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Beach litter sources around Nuuk, Greenland: An analysis by UArctic summer school graduate course students

Marthe Larsen Haarr [a], Lis Bach [b], Catherine P. Chambers [c], Jannike Falk-Andersson [d], Thomas Juul-Pedersen [e], Ryan d'Arcy Metcalfe [f], Anna Sinisalo [g], Jakob Strand [b,*], Helene Svendsen [g], Julia E. Baak [h], Helga Hvanndal Björnsdóttir [h], Elsa Margaret Krook Brenner [h], Sigrid Christiansen [h], Cécilia Delattre [h], Maeva Gauthier [h], Rachel Helen Georgiou [h], Ljuba Günther [h], Fanny Hägg [h], Ulunnguaq Markussen [h], Karla Berenice Parga Martínez [h], Arnaud le Pevedic [h], Alice Refosco [h], Bror Kristian Raanaas Tandberg [h], Felix Tulatz [h], Silke Van Broeck [h], Nathan Thomas Visser [h], Louise Wittwer [h]

[a] Salt Lofoten AS, Norway
[b] Aarhus University, Department of Ecoscience, Denmark
[c] University Centre of the Westfjords, Iceland
[d] Norwegian Institute of Water Research, Norway
[e] Greenland Institute of Natural Resources, Greenland
[f] KIMO, Denmark
[g] GRID-Arendal, Norway
[h] UArctic International Secretariat, Finland

A B S T R A C T

Modeling studies illustrate the potential for long-range transport of plastics into the Arctic, although the degree to which this occurs remains relatively undocumented. We utilised a teaching exercise at a UArctic summer school graduate course in Nuuk, Greenland to conduct a preliminary in-depth analysis of beach litter sources in the Nuup Kangerlua fjord. Students and instructors collected and analysed 1800 litter items weighing 200 kg from one location in the fjord and another at its mouth. The results suggest a predominance of local sources to macrolitter, rather than long-range transport from Europe. Fisheries-related items and rope were common. Packaging which could be identified was largely suspected to be products distributed in Greenland, and soft plastics, which rarely disperse far from its source, were also common. The results suggest local measures to reduce mismanaged waste and emissions from fisheries are important for reducing marine litter in West Greenland.

1. Introduction

The Arctic is a rapidly changing environment, which greatly impacts both its peoples and ecosystems (Heikkilä et al., 2022; Smieszek et al., 2021). Climate change is forcing adaptation to a changing environment, which can lead to profound changes to culture, identity and way of life (Hayashi and Walls, 2019; Vecchio et al., 2022). Marine litter is an additional environmental issue also extending to socioeconomic and political concerns; adding to the environmental stressors experienced by peoples in the Arctic (Smieszek et al., 2021).

Marine litter and plastic pollution have been documented across the globe, including remote polar regions (Erni-Cassola et al., 2019; Mishra et al., 2021). However, the abundance, distribution, and sources of litter around Greenland are relatively unknown. Microplastics (<5 mm) in surface waters has been documented off both the east and west coasts (Bergmann et al., 2022; Halsband and Herzke, 2019; Jiang et al., 2020; Rist et al., 2020). Currents provide a possible pathway for microplastics from central European and Russian rivers to the Arctic, including West Greenland (Huserbråten et al., 2022). Plastic ingestion by fish, seabirds and marine mammals has also been documented in the region (Baak et al., 2020; Morgana et al., 2018; Pinzone et al., 2021; van Franeker et al., 2022).

* Corresponding author.
E-mail address: jak@ecos.au.dk (J. Strand).

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The presence of macrolitter (>2.5 cm), its material composition and common items has been described for beaches, surface and seafloor surveys in West Greenland (Kirkfeldt, 2016; Mallory et al., 2021; Syberg et al., 2020). The best replicated survey was one of floating litter along north-eastern North America, including the eastern Canadian Arctic, which documented similar litter densities across the study area despite covering 23° of latitude (Mallory et al., 2021). In general, however, replication has been too low to draw conclusions regarding average densities for comparison with other geographic regions, and the resolution of litter registration protocols too coarse to discern detailed source information. The exception to the latter is a limited study carried out in 2019 investigating litter sources from three locations in less populated parts of West Greenland (Strietman et al., 2021).

