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Abundance and types of plastic pollution in surface waters in the Eastern Arctic (Inuit Nunangat) and the case for reconciliation science

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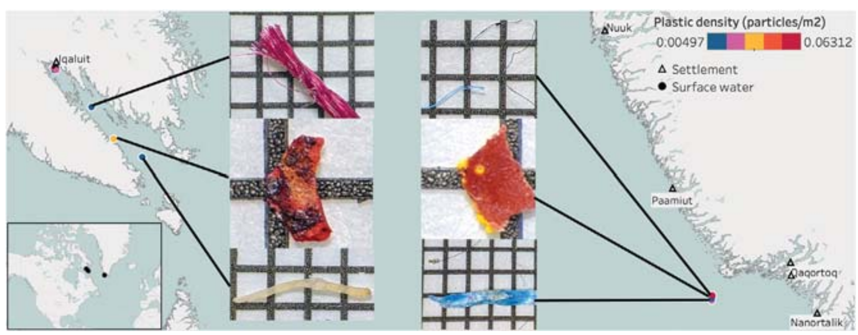
HIGHLIGHTS

- Reports plastics in surface water in SW Greenland (0.026/m^2) & Tasiujarjuaq, Nunavut (0.014/m^2)
- Recovered plastics show indications of both long-range and local sources.
- Surface water plastic research in Inuit Nunangat and Greenland is led by southerners and non-Inuit.
- "Reconciliation science" requires changes in personnel, methods, and communicating results.

GRAPHICAL ABSTRACT



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ABSTRACT

Plastics are not only an environmental concern but also an issue of justice in the Arctic, particularly in Inuit Nunangat (Inuit homelands), as plastics and other contaminants that originate in the south accumulate in the north and have implications for Inuit sovereignty and wellness. This collaborative study finds an average of 0.018 plastics/m^2 in surface waters in two sites in the eastern Arctic (Tasiujarjuaq in Nunavut near Iqaluit and southwest Greenland offshore from Qaqortoq and Narsaq). A comparison with other studies shows this abundance of plastics is lesser than abundances reported further north in the Arctic, but greater than adjacent waters further south. However, within and across study areas at similar latitudes, there does not appear to be a significant difference in plastic abundance. Some characteristics of recovered plastics such as morphology and colour support local origins, while others support long range transport. Research moving forward should consider relative scales in spatial trends of plastic abundance. The discussion concludes by reflecting on the methods and findings in terms of their role in Inuit governance and research relationships, including elements of research personnel, permitting, categorization, measurement, and

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Marine debris
Colonialism
Greenland
Nunavut
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Reconciliation science

reporting findings. Our goal is to provide insights of where we, as scientists, may choose to intentionally move our scientific work towards reconciliation while we produce knowledge about environmental pollution in Inuit Nunangat and the Arctic broadly.

1. Introduction

Plastics are not only an environmental concern, but also an issue of justice in the Arctic, particularly in Inuit Nunangat (Inuit homelands), as plastics and other contaminants that originate in the south accumulate in the north and have implications for Inuit sovereignty and wellness (Bourdages et al., 2020; Sudlovenick, 2019; Watt-Cloutier, 2015; Furgal et al., 2005; Van Oostdam et al., 2005). Inuit Nunangat contains four regions: the Inuvialuit Settlement Region (northern Northwest Territories), Nunavut, Nunavik (northern Quebec), and Nunatsiavut (northern Labrador). It includes 53 communities and encompasses roughly 35% of Canada's land mass and 50% of its coastline, but no manufacturing infrastructure for the production of plastics (Royal Canadian Geographical Society, 2018). Yet studies have shown a clear trend where plastic has been found to accumulate in Arctic waters and ecosystems compared to waters further south with higher populations and plastic manufacturing infrastructure (Obbard, 2018; Cózar et al., 2017). The hypothesis is that as the global Thermohaline Circulation (THC) actively moves "warm surface water from low to high latitudes across the North Atlantic Ocean to the Arctic, it could collect buoyant plastic from highly populated latitudes, leading to accumulation in the Greenland and Barents seas, where the landmasses, together with the polar ice cap, would constitute a dead end for the surface transport of floating debris" (Cózar et al., 2017: 1; see also Lusher et al., 2015). Southerly movement of plastics to Arctic locations also takes place through atmospheric transport of microplastics such as microfibers (Evangeliou et al., 2020; Bergmann et al., 2019), the release of plastics deposited by Pacific Ocean waters through melting sea ice (Peeken et al., 2018; Obbard et al., 2014), and the biotransport of plastics via seasonally migrating animals, such as seabirds (Bourdages et al., in press; Provencher et al., 2010; Mallory et al., 2006).

At the same time, the Arctic is relatively understudied from a scientific perspective (AMAP/EU-PolarNet, 2020), meaning more work is needed to describe the patterns in plastic accumulation in the North. Existing scientific studies of plastic pollution in the Arctic are framed in terms of baseline figures (Lusher et al., 2015; Mallory, 2008) or plastics' environmental effects (Kanhai et al., 2018; Provencher et al., 2010). Our study continues this scientific trajectory by providing abundance measures (number of plastics/m^2) and an analysis of types of plastic pollution in surface waters near the capital city of Iqaluit in Tasiujarjuaq (Frobisher Bay), Nunavut, and offshore from Qaqortoq and Narsaq in southwest Greenland. We compare these findings to other results in the Arctic generally and Inuit Nunangat in particular.

This study is the result of a collaboration between four different groups: a scientific team based in St. John's, Newfoundland and Labrador, that collected all samples in Nunavut and Greenland; CLEAR, an interdisciplinary plastic pollution laboratory also based in St. John's that studies marine plastics as well as colonialism in science that conducted analysis and writing; scientists at Surface Science Western Lab at the University of Western Ontario that conducted spectrometry work; and a group of Inuit and non-Inuit research professionals who have lived and worked in Inuit Nunangat who provided expert insights, context, and validation for analyzing findings and recommendations. This partnership was not planned in advance but rather came together as research needs arose and has resulted in a unique extension of the scientific study in the Discussion section of the paper on reconciliation science. In addition to discussing research findings for trends in plastic pollution, we also provide critical reflection on research methods and findings in terms of Inuit-based research, reconciliation, and governance relationships (Loseto et al., 2020; Pedersen et al., 2020; Wong et al., 2020; ITK, 2018; Pfeifer, 2018; Moffitt et al., 2015; ITK and NRI, 2007). Such reflections are crucial for ongoing and future research in Inuit Nunangat to ensure our work as scientists and research partners is part of reconciliation. We are calling this "reconciliation science." Rather than dividing these reflections into a separate "opinion" piece or social science paper, we make the case that existing and ongoing Indigenous research relations should never be divided from scientific study and reporting, and our goal is to provide one model for how reconciliation science might be done.

