Regional report on plastic pollution in Newfoundland and Labrador, 1962-2019

Civic Laboratory for Environmental Action Research

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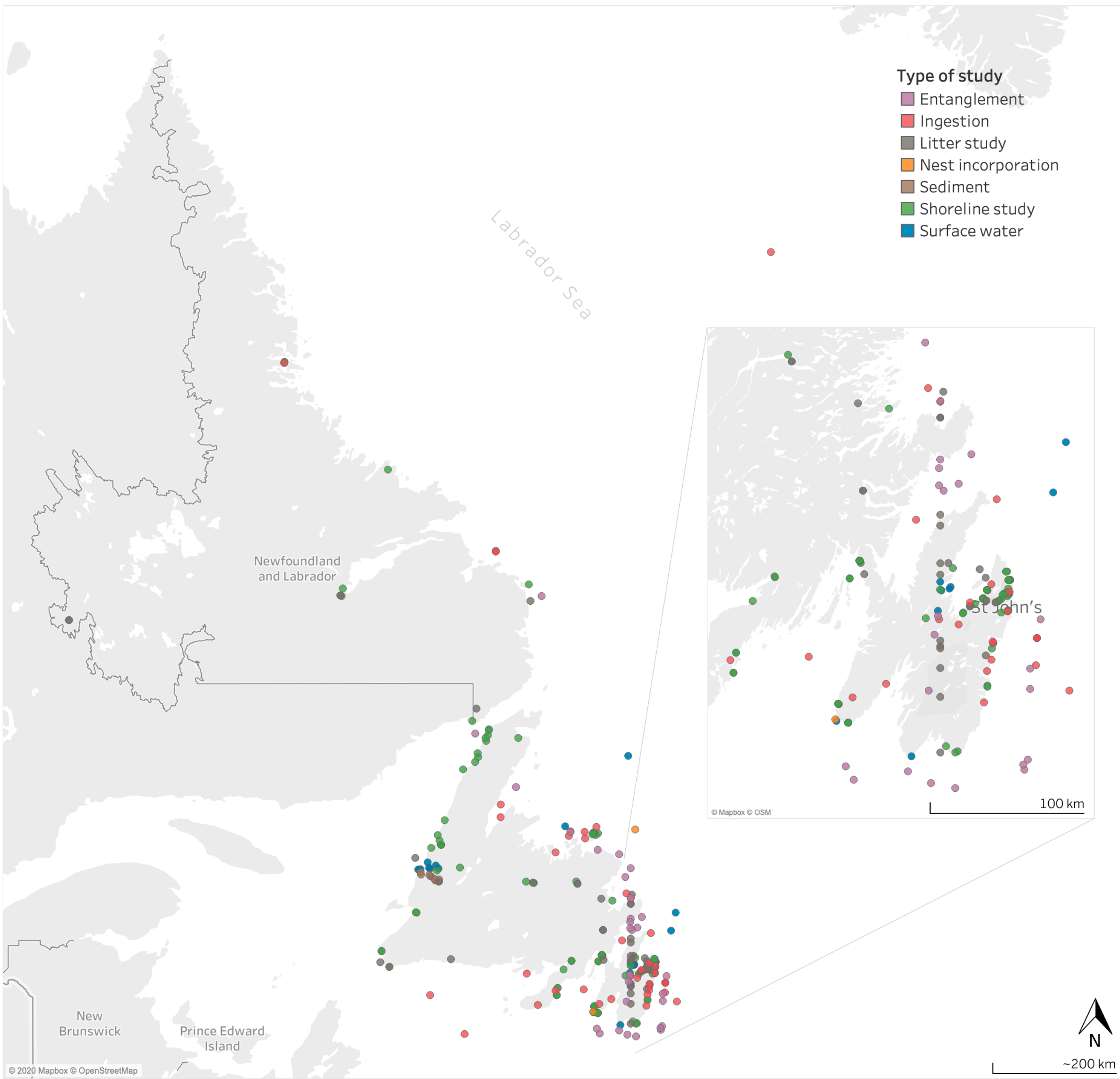
EXECUTIVE SUMMARY

This report synthesizes the findings of 57 published articles, unpublished datasets, and grey literature reports (Appendix 1). Unlike existing regional studies[2] that use a single key metric to report plastic pollution figures and trends or that simply list all known findings, *Regional report on plastic pollution in Newfoundland and Labrador, 1962-2019* aims to create a thicker description of plastics at a regional scale to encompasses all sources, data, and types of information on plastics (Figure 1).