In August 2022, the University of the Arctic, a network of universities, colleges, research institutes, and organizations concerned with education and research in and about the North, arranged a graduate level field course on plastic pollution in the Arctic, held in Nuuk, Greenland and hosted by Aarhus University and the Greenlandic Institute for Natural Resources (https://www.uarctic.org/news/2021/11/uarctic-summer-school-on-plastic-in-the-marine-arctic-from-sources-to-solutions/). As part of this course the students conducted a beach cleanup, followed by a lab exercise using a Deep Dive protocol for assessment of litter sources (Falk-Andersson, 2021; Falk-Andersson et al., 2021). While not geographically extensive or well-replicated, this nevertheless provided an excellent opportunity for a preliminary assessment of macrolitter sources around Greenland's capital city to guide further research in Greenland.

2. Methods

Beach litter was collected from two locations: (1) a single 133 m long beach along the exposed outer coast south of Nuuk (July 31st, 2022), and (2) a set of five beaches ranging from 25 to 110 m long within a 1 km radius on two adjacent islands in the Nuup Kangerlua fjord (August 2nd, 2022) (Fig. 1). Litter was collected from the exposed site by the instructors prior to the course to ensure sufficient litter for the students to analyse regardless of the outcome of their field trip; the sites within the fjord were sampled by the students.

Data were registered and entered into the online Deep Dive portal following its protocol (https://deepdive.grida.no, see also Falk-Andersson, 2021; Falk-Andersson et al., 2021). All litter from the sites in Nuup Kangerlua was pooled during statistical analyses. Litter was classified according to three broad categories: "fishing gear and rope" which speaks to the prevalence of sea-based litter, "packaging" as these may provide information regarding the age and nationality of litter (Falk-Andersson et al., 2021), and "other" litter types. Within each of these categories, litter was further classified by item following a protocol determined to provide useful management-related information elsewhere in the European Arctic (see Fig. 2a for a list of classified items and online resources at https://deepdive.grida.no for details).

Items were assessed and classified in detail only when this could provide higher resolution data pertaining to sources than can be obtained from standard composition data (e.g., volunteer cleanups or OSPAR data). When classifying ropes, distinctions were made not based on type (e.g., length or diameter), but on characteristics which reveal something about the behaviour or event leading to its loss, resulting in three categories (Falk-Andersson, 2021): (1) Cut-offs from fisheries,

