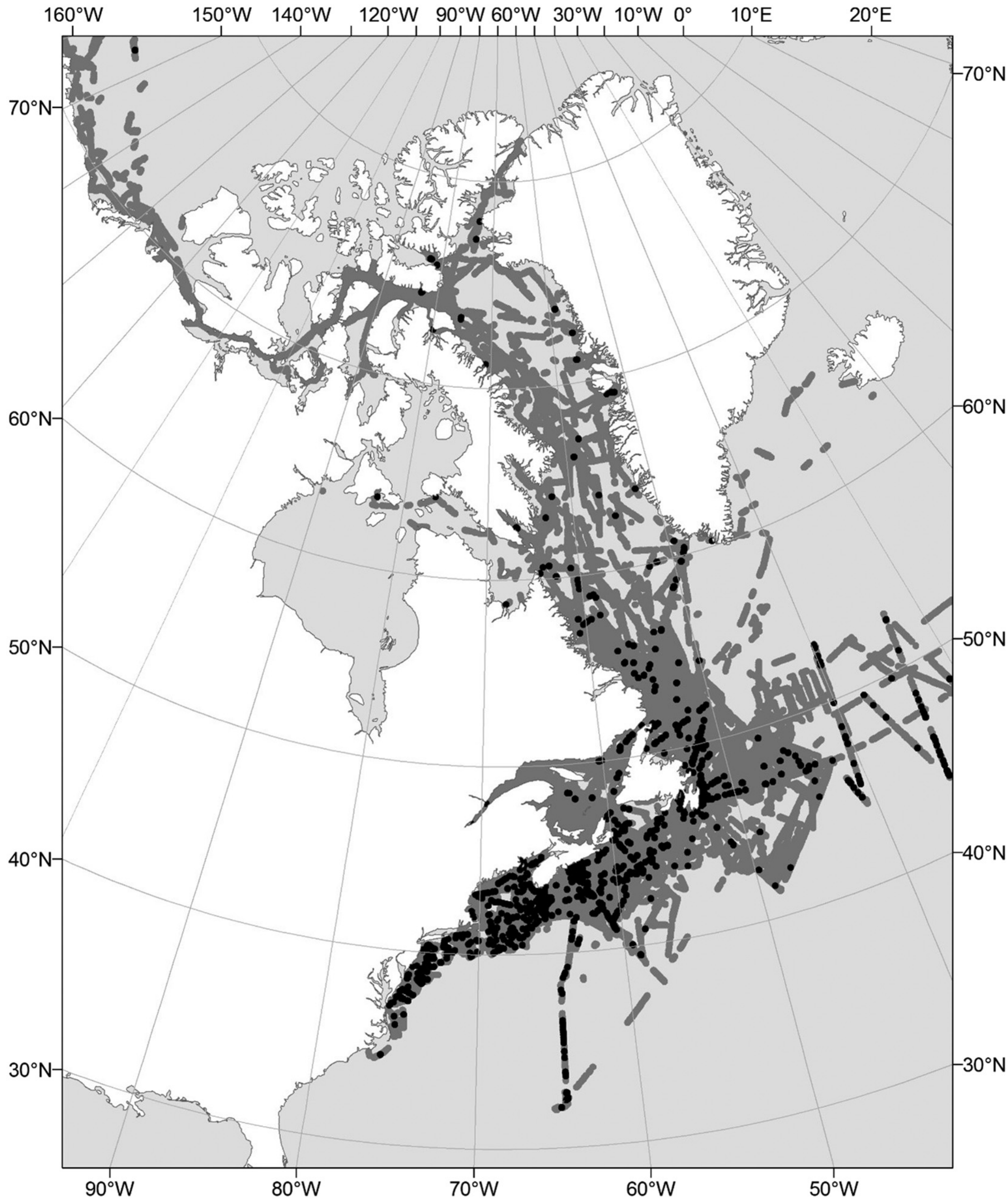

Fig. 1. Locations (ranging from 33 to 78^0 N) of at-sea seabird survey transects (light gray dots) and sites (black dots) where floating anthropogenic debris was recorded from 2007 to 2019.