Figure 1: Plastic pollution study sites by type and location, 1962-2019



Map shows study sites within each study. Entanglement = data on whale entanglements in macroplastic fishing gear. Ingestion = locations where animals, feces, or boluses were collected for plastic ingestion studies. Litter study = locations of terrestrial survey of waste on land. Nest incorporation = locations where birds were observed building plastics into nests. Sediment = analyses of microplastics in shoreline sediment. Shoreline study = mainly but not exclusively macroplastic studies of anthropogenic waste on shorelines. Surface water = location of where surface water was sampled for plastics.

How to use this report

This report is designed to be a reference of the state of knowledge on plastic pollution in Newfoundland and Labrador, rather than to be read from front to back. As such, some information will repeat in different sections (for example, trends in plastic ingestion by birds over time will appear in both the ingestion section and the temporal trends section). The report is written for a general audience of policy makers, leaders in environmental NGOs, industry leaders, researchers, and the general public. For researchers, methods are broken out in a dedicated appendix. Key datasets are available at civiclaboratory.nl.

Key characteristics of plastic pollution in Newfoundland and Labrador

Like most places globally, plastic pollution has been found in the Canadian province of Newfoundland and Labrador in every environment tested, and plastic pollution is increasing over time. While the province fares well in comparison to many other regions, in some forms of plastic pollution and impacted species our figures are worse. Uniquely, fishing activities characterize much of the plastic pollution in the province and most of the plastics in the province originate locally. Another unique characteristic of plastic pollution in the province is the high variability of plastic densities and types within in small geographic areas, making large scale geographic generalizations difficult or impossible—not surprisingly, the province itself is characterized by geographic extremes in population (one major city with a handful of smaller cities and many rural communities), weather (high variation in wind and precipitation in a single day), geological morphology (cliffs and beaches in close proximity), and ocean activities (commercial and sustenance fishing within seasons, aquaculture year-round) which likely contribute to a high variability in plastic pollution sources and accumulation as well. Notably, Labrador does not appear to have significantly less plastic pollution than the island of Newfoundland in areas studied, though Labrador is understudied at this time. This report is almost exclusively focused on monitoring plastics (presence and characteristics in the province), not how and whether plastics cause harm. In this report, "plastic" is used when studies and findings include multiple size classes of plastics or does not specify size in its methodology, "macroplastic" refer to plastics larger than 5mm, and "microplastic" refers to plastics smaller than 5mm. We do not use a mesoplastic category.

Figures, baselines, and benchmarks

Studies have provided both provincial and local baseline and benchmark figures that provide a reliable snapshot of the state of plastic pollution in the region, as well as to evaluate future plastic pollution trends and to gauge whether interventions have desired effects. Current provincial-scale figures include:

- **Plastics account for 85% of all marine shoreline** waste with a range of 60% to 95%. This is in line with global figures.
- **Plastics account for 73% of all freshwater shoreline waste** with a range of 53% to 91%.
- **Plastic bags account for 2%** of all marine shoreline plastics. This is lower than the Canadian average, where data is largely from urban sites.[3] The percentage is higher for freshwater locations.
- **Fishing gear accounts for an average of 37% marine shoreline plastics**, but this number is highly variable. This is higher than the Canadian average.[4] High percentages of fishing gear make up shorelines plastics in Spencer's Cove, St. Bernard's/Jaques Fontaine, and Arnold's Cove, a mid-range in Ferryland, Terrenceville, Black Tickle (Labrador), and to some extent in Makkovik (Labrador), and other areas have lower figures.
- **Cigarette waste accounts for over 88% of small terrestrial litter** along highways.
- The average **density of plastics in marine surface water in the province is 5,208 pieces of plastic/km^2**.This is higher than it was a decade ago.
- The average density of **microplastics in sediment in Humber Arm is 22.6 plastic items/m^2** or 22,600,000 items/km^2.