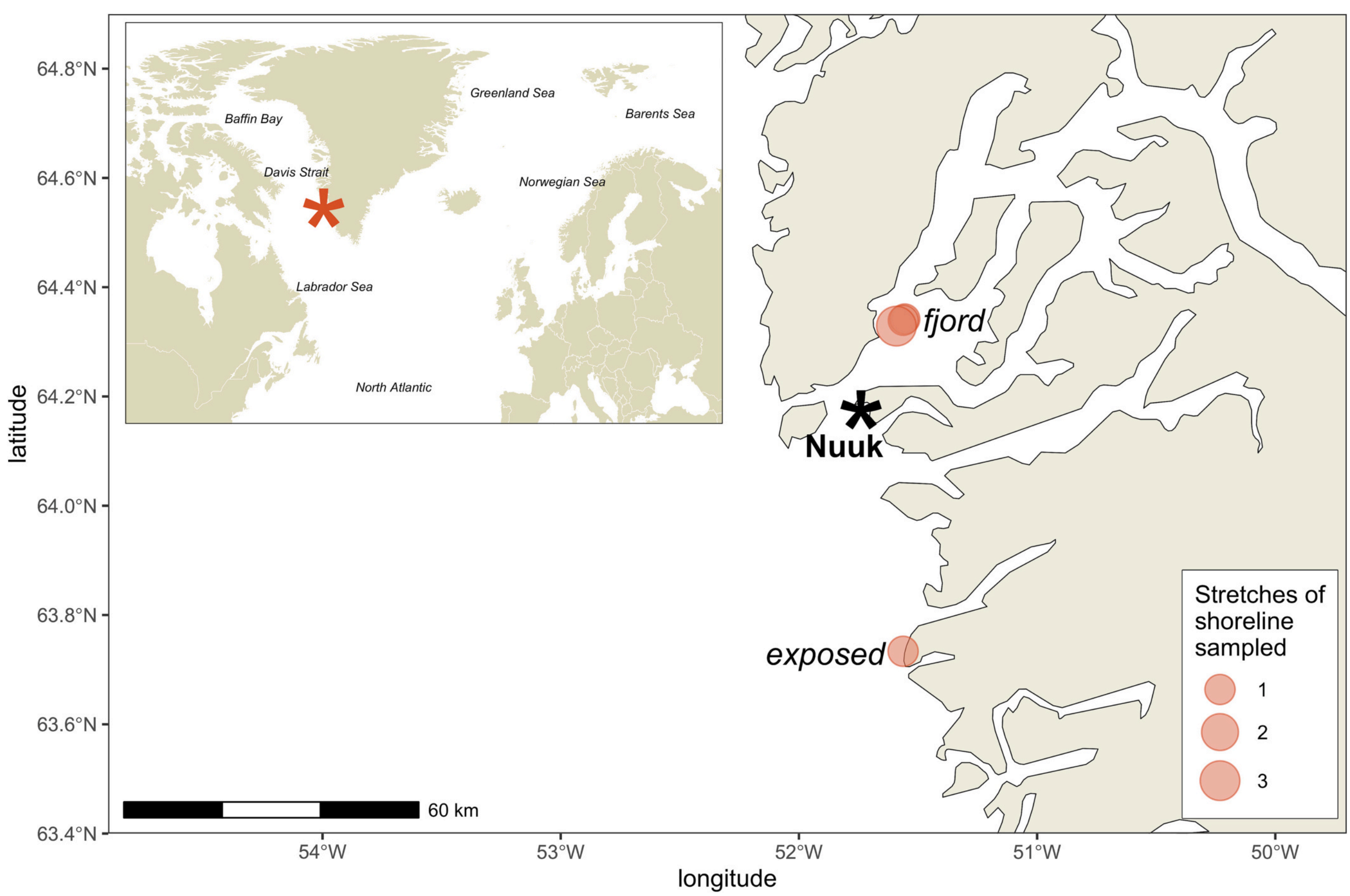

Fig. 1. Map of study area. The exposed location consisted of a single 133 m long beach. The fjord location consisted of 5 smaller beaches (25–110 m long) within a 1 km radius on two adjacent islands.