2. Materials and methods

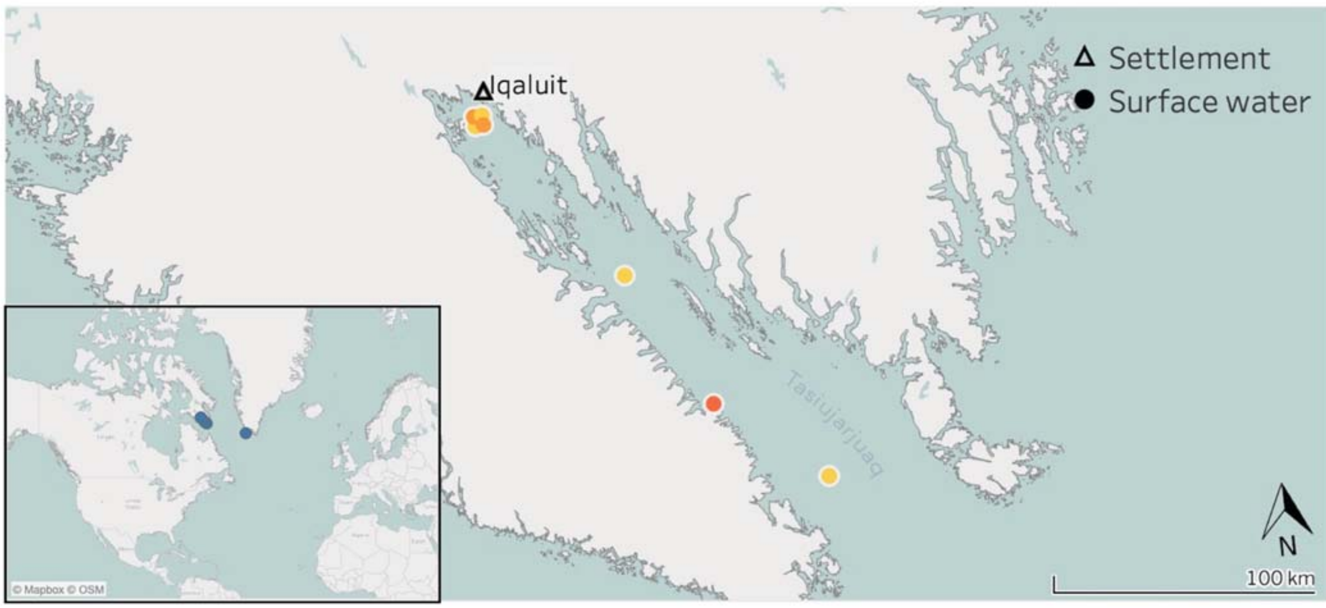
2.1. Sample collection

Samples for this study were collected in 2018 by a team of settler, non-Inuit authors based in St. John's, Newfoundland and Labrador, who were already traveling to Inuit Nunangat and southwestern Greenland for research unrelated to plastic pollution for seafloor mapping and biodiversity (via the Amundsen Science Leg 2c, 2018). Sample collection took place in July and August of 2018 near the capital city of Iqaluit in Tasiujarjuaq (Frobisher Bay), Nunavut, and in the Labrador Sea offshore from Qaqortoq and Narsaq in southwest Greenland aboard the Canadian Coast Guard Vessel (CCGS) *Amundsen* (Fig. 1).

Sample collection sites were designed to answer two questions. (H1) First, we aimed to discern whether plastics that might have originated in the Iqaluit landfill, which burned for 178 days in 2014, were moving from land into Tasiujarjuaq, a local hypothesis that resulted in an invitation to do related plastic pollution research in the area (also see Watson, 2014, Nunatsiaq News, 2015, Varga, 2015). Sampling locations in Tasiujarjuaq were grouped close to Iqaluit and further out in the bay to test that hypothesis, and plastics were inspected for signs of burning or melting. (H2) Secondly, the site in southwest Greenland was used as a comparison to determine whether the abundance and types of plastics in Tasiujarjuaq were markedly different than those of a location in another current but at a similar latitude. Tasiujarjuaq is macrotidal (11 m tide range) with particularly strong tidal currents through the mid-bay islands, and southwest Greenland is dominated by the West Greenland current, bringing surface waters around Greenland from the northeast Atlantic Ocean (see S13). This sample collection design provided a snapshot of plastic profiles in two key locations and cannot be used for wider generalizations of geographic patterns of plastic pollution, given its relatively low sample size and limited duration of sampling.

Researchers used a Manta surface water trawl with a net mesh size of 335 μm, and each trawl was conducted for 30 min. The mouth of the trawl is 0.53 m, determining the maximum size of plastic we would have collected. A flowmeter was attached to the trawl to determine the amount of water sampled. Entire cod ends containing samples were placed in sample bags with 20 mL of hydrogen peroxide (3%) for storage and frozen at −20 °C for later laboratory analysis. Contamination samples were taken each day from mittens, gloves, scarfs, toques (winter hats), jackets, and other fabrics of all personnel in contact with the trawl to ensure potential sources of contamination during data collection could be identified. The colour of the ship's paint, sampling gear, and ropes were also recorded as potential sources of contamination.

Abundance of plastics in surface water, Tasiujarjuaq, Nunavut



Abundance of plastics in surface water, Eastern Arctic

Location	Sample ID	
SW Greenland	Average	0.026
	Trawl-9	0.063
	Trawl-10	0.005
	Trawl-11	0.011
	Trawl-12	0.025
Tasiujarjuaq, Nunavut	Average	0.014
	Trawl-1	0.018
	Trawl-2	0.014
	Trawl-3	0.021
	Trawl-4	0.011
	Trawl-5	0.005
	Trawl-6	0.029
	Trawl-7	0.011
	Trawl-8	0.005

Abundance of plastics in surface water near Qaqortoq, Greenland

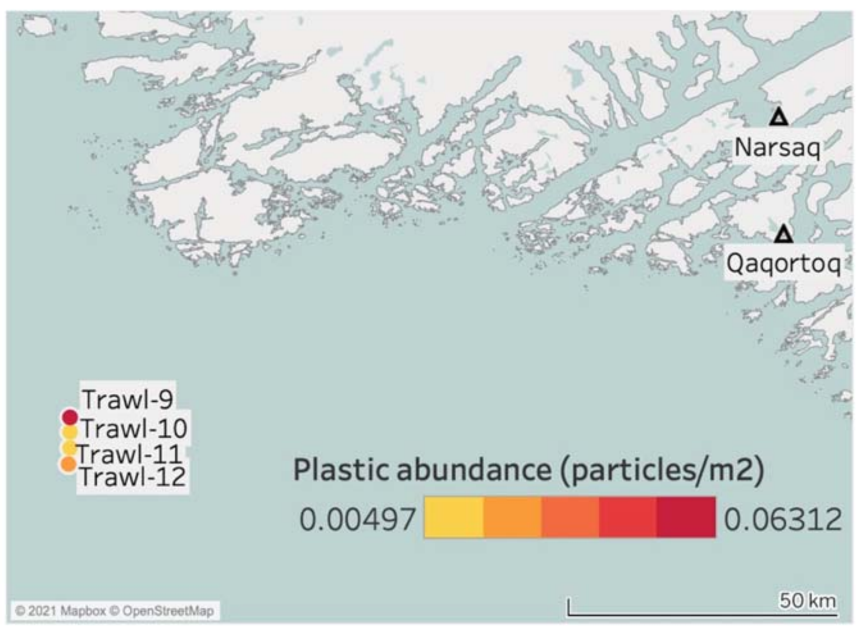


Fig. 1. Abundance of plastics in surface water near Iqaluit and Qaqortoq. The map shows the relative abundance of plastics (particles/m^2) for each surface water trawl. For a more detailed map of trawl sites near Iqaluit, see S10.

2.2. Permits

Permits, licenses, and/or permissions are required before conducting research in most areas, including the Arctic. Following research permitting protocols is particularly important in Indigenous land claim areas and traditional homelands as part of Indigenous sovereignty—the right of Indigenous peoples to govern Indigenous lands. Permits were sought and obtained by Amundsen Science, including: Nunavut Research Institute Scientific Research License # 0501318R-M; Department of Fisheries and Oceans License to Fish for Scientific Purposes in the waters of Nunavut # S-18/19-1012-NU; Vessel Clearance to conduct scientific work in Greenland waters; Danish Ministry of Foreign Affairs file # 2018-15931; and Government of Greenland Survey License # G18-028. For an overview of research licensing bodies in Inuit Nunangat, see ITK (2018): 15–16 and Table S1.

2.3. Lab analysis

After collection, samples were transferred to a team at the Civic Laboratory for Environmental Action Research (CLEAR) based in St. John's (Beothuk homelands) for processing and analysis. CLEAR team co-authors are non-Inuit: some are settlers and some are Indigenous from other places. Samples were transferred from the freezer to a bleach solution for 18–20 h to discolour any organics to aid in identifying plastics. Once bleached, samples were sieved to eliminate items smaller than 425 μm. This size cut off was chosen to align with existing plastic monitoring occurring in Nunatsiavut, another region of Inuit Nunangat, and because this size allows accurate visual identification (Song et al., 2015), a more accessible method for future comparisons (Government of Canada, 2018). We visually examined sieve contents using a stereo microscope (Olympus SZ61, model SZ2-ILST) with a magnification range of 0.5–12×. Suspected plastics were extracted from the sample and placed into folded filter paper to dry for a minimum of 4 days, until a consistent weight was observed.