anthropogenic litter observed in each photo, using the ruler within the image as a scale (Fig. 3). Images were viewed on a 56 cm LCD screen and zoomed in as necessary to examine all areas within the quadrat. Note that much of the litter was partially buried, so we have not included a detailed analysis of size as it would be biased, but we have provided the range and mean sizes we could measure. The type of anthropogenic litter was categorized as plastic (subclassified as fragments [bottle caps, pieces of containers, shotgun cell cases]; bottles; threads [rope, fishing net or line]; rubber; sheets [tarp, packaging, bags]; polystyrene foam; cigarette butts; other [mostly fragments, sheets or threads but uncertain about precise type from images]; from OSPAR, 2015, Van Franeker and Law, 2015); as well as metal (cans, wire), glass, cloth (clothing), paper and cardboard, or wood (packing crates, lumber). Pieces of anthropogenic litter were recorded individually in the datafile, and then numbers of litter were aggregated to assess densities at landing sites.

We analysed data using R 4.0.3 for Windows (https://www.r-project.org/). We used *t*-tests and Pearson correlations for some comparisons, while others were made using general linear models (GLM) for appropriate distributions; we applied several models with different distributions and used both model fit and dispersion measures to determine the best model. In all cases, all models yielded similar results (i.e., showed the same significant or non-significant pattern), and these were confirmed with separate Mann-Whitney tests. All means are reported ± standard deviation.

3. Results

3.1. At-sea surveys

Based on at-sea surveys covering 263,543 km of marine survey transects, anthropogenic litter was observed floating in marine waters from