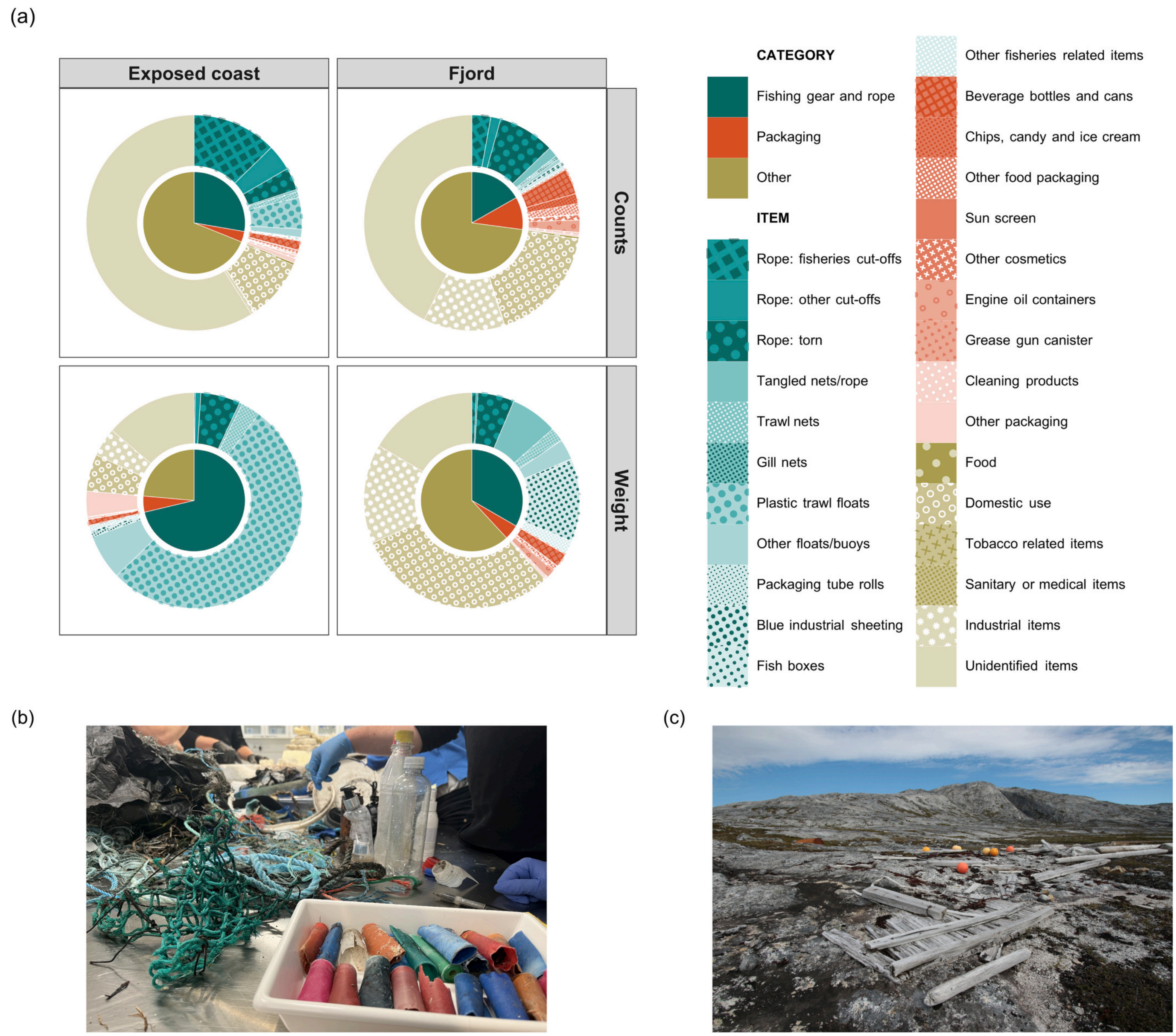

Fig. 2. (a) Composition of litter collected at the exposed site and the fjords sites (pooled), based on abundance and total weight. The inner pie charts show the relative abundance of the three broad litter categories, while the outer donuts show the composition of items within the broader categories. (b) Photo from litter registrations showing beverage bottles (packaging), various ropes and net pieces (fishing gear and ropes), and shotgun and rifle cartridges (common items in the "other" category). (c) Photo of brightly coloured rigid plastic trawl floats at the exposed location. Readers are referred to the online version for a colour rendition of the figure.

typically from net mending; identifiable by having been clearly cut in both ends (individual strands are of the same length), small diameter (typically approx. 0.5 cm), and <20 cm in length (often <10 cm). (2) Rope which ends have been clearly cut, but which do not otherwise match the criteria for cut-offs from net mending. (3) Rope with at least one clearly torn end. Packaging was assessed for text, logos, printed expiry dates, and production date mold stamps which may indicate the origin (nationality) and approximate age of items (Falk-Andersson et al., 2021).

Data were analysed using RStudio Version 1.4.1106 (https://www.r-project.org/). Figures were made using packages "ggplot2", "ggpattern", "ggtext", "patchwork", "sf", "rnaturalearth", "cowplot", "dplyr", "magick", and "Rmisc" (FC et al., 2022; Hope, 2022; Ooms, 2021; Pebesma, 2018; Pedersen, 2020; South, 2017; Wickham, 2016; Wickham et al., 2022; Wilke, 2020a, 2020b).

3. Results

A total of 1773 items were analysed, half from the fjord sites and half from the exposed site. The litter from the exposed site comprised 70 % of the weight despite nearly equal numbers of items. The total weight analysed was 193 kg. The higher weight of litter from the exposed location was primarily due to more and heavier fisheries-related items, particularly plastic trawl floats (Fig. 2). Driftwood was not collected.

There was a significant association between litter category and area ($\chi^2 = 59.18$, DF = 2, $p < .0001$) (Fig. 2). Fishing gear and rope were more prevalent on the exposed site compared to within the fjord (28 % vs. 17 % of litter by abundance (i.e., item counts), respectively). Similarly, 63 % of the fishing gear and ropes analysed originated from the exposed site. Packaging was more prevalent among litter found within the fjord than at the exposed site (10 % and 3 % of litter by abundance, respectively), and 75 % of all packaging recorded was found within the fjord. The differences in composition were even more pronounced by weight, where 71 % of litter from the exposed site consisted of fishing gear and rope, compared to only 33 % within the fjord (Fig. 2).

Within the broader categories, certain items were particularly common. By weight, most fishing gear and ropes from the exposed site consisted of plastic trawl floats (74 %), which constituted only 17 % of the fishing gear and rope by abundance, none of which were found within the fjord (Fig. 2). By abundance, rope was the most common item in the category at both the exposed (72 %) and fjord (76 %) sites. However, the type of ropes differed. At the exposed site rope cut-offs from fisheries comprised nearly half the litter in the category, followed by other cut-offs (14 %) and torn rope (12 %). Contrastingly, cut-offs from fisheries accounted for only 17 % of items in the category within the fjord and torn rope 51 % (Fig. 2).