After the drying period, suspected plastics were re-examined under the microscope to further confirm plastic identification. Visually confirmed plastics were classified based on morphology, colour, size class, and whether and what types of erosion were present, including burning and melting (Table 1. See Tables S2–S6 for detailed results and category definitions). Mass, length, width, and height of plastics were also recorded. Plastics were classified as microplastics (<5 mm), mesoplastics (5–20 mm) or macroplastics (>20 mm) following other studies in the region for comparability (Baak et al., 2020; Avery-Gomm et al., 2018; Avery-Gomm et al., 2016). Plastics were transferred into labeled scintillation jars for storage and then glass slides for Fourier-transform infrared (FTIR) polymer analysis.

2.4. Contamination measures and controls

To mitigate contamination of samples by airborne microfibers, all equipment (petri dishes, sieves, tools, and the microscope) was rinsed or wiped down with paper kimwipes and tap water filtered by a 333 μm mesh identical to that in trawl nets. Cotton lab coats were worn, and hair was tied back. Pinches of clothing fibres were part of contamination samples to account for possible contamination from our clothing. Separate blanks were taken for each sampling day. We used blanks to account for plastic contamination that may come from the air, our clothing, and/or lab equipment. Blanks were taken each day.

To eliminate contamination plastics from our analysis, sample plastics were compared with those in blanks from both the lab and the ship and any plastics in our sample that were identical to those in the control were eliminated. Criteria for elimination included identical: colour, thickness, and "kinkiness" (shape characteristics) for microplastics, and colour, morphology, and erosion patterns for non-microplastics such as paint chips or ropes. Any plastics confirmed as contamination were recorded and removed from the sample analysis.

2.5. Spectroscopy

Samples were sent to the Surface Science Western Lab at the University of Western Ontario on the homelands of the Anishinaabek, Haudenosaunee, Lūnaapéewak and Attawandaron peoples for FTIR spectroscopy to determine the polymer type of plastics and to validate visual identification. This technique involves shining a beam of many frequencies of light at an object, producing a spectral graph of absorption. Outputs from individual plastics were compared to outputs of known polymer types to determine identity.

Table 1
Abundance of plastics in surface water in Tasiujarjuaq, Nunavut and Southwest Greenland.

Site	Sample size	Total plastic abundance		
		Median (#/m^2)	Mean (#/m^2)	SD
Tasiujarjuaq, Nunavut	8	0.0126	0.0143	0.0082
Southwest Greenland	4	0.0182	0.0262	0.0260

2.6. Statistical analysis

Two statistical analyses were performed to address two questions: (1) to determine whether the total plastic abundance differed between the two research of Tasiujarjuaq and SW Greenland; and (2) to test the effect of local-scale latitude on plastic abundance within each site.

To determine whether the difference in abundance between the two sites was significant, we performed a *t*-test (two-sided) with a 95% confidence interval using the function t.test (R v.3.6.0). To determine the power of the *t*-test we performed a power analysis, using the function pwr.t2n.test (R v.3.6.0) for unequal sample sizes. We also conducted a power analysis to predict the number of samples that should be taken in future research to detect a difference in abundance. The power analysis was performed using the function pwr.t.test (R v.3.6.0) for equal sample sizes, with a power of 0.8 (standard), a significance level of 0.05, and the effect size of this study (Cohen's $d = 0.7335$; the absolute mean difference divided by the standard deviation). The certainty (probability) of not committing an error (type 1 or 2) in this test is represented by the "power" of the test, which is low in this case: 0.19. This is primarily due to the small sample size. We performed an ANOVA on total plastic abundance as a function of latitude within each site independently of one another.

2.7. Literature review

To compare our findings to other plastic research in the region, the CLEAR research group conducted an exhaustive literature review for all English-language, peer reviewed publications on plastic pollution conducted in Inuit Nunangat and Greenland. To do so, we used Web of Science Core Collection and Scopus for the following terms in topic and title searches: Inuit Nunangat plastic, Arctic plastic, Arctic plastic Canada, Arctic plastic pollution, Arctic microplastic. Using Scopus, the following search terms were used in the title, keywords, and abstract category search feature: 'Arctic AND plastic', 'Inuit Nunangat AND plastic', 'Nunavut AND plastic', 'Nunatsiavut AND Plastic', 'Inuvialuit AND plastic', 'Nunavik AND 'plastic', 'Greenland AND plastic', 'Northwest Territories AND plastic', 'Yukon AND plastic', and 'Labrador AND plastic'.

Titles and abstracts were examined to ensure studies were scientific research on plastic pollution. We also contacted the Nunatsiavut Government and the Nunavut Research Institute for unpublished data sets. Duplicates and papers whose study areas did not fit the geographic area of interest or were not primary studies on plastic pollution were eliminated and all abstracts were reviewed to ensure fit.

We recovered a total of 18 peer reviewed papers and one grey literature report on plastic pollution from across regions of Inuit Nunangat, Greenland, and adjacent waters. These existing studies were organized based on region and location of study, type of plastic pollution study conducted (e.g. ingestion, surface trawl, benthic, ice core), plastic pollution findings (Table S7) and statements regarding research licensing (Table S8). Because a number of different methods were used in each study, we included a measurement unit reported as well as minimum detection limit so comparison between studies account for key methodological similarities and differences.

2.8. Analysis of methods for reconciliation science

A unique feature of this study is its framing of scientific methods and findings in terms of Inuit relationships and Northern governance, one aspect of reconciliation. We analyzed the scientific methods and findings according to key concepts and texts, supported by fluency in literature in the social studies of science (STS), decolonizing research and science in particular (e.g. Wilson, 2008; Tuck, 2009; Smith, 2012; Kimmerer, 2013), and settler colonial studies (e.g. Byrd, 2011; Snelgrove et al., 2014). Key concepts include reconciliation, colonialism and research sovereignty (e.g. Liboiron, 2021; Loseto et al., 2020; Carroll et al., 2019; Pfeifer, 2018; Rodriguez-Lonebear, 2016; Coulthard, 2014;

Walter and Andersen, 2013; Gaudry and Lorenz, 2018). To avoid a pan-Indigenous analysis that homogenizes thousands of different Indigenous cultures, we foreground locally salient Inuit texts such as Inuit Tapiriit Kanatami's publications on *National Inuit Strategy on Research* (2018) and *Negotiating Research Relationships with Inuit Communities* (2007), among others.

2.9. Community peer review

When CLEAR conducts plastic pollution research on Inuit lands and food webs, we engage in community peer review of findings before we disseminate to academic venues (Liboiron et al., 2018. Also see Loseto et al., 2020 and Wong et al., 2020). We shared a manuscript draft with key personnel in research institutions in Nunavut (Nunavut Arctic College, Nunavut Research Institute) and Nunatsiavut (Nunatsiavut Research Centre). Many reviewers provided substantial feedback and are co-authors.

2.10. Author order

The method to determine author order followed Liboiron et al. (2017). The forms of labour in the study were discussed and ranked, and the people who performed those types of labour were listed. Forms of labour that attended to accountability were ranked highest for this report. Where two or more researchers were ranked identically, we considered issues of equity to order them. All authors as well as the full lab were invited to be part of these discussions, which were recorded. This process was revisited during review and subsequent edits as necessary.

3. Results

3.1. Abundance of plastics in surface waters

A total of 12 marine surface water trawls were deployed (Fig. 1 & Table S2). Plastic pollution was found in all surface trawls. Plastic abundance ranged between 0.005 and 0.063 plastics/m^2 and averaged 0.018 plastics/m^2 across all samples (Fig. 1). For lay reference, this represents an average of about 27 pieces of plastic in a body of water the size of a National Hockey League (NHL) ice rink. Southwestern Greenland samples averaged the highest plastic abundance at 0.026 (±0.026 SD) plastics/m^2 compared to Tasiujarjuaq at 0.014 (±0.008 SD) plastics/m^2. The highest abundance tow was the northernmost trawl (Trawl 9) in the Davis Straight/Labrador Sea by Qaqortoq, Greenland at 0.063 plastics/m^2 (Fig. 1 & Table S2).