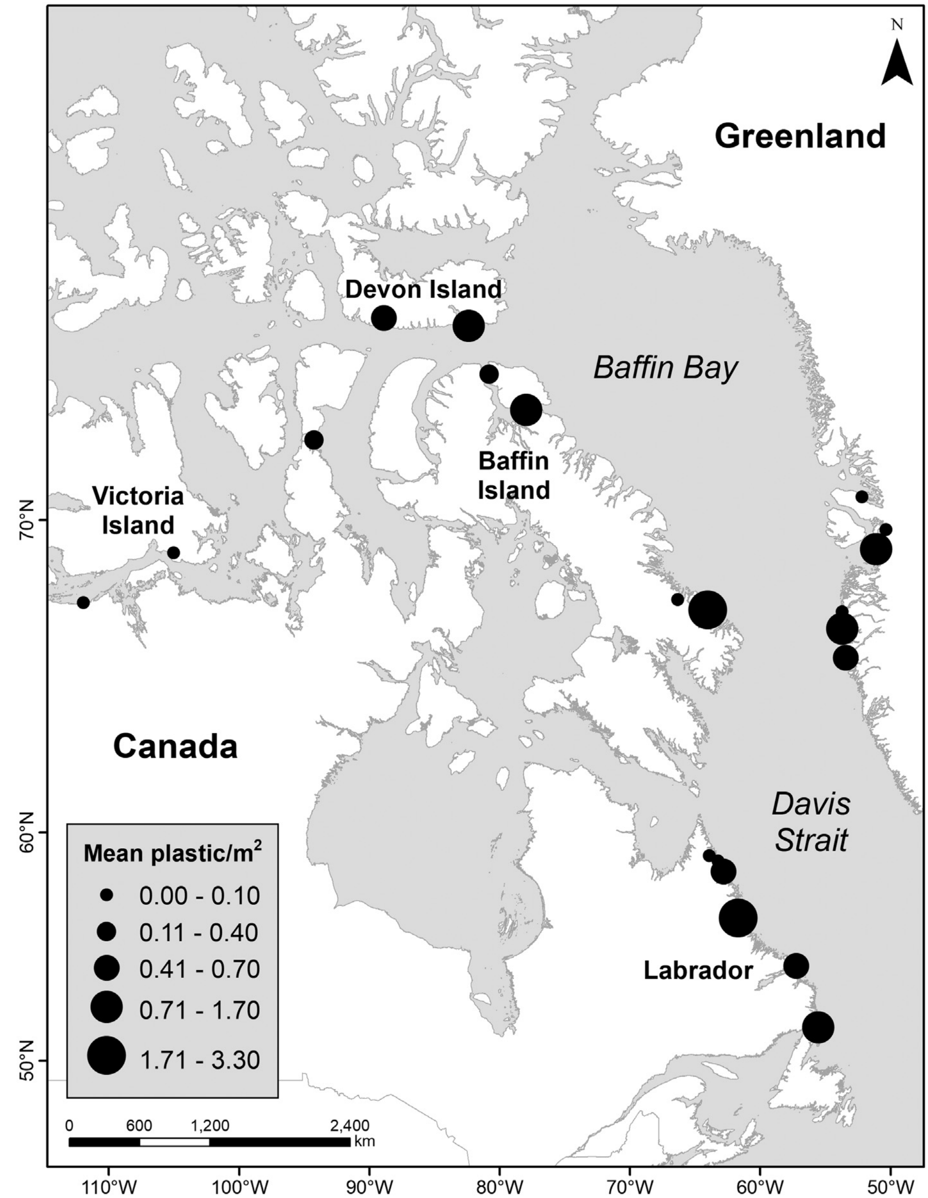

Fig. 2. Locations of coastal low slope beaches in Arctic Canada and West Greenland where anthropogenic debris was sampled in 2018 and 2019. Sites were often in bays and fjords; areas protected from major storm waves (an exception being the southernmost site at L'Anse aux Meadows, Newfoundland and Labrador). Size of circles depicts density of plastic debris found, from Table 1.

the southeastern coast of North America into the Canadian Arctic, north to ~78°N and west to ~83°W (Fig. 1). Over this region, 1266 pieces of floating litter were observed, of which 74% were plastics. Within the Arctic region (i.e., north of 60°N), 43 pieces of litter were observed, of which 77% were plastic (65% plastic fragments, 9% fishing gear, 2% polystyrene foam), 12% paper, 7% industrial, and 2% were each of wood and unidentified. For transects where plastic was observed, the median density in Arctic waters (median 0.60 items$\cdot$km^{-1}, mean 0.67 $\pm$ 0.24, range 0.42–1.46, $n = 42$ transects) was similar to the density in waters south of 60^{0}N (0.61 items$\cdot$km^{-1}, 0.75 $\pm$ 0.44, 0.20–6.10, $n = 1059$; GLM, Gaussian, $p = 0.24$).

3.2. Coastal surveys

Although two locations had a mean and median density of 0 pieces of plastic (Table 1), we observed anthropogenic litter at all 22 sites, and plastic litter along the coast at every location we visited, except for Nachvak Fjord, Newfoundland and Labrador. Much of the litter included larger, intact, non-degraded pieces of plastic (e.g., drink bottles with non-faded paper labels still adhered, candy bar wrappers), often at the high water line or inshore (i.e., inshore from the high tide line that we surveyed), which suggested that they were of local, not long range, origin. Across this Arctic region we took 330 photos of high tide line coastal quadrats at 22 locations (two locations sampled in two years) and observed 446 pieces of anthropogenic litter in those images. This litter was dominated by plastic pieces (73%), but other types of litter were also observed, including metal (8%), glass (8%), processed wood (7%), cardboard (2%), and cloth (<1%). Plastic litter that we could observe were clearly meso- and macroplastics (most >5 mm is size): mean ($\pm$ standard deviation) visible length of 326 pieces was 15.0 $\pm$ 17.3 cm and mean width was 5.5 $\pm$ 6.3 cm. Types of plastics observed included fragments (24%), bottles (6%), threads (17%), sheets (13%), polystyrene foam (6%), cigarette butts (3%; mostly found near communities), rubber (<1%), and other (30%; mostly fragments but

Fig. 3. Researcher demonstrating the sampling procedure with 1 × 1 m quadrat and cellphone camera in West Greenland. The inset depicts a typical image of the quadrat used to estimate anthropogenic debris on coastal low slope beaches in Arctic Canada and West Greenland. The quadrat was laid on the high tide line, photographed, and debris were identified and measured from those images.

some could have been smooth pieces of rope or sheet partly buried in sediment).