Beverage bottles and cans were the most common items within the packaging category in both locations by abundance (37 % and 40 % of packaging from the fjord and exposed sites, respectively) and within the fjord also by weight (43 % of packaging). Combined with snack wrappers and other food packaging, drink and food related items comprised most of the packaging found (combined 67 % and 57 % of packaging from the fjord and exposed site, respectively, by abundance). A single engine oil container was found at the exposed site, yet these constituted 18 % of packaging within the fjord by abundance and 27 % by weight (Fig. 2).

Most items not classified as packaging or fishing gear and rope (i.e., "other") were unidentified (Fig. 2). However, items which could be tied to domestic or private use (e.g., clothing, footwear, appliances, batteries, light bulbs, balloons) comprised 24 % by abundance and 49 % by weight of "other" items within the fjord. Among these, shotgun and rifle cartridges were quite abundant (Fig. 2).

There was a significant association between location and material composition ($\chi^2 = 525.44$, DF = 7, $p < .0001$). The latter was relatively uniform at the exposed site with 21 % of litter constituted of rope material (incl. nets) and 68 % of various rigid plastic by abundance (90 % combined). The material composition within the fjord was more heterogeneous. Only 15 % and 26 % of items were rope material and rigid plastics, respectively. Additionally, expanded foam constituted 13 % of items and soft plastic 42 %.

Packaging was relatively rare (n = 121) and most of it was found within the fjord. Consequently, the results must be treated with some caution. Overall, 48 % of the packaging could be allocated a nationality. Identification was the most successful for snack wrappers (origin of 12 of 14 items identified). Most items (65 %, n = 36) were allocated to a nationality based on text, although some also based on logo/brand (n = 8) and design (n = 11). There was no detectable difference in the nationalities of packaging found at the exposed site and within the fjord ($\chi^2 = 14.44$, DF = 10, p = .154). Data were thus pooled across locations. In total, 80 % of the packaging for which nationality could be identified were identified as Greenlandic, Danish, or Scandinavian (Fig. 3a). Note that nationality was identified to the highest resolution possible, which in some cases was a country and other times a region which may encompass individual countries also identified (e.g., Scandinavia includes Denmark).

Very few items could be dated (17 %, n = 20). Consequently, the ability to draw conclusions regarding the age of litter is limited and there was no discernable difference between locations in the proportion of recent and older items ($\chi^2 = 1.68$, DF = 2, p = .432). However, litter of a wide range of ages was present, both quite recent and some decades old (Fig. 3b–c).

4. Discussion

This study was relatively limited in scope given the primary objective was teaching rather than research, and hence the generalisability of the results is somewhat limited. Additionally, packaging, the fraction for which one can most readily determine geographical origin and age (Falk-Andersson et al., 2021), constituted a relatively low proportion of the litter. While power analyses were not conducted, power is expected to be low for analyses of nationality and age given the limited sample in addition to few sites sampled. Nevertheless, the students' Deep Dive provides valuable preliminary insights into macrolitter sources in the vicinity of Nuuk, a region for which in-depth analyses have not previously been conducted.

As the world's largest island, yet with only 56,000 inhabitants, Greenland is vast and sparsely populated (Christensen et al., 2020). Local litter source points might be expected to be low compared to densely populated regions, which are estimated to generate most land-based emissions of mismanaged plastic waste (Jambeck et al., 2015;