3.2. Characteristics of plastics

Samples yielded a total of 42 different plastics, 22 of which were from Tasiujarjuaq and 20 of which came from southwest Greenland. Plastics were arranged by site and categorized by size, morphology, polymer type, colour, and erosion. The majority of plastics were microplastics (81.0%, $n = 34$) between 0.45 and 5 mm in size (Table 1). This size trend was consistent across both study regions, including 82% of plastics from Nunavut ($n = 18$) and 80% of plastics from Greenland ($n = 16$). Mesoplastics between 5 and 20 mm comprised 14.3% of all plastics ($n = 6$), the majority of which were threads. Only two macroplastic pieces larger than 20 mm were collected: one green polyacrylonitrile thread collected from southern Greenland and one clear polypropylene film from Tasiujarjuaq, Nunavut.

Fragments comprised the majority of all plastic types collected (50%, $n = 21$), followed by threads (26%, $n = 11$), foam (12%, $n = 5$), film (10%, $n = 4$), and a single microbead (2%). No microfibers were recovered, which is common when using a 0.45 mm cut off size. While both regions had similar percentages of fragments and film, they varied in the abundance of other morphologies. All foam (n = 5) was found in Frobisher Bay, for example, and more threads were found near Greenland (Table S2).

The most abundant colour was red (26%, split evenly between the two study sites). White and black were the second most plentiful at 12% of the total (Table S3). All plastics (100%, $n = 42$) had signs of erosion or wear. More than one erosion pattern can occur on a single plastic, and 75 erosion notes were gathered on the 42 plastics (Table S4). The most common erosion type was fraying, which was related to the high number of plastic threads recovered. Among plastics, 19% were discoloured, 19% were pitted, 14% were fragmented, and 9% were stretched. All other erosion patterns were noted on 5% of plastics or less. Four, all from Tasiujarjuaq, were melted and/or burned.

All suspected plastics were submitted for FTIR analysis to determine polymer type (Table 2). Four threads were cellulosic and likely from non-plastic textile sources (Athey et al., 2020). Two plastics could not be identified, and 39 plastics were identified as synthetic polymers. The most common polymer was polyethylene (21%, $n = 8$), followed by epoxy blends (18%, $n = 7$), and polystyrene (15%, n = 6), though all polystyrene was recovered from Tasiujarjuaq. Table 3 shows polymer types at each location. We also include common uses of each polymer type in anticipation of diverse users of this data.

3.3. Spatial distribution of plastics between and within study sites

There was no significant difference in total plastic density between both locations ($p = 0.4335$. DF = 3.3022). In short, the difference in averages between the abundance of plastics in Tasiujarjuaq and southeast Greenland cannot be differentiated from chance (H2 is null). However, this test had a power of 0.19, indicating a high potential for type 2 error. This result is somewhat surprising given that the currents and land use patterns for each site are different. A power analysis shows that a minimum sample size of 30.2 samples (or 30 trawl tows per site) would allow future studies to detect a significant difference from these findings.

The ANOVA test also showed that abundance within each site was not related to local-scale latitude, which was also somewhat unanticipated, especially given that in Tasiujarjuaq, the location of the City of Iqaluit is located further north in the bay and thus is anticipated to be a source of urban plastic pollution (H1 is null) (p-value was >0.05. It was 0.662 for Tasiujarjuaq and 0.04738 for SW Greenland). The F value was 0.2112 for Tasiujarjuaq and 0.7658 for SW Greenland.

3.4. Comparison of findings with existing studies in the literature

The systemic literature search for all research on plastic pollution in the Arctic resulted in 1116 title results, of which 1099 were excluded because they were not primary research on plastic pollution (merely mentioning the Arctic and plastics in passing), or were outside of the study area, or were duplicates. One additional grey literature report was found by contacting Inuit governments.

Table 2
Morphology and size of plastics near Iqaluit in Tasiujarjuaq (Frobisher Bay), Nunavut and southwest Greenland near Qaqortoq.

Location	Film	Foam	Fragments	Microbeads	Microfibers	Pellets	Threads	Macro	Meso	Micro
Tasiujarjuaq, Nunavut	2	5	11	1	0	0	3	1	3	18
Southwest Greenland	2	0	10	0	0	0	8	1	3	16
Total	4	5	21	1	0	0	11	2	6	34

Table 3
Polymer types of plastics recovered in surface water in Tasiujarjuaq near Iqaluit and the Labrador Sea near Qaqortoq (SW Greenland).

Polymer type	Common uses	Tasiujarjuaq (count)	Tasiujarjuaq (%)	SW Greenland (count)	SW Greenland (%)	Total (count)	Total (%)
Acrylonitrile butadiene styrene (ABS)	Automotive components, pipe fittings, consumer goods (like Lego)	0	0%	0	0%	0	0%
Acrylate	Cosmetics, paints, diapers, textiles	0	0%	1	5%	1	3%
Alkyd Resin	Paints and varnishes, furniture and architectural coatings	0	0%	0	0%	0	0%
Acrylonitrile styrene acrylate (ASA)	Automotive components, home appliances	0	0%	1	5%	1	3%
Polyamide/Nylon (PA)	Textiles, carpets, automotive components, fishing gear	1	5%	0	0%	1	3%
Polyacrylonitrile (PAN)	Textiles, cement reinforcement	0	0%	3	16%	3	8%
Polyethylene (PE)	Packaging, trash bags, wire and cable insulation	6	30%	2	11%	8	21%
Polyethylene terephthalate (PET)	Packaging, soda pop bottles, textiles	0	0%	2	11%	2	5%
Polypropylene (PP)	Packaging, textiles, medical applications, fishing gear	2	10%	3	16%	5	13%
Polystyrene (PS)	Foam packaging and coolers, medical applications	6	30%	0	0%	6	15%
Polyurethane (PUR)	Coatings, spray and rigid foams common in construction, transportation, and furniture	0	0%	0	0%	0	0%
Silicone	Sealants and adhesives, medical applications	0	0%	0	0%	0	0%
Epoxy blends	Sealants and adhesives	2	10%	5	26%	7	18%
Other polymer	–	3	15%	2	11%	5	13%
Totals		20	100%	19	100%	39	100%

The final 18 English-language, published studies on plastic pollution in Inuit Nunangat and Greenland (Table S7) were dominated by ingestion studies (66%, $n = 12$), almost exclusively in birds (61%, $n = 11$). Ingestion studies comprised all of the studies in Inuit Nunangat regions of Nunavut (100%, $n = 8$), Nunatsiavut (100%, n = 1) and Inuvialuit (100%, n = 1), while a greater variety of plastic pollution research has been conducted outside of Inuit Nunangat in Greenland, including ingestion (50%, $n = 3$), subsurface water trawl (33%, $n = 2$) and ice core studies (17%, n = 1). Studies conducted in polar areas adjacent to Inuit Nunangat (e.g. Labrador Sea, Arctic Central Basin) likewise included more diverse study types including ingestion (33%, n = 2), surface water (17%, n = 1), subsurface water (17%, n = 1), ice core (17%, n = 1), and benthic studies (17%, n = 1). Among all studies examined, over half of sample locations were in Nunavut (51.2%, $n = 32$) and in the Qikiqtani Inuit Region in particular (38%, $n = 24$), which include prominent migratory bird monitoring sites such as Prince Leopold Island (Provencher et al., 2009, 2010; Poon et al., 2017).