Using data from all quadrats, the mean density of anthropogenic litter was 1.4 ± 2.8 items·m^{-2} (median 1, range 0–27), and restricting this comparison to only plastics, mean density of plastic litter was 1.0 ± 1.7 items·m^{-2} (median 0, range 0–20). However, proximity to human communities had a strong influence on litter density. For 197 quadrats sampled within 5 km of human habitation (determined by GPS points), mean density of plastic litter was 1.5 ± 2.0 items·m^{-2} (median 1, range 0–20) which was ~7× greater than the density in 133 quadrats from areas remote from human settlement (0.2 ± 0.5 items·m^{-2}, median 0, range 0–3; GLM, negative binomial, $p < 0.0001$).

Table 1
Locations of coastal sites sampled in August and September of 2018 and 2019, number of quadrats per site, and mean density (m^2) of anthropogenic and plastic debris per quadrat. If plastic was observed along the coastal region at the shore stop but was not in quadrat samples, we noted that under "plastic observed?". Location short forms are: Newfoundland and Labrador – NL; Nunavut – NU; Greenland – GN.

Location	Latitude (^{0}N)	Longitude (^{0}W)	Plastic observed?	Quadrats (n)	Mean (SD) debris / m^2	Mean (SD) plastic / m^2
L'Anse aux Meadows, NL	51.6	55.52	Yes	57	1.5 (1.1)	1.4 (1.1)
Indian Harbour, NL	54.45	57.23	Yes	19	0.6 (0.6)	0.5 (0.5)
Nain, NL	56.53	61.68	Yes	28	4.4 (5.4)	3.3 (4.1)
Torngat Base Camp, NL	58.45	62.8	Yes	18	0.8 (0.5)	0.6 (0.5)
Ramah, NL	58.87	63.23	Yes	13	0.1 (0.3)	0 (0)
Nachvak Fjord, NL	59.08	63.88	No	12	0 (0)	0 (0)
Nordre Stromfjord, GN	66.05	53.42	Yes	10	1.1 (0.9)	0.7 (0.7)
Sisimiut, GN	66.94	53.68	Yes	11	1.8(1.7)	1.7 (1.7)
Disko Fjord, GN	67.45	53.7	Yes	5	0 (0)	0 (0)
Qikiqtarjuaq (2018), NU	67.5	64.02	Yes	10	1.4 (0.5)	1.4 (0.5)
Qikiqtarjuaq (2019), NU	67.5	64.02	Yes	8	3.9 (3.2)	2.5 (1.9)
Port Epworth, NU	67.72	111.95	Yes	13	0.2 (0.4)	0.1 (0.3)
Nedlukseak Fjord, NU	67.8	66.33	Yes	13	0.2 (0.4)	0.1 (0.3)
Cambridge Bay, NU	69.12	105.03	Yes	9	0.1 (0.3)	0 (0)
Ilulissat (2018), GN	69.22	51.1	Yes	10	1.3 (1.7)	1.1 (0.9)
Ilulissat (2019) GN	69.22	51.1	Yes	5	1.4 (1.5)	1.4 (1.5)
Eqip Sermia, GN	69.75	50.33	Yes	7	0 (0)	0 (0)
Qilakitsoq, GN	70.6	52.18	Yes	5	0 (0)	0 (0)
Fort Ross, NU	72	94.23	Yes	15	0.3 (0.5)	0.3 (0.4)
Pond Inlet, NU	72.7	77.95	Yes	16	1.4 (1.1)	1.2 (1.2)
Tay Bay, NU	73.5	80.78	Yes	11	0.6 (0.5)	0.4 (0.5)
Dundas Harbour, NU	74.52	82.38	Yes	10	6.2 (10.0)	1.2 (1.8)
Croker Bay, NU	74.55	82.45	Yes	10	0.3 (0.5)	0.1 (0.3)
Maxwell Bay, NU	74.68	88.88	Yes	15	0.7 (0.8)	0.6 (0.8)