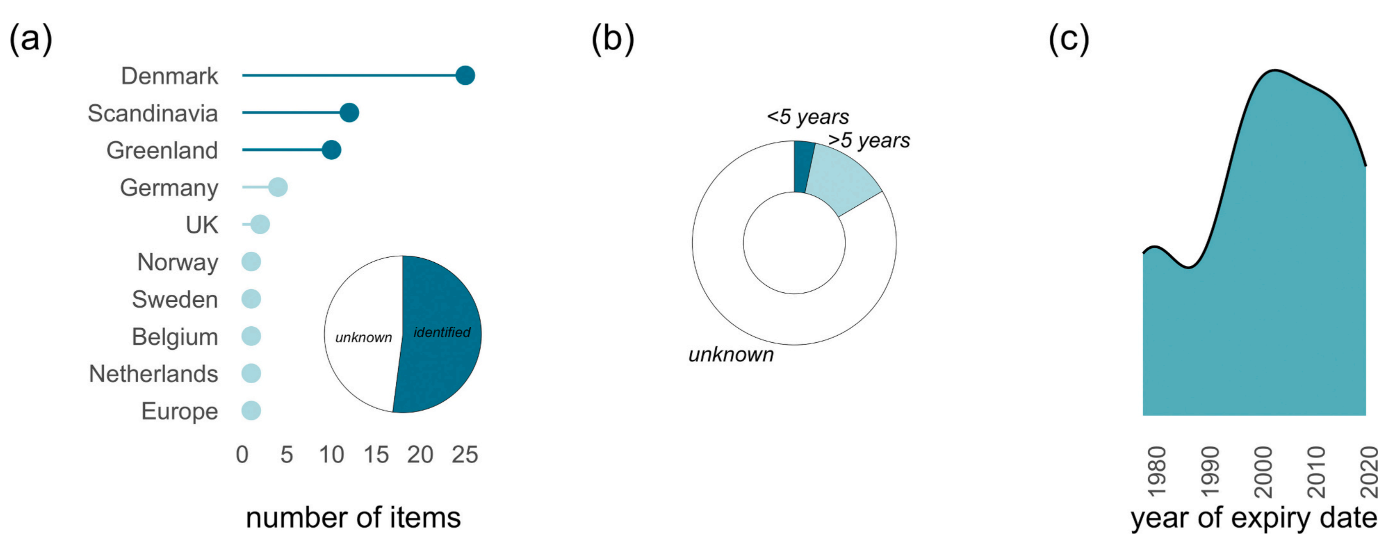

Fig. 3. Origin and age information gleaned from packaging (n = 121). Litter from both locations was pooled due to no detectable differences between them. (a) Apparent nationality of packaging, based primarily on the language of text printed on labels. The darker bars show litter which are likely to be of local origin (i.e., high probability of being distributed in Greenland), while the lighter bars show items identified to a nationality for which products are less likely to have been distributed in Greenland (i.e., possible long-distance transport items). Note that nationality was identified to the highest resolution possible, which in some cases was a country and other times a region (e.g., Scandinavia or Europe) which may encompass individual countries also identified. The inset pie chart shows the proportion of packaging items for which origin could be determined. (b) Distribution between age categories of litter. (c) Density plot of expiry dates for items where this was discernable (n = 10).

Lebreton and Andrady, 2019). Current patterns in the North Atlantic are also conducive to long-distance transport of litter. The Greenland current brings water from the North-East Atlantic around its southern tip, and north along the west coast (Brearley et al., 2012; Kawasaki and Hasumi, 2014; Pacini and Pickart, 2022). Modeling suggests that these currents can transport at least microplastics from several major European rivers north to the Barents Sea, Arctic Ocean and Greenland Sea, around Greenland, and north again along its west coast to a potential accumulation zone in Baffin Bay (Huserbråten et al., 2022). Presumably buoyant macrolitter has the potential to follow similar trajectories assuming they are not fragmented or biofouled and settle out of circulation *en route*.

Some packaging of variable western and northern European origin was found during the study (n = 11), suggesting that long-distance transport from Europe may indeed occur. The average predicted time for microplastics to drift from the North Sea to Baffin Bay is 3–4 years (Huserbråten et al., 2022). Thus, the age of European litter could help elucidate the likelihood of long-range transport versus local emissions (e.g., from ships) (Ryan et al., 2019). The sample of packaging analysed was small, however, and the proportion possible to date low, although a couple of European items older than 5 years were identified. A reported lack of a latitudinal trend in floating macrodebris densities along the east coast of North America from Cape Hatteras to Baffin Bay and the Northwest Passage (Mallory et al., 2021) is consistent with drift modeling of microplastic accumulation and density predictions (Huserbråten et al., 2022), as is the fact that no North American packaging was identified in this study despite the geographical proximity to its shores. This suggests that drifting macrolitter may at least partially follow a similar pattern to what is modeled for microplastics.

Despite the possibility of long-distance transport, the composition of most of the litter analysed does not support a prevalence of items stemming from across the Atlantic. Most packaging with identifying characteristics could have originated in Greenland. As part of the Kingdom of Denmark, approximately 80 % of Greenlandic imports come from Denmark and Danish products are widely distributed there (International Trade Administration, n.d.). Many products are also distributed across Scandinavia and will have labels printed in 3–4 Nordic languages, making the exact origin hard to determine, but the likelihood that these products are distributed both in Denmark and Greenland is high. Consequently, the most parsimonious assumption is that this litter was of local origin. If items of Scandinavian distribution entered the marine environment in Scandinavia and later drifted to Greenland one would also expect a similarly high prevalence of products distributed in other European countries within the North Sea region.