We conducted a comparison of plastic abundance among water studies (i.e. surface water, subsurface water, ice) in all of Inuit Nunangat and the nearby Arctic and subarctic in relation to the findings in this study (Table 4, S11). Findings from published studies show a greater abundance of plastics at higher latitudes in the Arctic, and particularly high concentrations in sea ice (S11). The average abundance in our study is 0.018 plastics/m^2, lower than an average abundance of 0.063 plastics/m^2 found by Cózar et al. (2017) in the Greenland and Barents Seas north of our study sites using similar surface water methods. Subsurface water studies in Ukalqearteq (Amélineau et al., 2016), Northeastern Greenland (Morgana et al., 2018), and the Arctic Central Basin (Kanhai et al., 2018) also found higher abundances further north of our study area but used different methods and are not directly comparable (Table 4). Studies find a lower abundance in plastics south of our sites: published studies that used identical methods to our own shows Nunatsiavut to the south averaged 0.008 plastics/m^2 (Liboiron et al., 2020), followed by the more southerly region of Newfoundland and Labrador outside of the Arctic, which averaged 0.007 plastics/m^2 of surface water (Liboiron et al., 2020).

4. Discussion

4.1. Spatial trends of plastics abundance

Arctic and subarctic regions (north of 60° latitude), which include many Inuit communities, are less populated than locations further south and there are no sources of plastic production in the Arctic. Yet, both models (Van Sebille et al., 2012) and published studies (Obbard et al., 2014; Lusher et al., 2015; Bergmann et al., 2016; Cózar et al., 2017) find high plastic accumulation in the northern and easternmost areas of the Greenland and Barents seas and the Arctic Polar Circle generally. For this reason, we chose two sites at relatively similar latitudes (between 60 and 63°) to compare the abundance of plastics in surface

Table 4
Plastic density figures from surface water, subsurface water, and sea ice core studies in waters surrounding Inuit Nunangat and Greenland.

Citation	Year	Environment	Sample depth (m)	Location	n	(#/unit)	Unit	Detection limit (mm)
Cózar et al., 2017	2013	Surface water	0.15	"Rest of Arctic Ocean"	42	0.0000	m^2	0.5
Liboiron et al., 2020	2017	Surface water	Surface	Ramah Bay	1	0.0000	m^3	0.425
Liboiron et al., 2020	2017	Surface water	Surface	L'Anse aux Meadows	3	0.0049	m^2	0.425
Liboiron et al., 2020	2017	Surface water	Surface	Indian Island	2	0.0074	m^2	0.425
Liboiron et al., 2020	2017	Surface water	Surface	Grady Island,	3	0.0084	m^2	0.425
Liboiron et al., 2020	2017	Surface water	Surface	Nunajnguk (Nain)	4	0.0093	m^2	0.425
Liboiron et al., 2020	2017	Surface water	Surface	Tongait Kakkasuangita SilakKijapvinga	1	0.0094	m^2	0.425
Liboiron et al., This study	2018	Surface water	Surface	Frobisher Bay Nunavut	8	0.0144	m^2	0.425
Liboiron et al., This study	2018	Surface water	Surface	East Greenland	4	0.0263	m^2	0.425
Cózar et al., 2017	2013	Surface water	0.15	"Greenland and Barents Seas"	42	0.0630	m^2	0.5
Kanhai et al., 2018	2016	Subsurface water	8.5	"Arctic Central Basin"	58	0.9700	m^3	0.25
Amelineau et al., 2016	2005	Subsurface water	50	Ukalqearteq	18	0.9900	m^3	0.5
Amelineau et al., 2016	2014	Subsurface water	50	Ukalqearteq	20	2.3800	m^3	0.5
Morgana et al., 2018	2018	Subsurface water	6	Northeastern Greenland	7	2.4000	m^3	0.08
Peeken et al., 2018	2014	Sea ice	–	Fram Strait	1	4.1000	m^2	0.011
Obbard et al., 2014	2014	Sea ice	1.07	"Arctic Ocean"	1	50	L	–
Obbard et al., 2014	2014	Sea ice	1.35	"Arctic Ocean"	1	238	L	–

water in each, and to locations further north and south (via other published literature).

We did not find a statistically significant spatial trend of abundance within either site, even though in Tasiujarjuaq one cluster of trawl tows were close to Iqaluit and its landfill, which is located on a cliff overlooking the ocean, and the others ran out into the bay including two tows near the mouth of the bay. We expected a statistically significant increase of abundance close to urban centers (Iqaluit population is 7740) (City of Iqaluit, 2021) and its landfill as per H1, but this was not the case. While proximity to urban centers and latitude are not synonymous, in the specific case of Tasiujarjuaq they have an equivalency. Based on our statistics, differences in abundance between trawls, as a function of latitude, were likely due to chance.

There was also no a statistically significant difference in the two abundance measures between Tasiujarjuaq and southwest Greenland (p-value $= 0.4335$) (H2). However, the number of samples in this study makes the certainty of these measures relatively low. More samples (30 per site, based on power analysis) would allow not only more certainty, but would be able to show a demonstrable change in future studies. It should be highlighted that deploying 30 trawls per site, at 30 min each, would represent an important time commitment during any expedition, particularly during inter-disciplinary surveys, and in practice it might be challenging to obtain such elevated number of samples.

The literature review allowed us to situate our findings within other studies of plastic abundance in water and ice further north and south of our sites. Our study found abundances of microplastics that are similar to those found in Arctic surface waters at comparable latitudes, such as off the coast of Svalbard, Norway (0.028 plastics/m^2), though this study sampled subsurface water and had a lower cut off size than our study (Lusher et al., 2015). As mentioned above, our results show a lower abundance of plastics than in the suspected plastic accumulation zone further north near the Greenlandic and Barents seas using similar surface water methods and cut off sizes (0.0630 plastics/m^2) (Cózar et al., 2017; also see Van Sebille et al., 2012 for a model). Subsurface water studies in Ukalqearteq (Amélineau et al., 2016), Northeastern Greenland (Morgana et al., 2018), and the Arctic Central Basin (Kanhai et al., 2018) also found higher abundances further north of our study area but used different methods and are not directly comparable (Table 3). However this trend in higher abundance at northern latitudes is complicate by the study by Cózar et al. (2017), which included 42 sites across the Arctic Circle, 37% of surface net tows were free of plastic, while none of the tows in this study were plastic-free.

The average abundance in both our locations was higher than those in adjacent southern Arctic, subarctic and North Atlantic regions including an average of 0.008 plastics/m^2 in Nunatsiavut and 0.005 plastics/m^2 near L'Anse aux Meadows just south of Labrador in studies that used identical methods and cut off sizes (Liboiron et al., 2020). Indeed, the highest abundance found in this study (trawls 3 and 6 in Tasiujarjuaq and trawls 9 and 12 in southwest Greenland) were closer to those found in more heavily populated south Pacific waters (0.027 plastics/m^2) with similar methods (Eriksen et al., 2013). Caution should be exercised when doing these sorts of comparisons, however, as sampling and laboratory methods are not standardized across all studies. For this reason, Table 4 includes the environment sampled, sample depth, number of samples, and the lowest detection size, all of which can influence findings. We have consistently noted where results are more or less comparison due to these different methods in the text above.

Such a comparison leads us to believe that the effects of latitude on plastic abundance occur over large scales rather than those of single bays or study areas, and our findings do not invalidate research that shows the high Arctic as a sink for long-range transport of plastics that originate further south. Thus, we propose that spatial nuance in studies is important, as studies that consider localities and scales that have meaning to local Arctic residents may well have different spatial patterns than those that consider entire oceans or regions of the Arctic. In the future, a greater number and more even coverage of sampling within a bay such as Tasiujarjuaq is recommended for making meaningful data about local plastic conditions.

4.2. Trends of plastics type (morphology, polymer, erosion) and relationships to local or long-range sources

One of the core questions in a study like this is whether plastics might be local or from long-range sources. This is a difficult question to answer, as it is impossible to definitively determine the source of plastics in nearly all cases. In this study, there are conflicting indications of local and long-range plastics, and it is likely that both sources are represented here.

The polymer type most commonly found in this study was polyethylene (21%), which likewise comprised the largest percentage of polymers found in studies of surface water in Northwest Greenland (41%) (Morgana et al., 2018) and in Arctic sea ice cores (48%) (Peeken et al., 2018). A similar percentage was found in the Greenland Sea (23%), though in this last case polyester was more abundant (53%) (Amélineau et al., 2016). Polyethylene is commonly found in plastic packaging materials and other 'user' plastics, though this does not indicate that these plastics are from local sources. The prevalence of polyethylene is in line with many other studies and may indicate long-range sources, our percentage (21%) was comparatively low. Uniquely, the polymer types identified in this study were more diverse that other studies in water and ice in the Arctic and we found an unusually high prevalence of epoxy blends (18% of the overall study, and 26% of those in SW Greenland), which are not noted in other Arctic water and ice studies in our literature review. Likewise, polystyrene is rarely or never mentioned in these other studies, but it was our second most abundant category (15%), all of which was found in Tasiujarjuaq.