To ground-truth counts from saved images, we counted litter in 10 quadrats while in the field. Mean count (2.2 ± 0.9) was higher, but not significantly different, than that counted on photographs (1.9 ± 0.6; paired *t*-test, $t_9 = 1.4$, $p = 0.19$).

Across all sites, density of plastic in quadrats did not decline with increasing latitude (Pearson correlation; $r_{22} = -0.25$, $p = 0.25$), which was consistent restricting the comparison to sites near communities ($r_{10} = -0.39$, $p = 0.26$) or remote from communities ($r_{12} = 0.05$, $p = 0.86$).

4. Discussion

Anthropogenic litter has been found throughout our oceans (Cózar et al., 2014; Cressey, 2016). Our at-sea data, while not designed to focus on litter, provided some new additional insights on this type of pollution in a little-studied region. With so few pieces of litter observed, it suggests that macroplastic in the Northwest Atlantic and Arctic oceans is probably at much lower densities than reported farther south in tropical regions (e.g., Ryan and Schofield, 2020), consistent with the data from the Svalbard region (Bergmann et al., 2016). However, plastics in surface waters seem to be increasing, at least at the southern portion of our study area (Liboiron et al., 2020), and we did observe litter on the ocean as far as 78°N and to ~83°W in the Northwest Passage, adding further evidence that all forms of plastic can effectively reach most places on Earth, even larger pieces. One difference from Bergmann et al. (2016) was that 23% of the items we spotted were non-plastic, whereas all of the floating debris observed west of Svalbard was plastic. Future at-sea surveys of any focus (seabirds, marine mammal, other) are encouraged to also focus on anthropogenic litter and more accurately describe the amount of floating anthropogenic litter in this region to assess whether material types (and thus potentially sources) are changing through time.

Plastic and other anthropogenic litter are ubiquitous along coastlines around the world (Serra-Gonçalves et al., 2019) but their distribution has received limited attention in Arctic waters. Arctic beach studies have been conducted in Svalbard, Norway (Bergmann et al., 2017; Falk-Andersson et al., 2019; Halsband and Herzke, 2019) and Alaska (Polasek et al., 2017), both areas with warm water currents, which are somewhat less influenced by sea-ice than Arctic Canada and West Greenland. In our study region, warmer, north-flowing ocean currents may bring debris north along the coast of West Greenland, and then south with cold currents along Nunavut and Labrador (e.g., Tang et al., 2004). Like our project, Bergmann et al. (2017) also used expedition ships to access sites in Svalbard, but they had citizen scientists collect anthropogenic litter along the coastline. They found plastics were dominated by litter from fisheries, with concentrations up to 524 $g \cdot m^{-2}$, but unfortunately they did not measure spatial density. Liboiron et al. (2020) also found a high proportion of fishing gear in their plastic waste in Newfoundland. In contrast, only 17% of the plastic litter we found were threads (including fishing gear), and the only places we found fishing line or nets were in Greenland or Newfoundland and Labrador, probably attributable to the fact that most fishing in Nunavut has traditionally been small scale, subsistence fisheries (Roux et al., 2011), although that is changing (Anderson et al., 2018). However, direct comparisons are not possible because the protocol used in Bergmann et al. (2017) was very different from ours, which poses a challenge in trying to compare across studies (Lavers et al., 2016; see below). Nonetheless, we expected to find macroplastics in the Canadian Arctic, where microplastics have been found in various environmental media (La Daana et al., 2018). In fact, Huntington et al. (2020) showed that microplastics are ubiquitously distributed through marine waters of Arctic Canada, but we are unaware of any other work on determining densities of meso- and macroplastics of this region. This is an important consideration, because macroplastics degrade through physical and chemical processes into microplastics or smaller, and thus can move into local environments and food chains (Barnes et al., 2009; Efimova et al., 2018).