Shotgun cartridges were common among unclassified litter, presumably because of widespread hunting in the region (Hayashi and Walls, 2019). Most ammunition on Danish beaches originates from hunting on Danish waterbodies (Kanstrup and Balsby, 2018) and the same is likely true for Greenland. Some of the cartridges were actually rifle cartridges, an item not specified in established beach litter protocols. These are among items suggested to be specific to the Arctic and recommended included in monitoring protocols (AMAP, 2021). Other items of Arctic relevance include pyroplastics, detonating cords for explosives, aquaculture/animal feed bags, plastic sanitary bags, trawl and gill nets (AMAP, 2021). Only the latter were identified in this preliminary study. Current monitoring in Greenland applies a modified version of the OSPAR protocol (OSPAR Commission, 2020) extended with several other items from the EU joint list developed for MSFD monitoring (Fleet et al., 2021). Additionally, some Arctic relevant items such as detonation cords, pyroplastics and rifle bullet cases are included (Strand et al., 2022). Future Deep Dive studies should continue to identify key items for inclusion in protocols to guide preventive measures.

Other studies in the region also provide considerable anecdotal evidence that local sources are prominent among marine litter in West Greenland. In a rapid assessment of the Greenlandic and Canadian shores of Baffin Bay and Davis Strait, litter densities were on average ×7 higher at sites within 5 km of human habitation than at remote locations (Mallory et al., 2021). Mallory et al. (2021) also reported finding many intact items, such as beverage bottles with unfaded wrappers, and suggested this implies a considerable proportion of local origin litter. Unpublished analyses of beach litter in Greenland suggest that the less populated east coast, adjacent to the heavily fished Barents Sea, receives more fisheries-related litter, while litter on the west coast, where 90 % of Greenland's population lives, is closer in composition to litter found in much more populated regions of the North Sea (PAME, 2019), supporting the conclusion that local litter sources are highly important in and around Nuuk. Nuuk has also been identified as an important point source for microplastics based on a spatial gradient of densities in surface waters within the Nuup Kangerlua fjord (Rist et al., 2020), possibly linked to a lack of wastewater treatment. There are also many cabins in the fjord, which could be a source of litter. In a preliminary study similar to this one, researchers also identified litter of local origin and few clearly foreign objects from the Amerloq Fjord near the smaller town of Sisimiut north of Nuuk, as well as among two small samples from other locations in West Greenland (Strietman et al., 2021).

The high prevalence of soft plastic items within the fjord is also congruent with the assumption of predominantly local litter sources. Soft plastic, such as bags and films, has a high surface area to volume ratio and rapidly sinks out of circulation, thus rarely drifting far from its release point (Ryan, 2015). Even litter at the exposed location could originate from Nuuk as prevailing winds and surface currents in Nuup Kangerlua push outwards to the mouth of the fjord and microplastic densities increase in this direction (Rist et al., 2020), particularly during winter months with prevailing overland winds from the east; during the summer the prevailing winds blow out of the south, more or less parallel to the West Greenland current along the coast (Tang et al., 2004). Less soft plastic and packaging at the exposed site could be partially the result of increased drift time from Nuuk compared to within the fjord and the site's location relative to local environmental forcing.

The greater prevalence of fisheries related litter at the exposed site, combined with less packaging and soft plastics, point to somewhat differing sources of litter within Nuup Kangerlua and along the open coast. While the litter within the fjord appeared to be largely of local origin, it was somewhat harder to discern for litter at the exposed site as most fishing related items and rope provide little information as to their geographical origin or age. The proportion of rope that was clearly cut, including from net mending, was high among litter at the exposed site, signifying a strong influence of fisheries here,. In another study, fishing line and nets in the Labrador Sea, Davis Strait and Baffin Bay were only found in areas with nearby commercial fishing (Mallory et al., 2021). The numerous plastic trawl floats at the exposed site may result from losses in nearby waters within the Davis Strait and Labrador Sea but could also stem from long-distance transport from the heavily fished Barents, Norwegian and North Seas. The floats are highly buoyant, have relatively large volumes and are sturdy, all traits conducive to long-range transport (Ryan, 2015).