We found five burned and/or melted erosion patterns on plastics, all from Tasiujarjuaq. As the dump in Iqaluit has been a source of both controlled and uncontrolled burning of plastics in the past (Watson, 2014; Varga, 2015; Zahara, 2015, 2018), this may indicate the plastic is local in origin. However, other studies have found burned plastics in regions further south where burning is not a part of official waste management (Saliu et al., 2018). Avery-Gomm et al. (2016) for example, found that 37% of plastics ingested by dovekies (*Alle alle*) on the island of Newfoundland south of this study were burned or melted. It is likely these are local plastics, though we cannot be sure.

Finally, most studies of Arctic sea water and ice found that blue plastics are the most prevalent (e.g. Obbard et al., 2014; Morgana et al., 2018; Kanhai et al., 2018), but we found that red was the most prevalent (26% of plastics overall, split evenly between sites), followed by white and black (both 12%). Taken together, these findings on polymer type and erosion patterns may indicate a unique profile of plastics in these regions or at this latitude.

At the same time, there are indications that some of the plastics are likely from long-range transport. We found the presence of erosion on all plastics (100%, $n = 42$). Following Cózar et al. (2017: 1), "an abundant presence of aged debris" is a possible indicator that plastics "originated from distant sources." Of course, aged plastics do not necessarily mean they are from distant sources as they could accumulate in local areas over time, and indeed, the freezing and thawing cycles at high latitudes can contribute to fragmentation and other erosion patterns, as can warm and sunny shorelines (Cooper and Corcoran, 2010).

Cózar et al. (2017) and others have used the high abundance of plastics in the Arctic in juxtaposition to low local populations to argue that Arctic plastics are likely not local. Our findings on abundance are consistent with this hypothesis. Abundance compared to population, ubiquitous erosion patterns, and the lack of statistical evidence that areas closer to Iqaluit have a higher abundance of plastics appear to support the idea that many Arctic plastics are not originating locally (Van Sebille et al., 2012), though very likely some are. More research that considers plastics along entire potential pathways into local regions would be able to shed more light on the issue.

There are several explanations for long-range transport of plastics from the south to the Arctic. Studies have predicted hotspots of plastic accumulation in Arctic waters caused by converging currents (Van Sebille et al., 2012), for example. The West Greenland Current is a northerly flowing current with inputs of southern waters (Yang et al., 2016) and is a potential source of plastics found in our samples collected off the coast of Greenland. The West Greenlandic Current merges with the East Greenlandic Current and may indirectly receive plastics from highly populated regions of northern Europe (Morgana et al., 2018) in addition to those brought north from Atlantic regions (Cózar et al., 2017). In Tasiujarjuaq, southerly flowing water from the Baffin Current may also be a source of plastics, given high abundance of plastics found in nearby sea ice (Obbard et al., 2014; Peeken et al., 2018), likely deposited from Pacific waters. Yet, other studies hypothesize that plastics in the Greenland Sea originated from the higher Arctic via melting sea ice traveling on the East Greenland current rather than originating from the south directly (Amélineau et al., 2016). See S13 for a map of currents.

Other potential sources of plastic pollution include atmospheric transport (Bergmann et al., 2019) and biotransport via migrating animals (Provencher et al., 2010; Mallory et al., 2006), which disproportionately deposit plastics in Arctic regions (Bourdages et al., in press; Evangeliou et al., 2020). At the same time, there are complex oceanographic factors at play in the circulation of plastics in and to the Arctic. This includes the reduced buoyancy of material in cold water and Enders et al. (2015) have suggested a strong dispersal of small plastics throughout the surface mixed layers. Cózar et al. (2017) have noted that forces impacting the density of water, including melting ice creating a freshwater layer and differences in salinity, may impact transport as well as where in the water column plastics accumulate. Future studies might investigate both surface and subsurface water for plastics and consider a full range of indicators of local and long-range transport.

4.3. Reflection on research relationships to Inuit Nunangat in this study

Inuit Tapiriit Kanatami is an Inuit-led non-profit organization that protects and advances the rights and interests of Inuit in Canada, including in research. Their *National Inuit Strategy on Research* (2018) makes the legacy and context of research in Inuit Nunangat clear: “The relationship between Inuit and the research community is replete with examples of exploitation and racism. Research has largely functioned as a tool of colonialism, with the earliest scientific forays into Inuit Nunangat serving as precursors for the expansion of Canadian sovereignty and the dehumanization of Inuit. Early approaches to the conduct of research in Inuit Nunangat cast Inuit as either objects of study or bystanders. This legacy has had lasting impact on Inuit and it continues to be reflected in current approaches to research governance, funding, policies, and practices” (2018: 5. Also see Smith, 2012). We and many other researchers understand that this legacy is not in the past and signs of it exist in this study. This is not a legacy that individual researchers or research organizations can opt out of, even if we are respectful in other ways such as using local place names or fostering anti-racist cultures in our workplaces. The moment researchers decide to pursue research in Indigenous territories and homelands, we inherit these legacies and we work within this context (O'Brien, 1993; McGregor, 2004; Tuck, 2009; Smith, 2012; Moffitt et al., 2015). For this reason, the discussion below highlights the ways that normal aspects of research, from permitting to categorization of plastics, are engaged in these relationships, usually in ways that are difficult to see because they are part of scientific norms. We aim to bring some of these contexts and legacies to light so that we, as settler and non-Inuit researchers, can actively make choices to conduct reconciliatory science that align with Inuit Tapiriit Kanatami's call to change research in Inuit Nunangat.

4.3.1. Permissions and permitting

Nearly all areas in Inuit Nunangat have research permitting and permission processes in place (Table S1). Of the 18 peer reviewed articles collected in our systematic literature review, seven (39%) included a statement regarding whether a research permit was obtained (Table S8). Two of these were in the Materials and methods section rather than the acknowledgments. Of these, five (28%) mentioned whether a permit from an Inuit Nunangat research center was obtained. Others included statements about federal permits, boating permits, or statements of community consultations and partnerships. A third ($n = 6$, 33%) of all papers did not include any type of statement on research permitting or permissions of any kind. This does not mean permits and permissions were not sought and obtained, but it does indicate that the formal protocols of permissions, permits, and consent as highlighted by Inuit Tapiriit Kanatami (2018) and Inuit researchers (Pedersen et al., 2020; Bull and Hudson, 2019) are not a core part of research discussions in one of the most authoritative places that research is discussed: peer reviewed publications.

Though all researchers in this study obtained required permits and permissions, CLEAR has been asked by others to process samples collected in Inuit Nunangat without permits or to reanalyze samples when reanalysis was not part of the original permit. We decline to process samples obtained without permit. It is clear to us that permits and permission for research in Indigenous homelands is not to be taken for granted as common knowledge or practice. We encourage researchers to report Indigenous permits in Materials and methods sections to formalize their critical nature in doing research, rather than relegating them to a “helping” role as per acknowledgements (Loseto et al., 2020).

Following research permits and permission processes is a simple step establishing good research relations, but at the same time it must be stressed that in many parts of Inuit Nunangat, permits and permissions are carried out by territorial or other settler state bodies that do not necessarily have Inuit staff, nor do they necessarily consult with Inuit. If they do, there is often no formal requirement to heed Inuit requests in the permit. Indeed, there are cases where research permits were granted in Nunavut despite the protests of Inuit (Qikiqtani Inuit Association. v. Canada, 2010; Riddell-Dixon, 2011). The role of Inuit in decision-making around research in their homelands is uneven across Inuit Nunangat and is in constant development.