There are several substantial issues that make determining plastic litter densities on coastlines challenging, or more importantly, comparable. Lavers et al. (2016) noted that physical attributes of the litter (e.g., plastic colour) and observer issues (e.g., experience) that can bias detection of plastic pieces. Moreover, differing methodologies and reporting used across studies make comparisons difficult; this has been reviewed in detail and standardization has been strongly recommended (Serra-Gonçalves et al., 2019). We recorded as much information as possible (location, date, plastic types), but our protocol was specifically designed as a rapid assessment approach without handling litter material. The advantages to our approach are that we could gather data quickly before or after we completed our regular duties for the expedition, and we also found that passengers (i.e., citizen scientists) could easily use our methods (we are currently developing this protocol for broader use). Moreover, our comparison of in-the-field versus on-the-screen counts of litter showed some undercounting of plastic pieces based on photographs, but for regions like the Arctic where plastic densities appear to be quite low, the magnitude of undercounting was small. The disadvantages to our approach were that we did not have time to cover a larger area, which generally provides more reliable results (e.g., Anfuso et al., 2020; Tavares et al., 2020), and we could not ground-truth all pieces that we observed, so we had a relatively high proportion of unknown plastic types.

Another issue that we have considered is that our sampling was principally on low slope beach areas (as recommended; Cheshire et al., 2009), and most of the areas we sampled were generally low tidal amplitude (< 1.5 m), often in bays or fjords protected from major waves. Consequently, the high tide line was often near the highest wave incursion (storm) line, and we did not observe additional litter farther inland (except in communities). We suspect that some of the plastic we found could have resided on the beach for some time and would not be displaced as much as it would be in more active, exposed or dynamic beaches farther south (see Ryan and Schofield, 2020). As a result, in regions more exposed to storms, densities along high tide lines probably represent a shorter duration of accumulation. Thus, our Arctic litter densities may be overestimating temporal aspects of plastic accumulation in this region relative to sites with more storm or wave action.

Consistent with our prediction, we showed that plastic litter densities were ~ 7× higher near communities compared to more remote locations, counter to the results on microplastics in Arctic Canada (Huntington et al., 2020). In Senegal, Tavares et al. (2020) showed the density of macroplastics were 20× higher near urban centres (3.6 vs. 0.2 items$\cdot m^{-2}$), the latter density very close to the mean value we found in sites remote from urban areas. Garcés-Ordóñez et al. (2020) also saw a greater density of plastics on more urban beaches in the Caribbean, although the difference was not as high as in other studies. Arctic communities in Canada generally have open landfills and are very exposed to wind, so materials may be blown from landfill sites into local streams or directly into the ocean. However, we saw examples where litter (e.g., cans, plastic bottles, broken runners from sleds) was relatively recent (undamaged, paper or plastic not faded), and we presumed it had either blown across snow and ice to the location, or was left or dropped by local residents during travel. In fact, one quarter of the debris we found on coastlines was not plastic, dominated by metal, glass, processed wood, cardboard and cloth. Certainly, much of the glass or metal debris at these remote sites was not from long-range transport as they were from items that would not be blown nor float; the Canadian Arctic has a long history of legacy solid wastes in some locations (e.g., Hird, 2016). However, in this region Arctic coastlines may be travelled extensively in winter when the ocean is frozen, and some of this waste could have arrived at coastal sites from those winter activities. In the future, studies should determine how much litter is arriving from long-range transport and how much is locally produced; the latter argues for better management of waste at Arctic landfills.