Despite the possibility of long-distance transport, findings clearly suggest a large portion of the issue is the result of local emissions and fishing activities, meaning potential solutions to reduce marine litter lie within realm of local decision-making. Potential local sources of litter include fisheries (Mallory et al., 2021), construction, which is substantial in Nuuk (including a new airport; Christensen et al., 2020), and waste management challenges tied to available infrastructure, weather and remoteness (Eisted and Christensen, 2013; Mokhorov et al., 2020; Ryberg et al., 2021). Historically, waste was burned in small-scale incinerators or disposed of in open dump sites, often close to the shore (Eisted and Christensen, 2013), leaving litter highly exposed to wind and potential dispersal (Mallory et al., 2021). The spread in age of the small portion of dateable litter suggests that past emissions are still washing ashore today. The waste management system in Greenland is currently undergoing restructuring to a more closed system (Strietman et al., 2021), which may reduce dispersal. Monitoring of the age composition of litter could provide useful data to measure potential positive effects of the new system.

In conclusion, this study suggests a high proportion of local litter sources with a broad age composition in West Greenland, which again suggest local waste infrastructure and fisheries as general target areas for preventative measures. The sample size (both litter and locations) was insufficient to obtain a complete picture of the relative prevalence of litter from different nationalities, particularly for rarer items or sources, although that the litter collected likely gives a reasonable indication of the most common sources as these are the items most likely to be present irrespective of sample size. More extensive studies should focus on spatial patterns in abundance, composition, origin and age of litter to more accurately elucidate spatiotemporal variability in the relative importance of local and long-range sources. Adding litter age assessments to monitoring protocols could also provide an opportunity to detect changes in ongoing leakage of mismanaged waste as the waste management system in Greenland is restructured. An increased use of Deep Dive methodologies is in line with current recommendations for marine litter monitoring to improve source characterisation of litter in the Arctic (AMAP, 2021).

CRediT authorship contribution statement

Haarr, Marthe Larsen: Conceptualization; Funding acquisition; Investigation; Methodology; Formal analysis; Visualization; Writing - original draft; Writing - review & editing.

Bach, Lis: Project administration; Conceptualization; Funding acquisition; Investigation; Writing - review & editing.

Chambers, Catherine P.: Conceptualization; Funding acquisition; Investigation; Writing - review & editing.

Falk-Andersson, Jannike: Conceptualization; Funding acquisition; Investigation; Methodology; Writing - review & editing.

Juul-Pedersen, Thomas: Project administration; Conceptualization; Funding acquisition; Investigation; Resources; Writing - review & editing.

Metcalfe, Ryan d'Arcy: Conceptualization; Funding acquisition; Investigation; Writing - review & editing.

Sinisalo, Anna: Conceptualization; Funding acquisition; Investigation; Methodology; Writing - review & editing.

Strand, Jakob: Project administration; Conceptualization; Funding acquisition; Investigation; Methodology; Writing - review & editing.

Svendsen, Helene: Project administration; Conceptualization; Funding acquisition; Investigation; Writing - review & editing.

Baak, Julia: Investigation; Writing - review & editing.

Björnsdóttir, Helga Hvanndal: Investigation; Writing - review & editing.

Brenner, Elsa Margaret Krook: Investigation; Writing - review & editing.

Christiansen, Sigrid: Investigation; Writing - review & editing.

Delattre, Cécilia: Investigation; Writing - review & editing.

Gauthier, Maeva: Investigation; Writing - review & editing.

Georgiou, Rachel: Investigation; Writing - review & editing.

Günther, Ljuba: Investigation; Writing - review & editing.

Hägg, Fanny: Investigation; Writing - review & editing.

Markussen, Ulunnguaq: Investigation; Writing - review & editing.

Martinez, Karla Berenice Parga: Investigation; Writing - review & editing.

le Pevedic, Arnaud: Investigation; Writing - review & editing.

Refosco, Alice: Investigation; Writing - review & editing.

Tandberg, Bror Kristian Raanaas: Investigation; Writing - review & editing.

Tulatz, Felix: Investigation; Writing - review & editing.

Van Broeck, Silke: Investigation Writing - review & editing.

Visser, Nathan: Investigation Writing - review & editing.

Wittwer, Louise: Investigation Writing - review & editing.

Declaration of competing interest

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

Data availability

Data are openly available in the online Deep Dive Portal once users register an account (https://deepdive.grida.no).

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