4.3.2. Personnel

Inuit Tapiriit Kanatami argues that “the primary beneficiaries of Inuit Nunangat research continue to be [non-Inuit] researchers themselves, in the form of access to funding, data and information, research outcomes, and career advancement” (ITK, 2018: 5). This observation held for this study: we mapped the locations (“research bases”) of first authors in all papers in our comparative analysis of plastics in water in the Eastern Arctic (Fig. 3). 100% of leads are based in the south.

This study only brought in Inuit and Northerners at the end, rather than at the beginning, which is not ideal. As contributors to this study, some consented to be co-authors. Several studies in our literature review mention working with Inuit hunters and guides, but few are listed as co-authors or appear to be considered researchers despite these activities generating samples and knowledge crucial to the success of scientific studies and despite the existence and excellence of Inuit researchers (Sawatzky et al., 2020). Our author list addresses the way northern and Inuit intellectual labour is often dismissed and unnamed in dominant scientific culture.

An investigation into the impacts of research personnel in plastic pollution research in the eastern Arctic yielded an unexpected outcome: while the majority of studies in the circumpolar Arctic are on surface water, in Inuit Nunangat they are on plastic ingestion (of 65 sites, 77%), and mainly in birds (54% of all species and sites) (Table S7). We hypothesize that this is due to the low diversity of published researchers working in this area, resulting in an overall regional skew of knowledge

Fig. 2. Places associated with marine surface water plastic research in the Eastern Arctic, including research sites, researcher home bases for first authors on published research on plastics in water in the region, and settlements in homelands. Inuit Nunangat is coloured for reference with different regions of Inuit Nunangat in different shades (Nunatsiavut in orange, Nunavut in yellow, and Nunavik in green), and settlements in Inuit Nunangat are coloured orange. The map shows a clear trend of researchers in the south producing all research in the north germane to this study.

in the direction of particular research team's or leads' interests and skills, even when they work with Inuit partners.

4.3.3. Categorization of plastics

Scientific categories can seem benign, exempt from social relationships by simply describing the natural world. However, categories and their standardization dictate what is counted and what is not, what is considered the best unit of measurement, and how different things are grouped together into measurable entities through categorization (Pine and Liboiron, 2015; Bowker, 2000; O'Brien, 1993; Porter, 1996). For example, the categories of "user" and "industrial" plastics are common in the literature (Eriksen et al., 2020; Provencher et al., 2010) but when used in Inuit Nunangat, they infer that plastics are locally sourced and users are Inuit despite the vast majority of these likely arriving from hundreds or thousands of kilometers away (Obbard, 2018). Moreover, research on waste and disposability argues that the production of "user" plastics are expressions of industry production goals and their circulation are not usually based on user behaviour, but rather on waste infrastructure and investment (MacBride, 2011; Lepawsky, 2018). All plastics have roots in industrial extraction, design, production, and circulation regardless of consumer choice (Liboiron, 2016; Amélineau et al., 2016). This mismatch between the agency of industry versus end consumers as sources of plastic pollution is amplified in the North, as consumer choice, the ability to choose between disposable packaging or other forms of plastic waste or not, and recycling and composting are often unavailable (Keske et al., 2018; Liboiron, 2018; ECCC, 2017; exp Services Inc., 2014; Dawley, 2013; Eisted and Christensen, 2011; Cantin et al., 2012; Arktis Solutions, 2011). Categorization should match this reality.

This may seem like an insignificant detail, but Inuit Tapiriit Kanatami opens their case for a *National Inuit Strategy on Research* with the argument that evidence provided by research is foundational to strong public policies, decision making, and governance (2018: 4). Measurements and their categories are related to governance and therefore to sovereignty. Sovereignty is not only about the right to self-determination and self-governance, but also the ability to access the resources, including data, to govern well (Carroll et al., 2019; Rodriguez-Lonebear, 2016). The use of user and industrial categories make implicit arguments about sources and thus intervention. Sociologist Stephen Lukes refers to this latent or potential shaping of governance through the measurements it depends on as a "mobilization of bias," or the ability to shape agendas before overt political conflict even emerges (in Scott, 1998: 58). This view is summed up in the truism, "You can't manage what you can't measure" and its inverse, "you can only manage what you do measure." Indeed, for this reason we have included a large number maps, detailed Supplementary material, lay understandings of measures (number of plastics in a hockey rink), checklists, and transparency in data—we anticipate that if Inuit groups wish to use this data for decision-making, it will have to be complete enough for such uses.

The relationship between scientific categories and evidence-based governance is why "threads" appear as a morphological category for plastics in this study. While plastic pollution research in the 1970s included the category of threads, more recent morphological standardizations do not (e.g. Rochman et al., 2019). For many places this makes sense. Yet, threads (Fig. 3) are the second highest category of plastic type in this study, accounting for 26% of plastics overall (Table 1). Threads typically originate from fishing gear (Saturno, 2020; Richardson et al., 2019). As such, our lab includes the category in all studies occurring in areas with high fishing activity to guide the governance of likely sources of plastic pollution.

4.4. Research as a source of waste and pollution

Research activities, usually conducted with gear and personnel from the south (Fig. 2), are a known source of plastic pollution and waste transport in Inuit Nunangat. In their baseline study of surface water plastics in the Southern Ocean, Suaria et al. (2020) found that more than half (58%) of plastics collection via neuston samples were paint fragments from survey ships. They explain, "Although most presumably came from our survey vessels, paint chips are continuously generated during ongoing repair, maintenance and cleaning of all ship decks and superstructures, including research vessels, cruise liners and fishing boats" (p. 6). A study by Gaylarde et al. (2021) found that while paint fragments "were 30 times more abundant than other plastic particles in the surface waters around the Antarctic peninsula," they are often not included in estimates of plastics abundance, making them a potential underestimated and understudied source of plastics (3). Other studies have found that the paint from research vessels are a source of pollution stemming from research activity (Lacerda et al., 2019; Song et al., 2014), and Peeken et al. (2018) found 27.2% of all microplastics in their study of the Arctic Ocean were acrylic or varnish, likely indicative of paint. In this study we found paint chips in both study locations; two acrylate fragments found in southwest Greenland did not match any sources of plastics on the research vessel, but four red fragments that FTIR classified as "other commercial polymers" were red on one side, with yellow or rust colours on the other (Fig. 4). The *Amundsen*'s hull is red and they may have originated from our research vessel. While none of the chips were identical to the ones on our contamination samples/blanks, the chips we archived account for only a small portion of the ship's paint. Any materials brought on research expeditions from the south to Inuit Nunangat left in the environment, from trash to sewage, is also part of the transport of waste from the south to the north through research activities. As one co-author based in Iqaluit can attest, researchers routinely leave plastic research disposables such as baggies and vials as well as toxic research materials such as acetone in Nunavut, where there are no safe methods of disposal. Other researchers have noted the extreme carbon footprint of Arctic research based in the south (Brook, 2009).

We suggest that researchers include research-based waste, pollution, and contamination as a form of harm within their research applications and designs. We also recommend researchers take samples of paint from their research vessels, not to eliminate paint as a form of contamination in samples but to compare to trawl samples as a potentially identifiable point source of marine plastic pollution.

5. Conclusion

This paper has two distinct, yet inextricably interrelated and dependant parts: (1) a traditional scientific study of plastic pollution in surface waters that aligns with other studies, finding that abundance of plastics are greater at higher latitudes in the Arctic; and (2) a reflective analysis of methods and findings with an eye to Inuit relationships and governance in the research area.