Table 2
Selected examples of densities of marine macroplastics from studies in other locations that conducted beach surveys since 2010; data suggest a 3000× difference in densities, depending on location.

Location	Year	Latitude (°N)	Longitude (°W)	Mean plastic pieces/m^2	Reference
Arctic Canada	2018–2019	51.6–74.7	50.3–112.0	1.0	This study
Washington USA	2008–2011	48	123	12.8	1
N. Mediterranean	2014–2016	43.5	16	0.7	2
Albania	2018	41.5	−19.5	0.1	3
China	2018	30	−121.5	3.8	4
West India	2016–2017	15.7	−73.8	102–303	5
Senegal	2019	14	16.5	1.9	6
Caribbean	2016	13–26	61–81	0.1–48.2	7
Aruba	2015	12.5	70	0.1–0.9	8
Columbia	2018–2019	11.25	74.17	8–12	9
Southeast India	2019	8.8	−78.2	4.6	10

1 - Davis III and Murphy, 2015; 2 – Vlachogianni et al., 2018; 3 – Gjyli et al., 2020; 4 – Chen et al., 2020; 5 – Maharana et al., 2020; 6 – Tavares et al., 2020; 7 – Schmuck et al., 2017; 8 - De Scisciolo et al., 2016; 9 – Garcés-Ordóñez et al., 2020; 10 – Jeyasanta et al., 2020.

Contrary to our other prediction, we did not observe a consistent pattern with plastic litter density and latitude, despite covering 23° of latitude. Although we were working in a generally remote and lightly populated region, we expected that regions farther north, that are more remote from urban or industrial centres or shipping lanes, would be less exposed to plastic litter. However, plastic densities along shorelines do not appear to hold an overall pattern with latitude (Table 2), and can vary greatly within a relatively small region, even on the same island, depending on exposure to wind and currents (e.g., Schmuck et al., 2017; Anfuso et al., 2020).

Our results provide both bad and good news for the health of the Arctic environment. In a negative sense, we found macroplastic litter throughout the Canadian Arctic and West Greenland at all but one site (in Labrador), suggesting that even the most remote locations of the world are receiving macroplastics, as has already been established from more transportable microplastics (Borrelle et al., 2017; Rochman, 2018). However, we point out three avenues for optimism and future research. First, most plastic litter densities we observed were low, and if better local waste management is implemented, we suspect that these plastic amounts will reduce even more, at least in the short term. However, if global release of plastics into the environment continues (Jambeck et al., 2015), and sea ice continues to decrease in extent and duration due to global warming (Holland et al., 2006), indeed more plastic could circulate into the Arctic (Bergmann et al., 2016). Clearly then, there is a need for new research in this part of the Arctic to discern locally sourced debris from long-range transport, as we suspect that much of the material we observed may have blown from local, open dumps. Second, the protocols we used were simple, quick and well-received by cruise ship passengers, thus this approach could be developed as a practical means of monitoring this pollutant in parts of the world that are difficult to access. Finally, better resolution of the relationship between debris and the high tide strandline (that we sampled) versus the maximum storm line (that we may have sampled in some locations) on the coast might help determine what the long term, total debris density is at these sites. The vast majority of these locations have never had a beach clean-up, and thus low debris densities we found at many of our sites may represent total accumulation since plastics have been produced.

CRediT authorship contribution statement

Mark L. Mallory: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Julia Baak:** Conceptualization, Investigation, Methodology, Software, Writing – review & editing. **Carina Gjerdrum:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. **Olivia E. Mallory:** Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. **Brittany Manley:** Conceptualization, Resources, Supervision, Writing – review & editing. **Cedar Swan:** Conceptualization, Resources, Supervision, Writing – review & editing. **Jennifer F. Provencher:** Conceptualization, Data curation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests of personal relationships that could have appeared to influence the work reported in this paper.

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