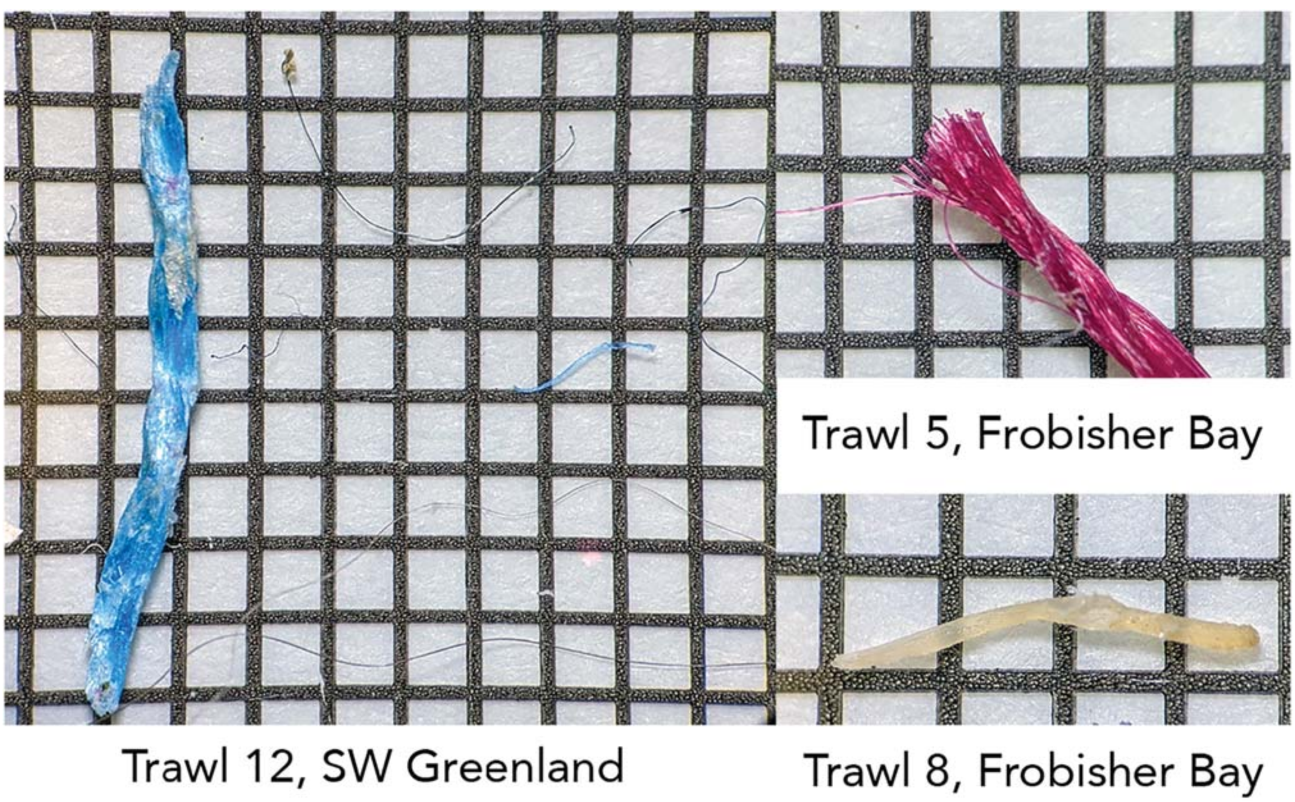


Fig. 3. Examples of threads from this study, which likely originate from fishing gear. Threads are sturdier than microfibers, even though they may be small. They are less kinked and often occur in woven bundles. Fraying of the ends is a common erosion pattern. Squares in images are 1 mm × 1 mm.

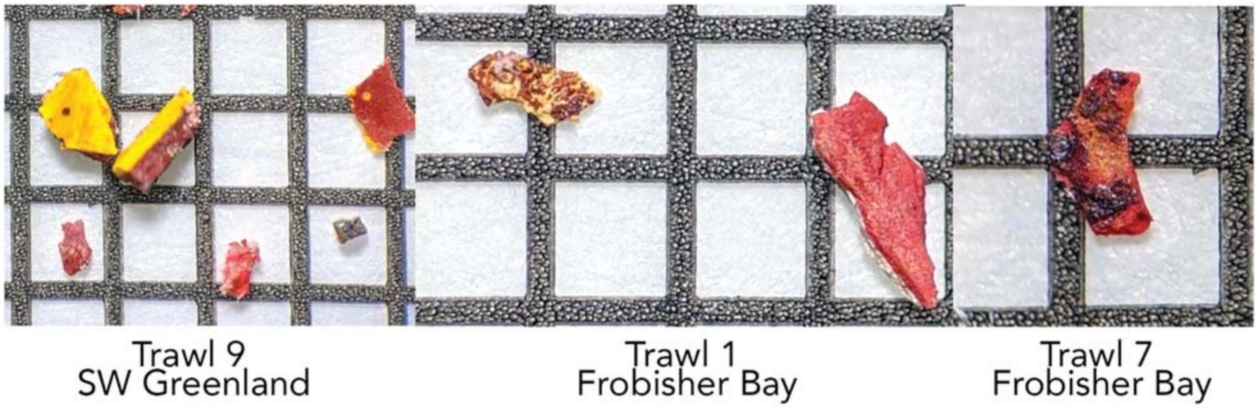


Fig. 4. Plastics fragments from surface water trawls likely to be paint chips. The squares in each image are 1 mm × 1 mm.

Focusing on these usually unintentional relationships gives us, in the scientific community, the opportunity to recognize that colonial relationships often exist in our work so we can then change relationships towards those characterized by reconciliation and respecting Indigenous sovereignty. While good intentions are a prerequisite to address colonial aspects of research, good intentions alone are not sufficient to challenge embedded colonial research practices; this requires a deliberate and rigorous change in behaviour, practices, and institutional paradigms and policies. Research methodologies are one such route for such change (Wilson, 2008; Kovach, 2010; Smith, 2012; Walter and Andersen, 2013; Wong et al., 2020; Liboiron, 2021).

Ensuring we gain permits and permissions to access Indigenous homelands, stepping back to allow and foster Inuit-led researchers and thus to decrease the need for outsider access to Inuit homelands, paying attention to the way categories, metrics, and standards are used in research and their ties to Inuit governance and sovereignty, and framing research findings for use by Inuit are all aspects of doing reconciliatory science (see also S8 for a summary of recommendations). This list should only be understood as a compliment to already existing documents such as the Inuit Tapiriit Kanatami's *National Inuit Strategy on Research* (2018) and *Negotiating Research Relationships with Inuit Communities* (2007) that clearly lay out desired researcher-Inuit relationships, principles, and protocols from an Inuit perspective. Research relations to Indigenous homelands will vary between homelands—what works for Inuit in Inuit Nunangat will almost certainly be different for Kumeyaay in US-Mexico borderlands, for example. Indeed, what works in Nunatsiavut will be different than what is needed in Nunavut, even though both are part of Inuit Nunangat (see Obed, 2017; Cunsolo Willox et al., 2012). But we do believe that some of the insights outlined here generalize to other Indigenous homelands in the Arctic and beyond.

Finally, the framing of action and good relations here falls squarely within definitions of reconciliation, based in “the promise of redemption and resolution” (Stein, 2020: 156) in a way that largely leaves existing land relations intact (Daigle, 2019). Gaudry and Lorenz (2018) articulate a spectrum of definitions, goals, and actions for indigenization. The first is Indigenous inclusion, into which our recommendation in Section 4.3.2 on foregrounding Inuit research personnel falls (also see Anonymous, 2019). The second is Indigenous reconciliation, which “locates indigenization on common ground between Indigenous and Canadian ideals, creating a new, broader consensus on debates such as what counts as knowledge, how should Indigenous knowledges and European-derived knowledges be reconciled, and what types of relationships academic institutions should have with Indigenous communities” (219). This is where we see this article falling. Finally, they describe decolonial indigenization, which would reorient “knowledge production based on balancing power relations between Indigenous peoples and Canadians, transforming the academy [and science] into something dynamic and new” (219). Our recommendations fall short of this final goal. That is, our framing of reconciliation science is more a call to reform of existing, dominant system rather than decolonization (Tuck and Yang, 2012; Gaudry and Lorenz, 2018), #Land Back (Briarpatch, 2020; Yellowhead Institute, 2019), or even allyship (Indigenous Action, 2014). This is a limitation. As such, we understand the reconciliatory moves in scientific research outlined here as the bare minimum of what might count as taking up land acknowledgements and meeting existing requirements of Inuit governance (Wong et al., 2020). Future projects may think about what other relations can take Arctic science further.

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CRediT authorship contribution statement

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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.

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