- The provincial average for all **waste near highways is 2.1 items/m²** or 2,100,000 items/km².
- Since the cod moratorium, an average of **10 Humpback whales and 3.2 Minke whales are entangled in fishing gear annually**.[5]
- The 2013 baseline for **plastic ingestion by Dovekies is 30.4%.** This is the percentage of a population that will have ingested plastics.
- The 1966-1967 baseline for **plastic ingestion by Herring gulls is 14.0%.**
- The 1987-1988 baseline for **plastic ingestion by Leache's storm petrels is 6%.**
- The 1985-1986 baseline for **plastic ingestion by Thick-billed murres is 7.7%.**
- The 2015 baseline for **plastic ingestion by Atlantic cod is 2.4%.**
- The 2015 baseline for **plastic ingested by Capelin is 0.0%.**
- The 2016 baseline for **plastic ingestion by Silver hake is 0.0%.**

Ingestion figures for other animals exist (Appendix 2) but cannot be considered baselines (see Method 13).

Areas of consideration based on the global literature

- **Sources of plastics are a key area of intervention**, rather than sinks.
- Plastics **fragment into smaller and smaller pieces**, which means accumulation of large items will eventually result in the accumulation of small items. **Plastics at different sizes present different environmental harms**.
- As the vast **majority of global plastics are smaller than 5mm in size** (microplastics), they are available to be ingested by a wide range of animals.
- Entanglement in macroplastics, often **fishing gear, can kill or impair animals**. Significant financial and stock losses to fisheries due to "ghost fishing" have been noted in other countries.
- Marine macroplastics on shorelines have been shown to **negatively impact tourism** in other countries.

Sources of pollution in the province

- The vast majority of plastic pollution found in Newfoundland and Labrador is expected to be **from local or regional sources** rather than from global sources.
- Plastic fishing tags found on shorelines in Newfoundland and Labrador **originate from the province and elsewhere in Atlantic Canada**.
- **Newfoundland and Labrador plastic waste flows to global shorelines** in the United Kingdom, France, Ireland, Portugal, and Spain.
- There are relatively **few industrial pellets** found in Newfoundland and Labrador.
- While the data is variable, **fishing gear is clearly a major source of plastics** in the province.
- **Plastic bags are a small portion** of total shoreline plastics with a provincial average of 2%.
- The **effect of banning plastic carrier bags on shoreline plastics is unclear**. Two locations that had banned plastic carrier bags before data collection (2014-2018) had plastic bags on their shorelines: 0.9% of Fogo Island (40 out of 4105 items) and 7.8% of Nain (159 out of 2046 items). For the latter, almost all plastic bags were types exempted under the new bag ban legislation coming into effect October 2020.
- Light plastics of all types **blow out of landfill infrastructure**. At Robin Hood Bay/Sugar Loaf trail ("the plastic bag forest"), the largest single category of waste was plastic bags, but that plastic bags account for less than half of all waste in the area, with the next highest category being foam plastics and fragments.

- **Cigarette waste is a major source** of both terrestrial and shoreline plastic pollution. A roadside litter audit in 2016 and found that **cigarette butts accounted for nearly 88%** of nearly 26,000 small litter items collected across the province. Approximately **24% of shoreline waste is cigarette butts**.
- For terrestrial litter, **51% of cigarette butts were documented in commercial areas**, three times the amount found in open spaces, which contained the second highest concentrations.
- For terrestrial litter, including plastics, the **top brands in the province are Tim Horton's** (27.3% of items), **McDonald's** (9.9%), and **Health Canada** health warnings for tobacco products (7.0%).
- Two diving survey studies have found that plastics and other forms of waste **accumulate at wharfs** compared to non-wharf areas and low-use sites.
- **Higher numbers of tourists near a shoreline significantly decrease the densities of fisheries plastic**, with no trend on plastics overall. This was the only statistically significant trend when looking at population, tourism, and fishing gear volume in an area compared to shoreline plastics.

Distribution of plastics in the province

- The uneven distribution of shoreline plastics in the province **does not indicate there are regional hotspots** at a large or medium geographic scale. However, there are smaller scale beaches with **unusually high plastic accumulation called loading beaches**, such as Arnold's Cove and Terrenceville.
- The **average density of microplastics in surface water is 5,208 pieces of plastic/km^2**, with a range from 280-13,480 pieces of plastic/km^2 . This figure is higher than it was in 2008.
- Near Humber Arm the average **density of microplastics in sediment is 22.6 microplastics/m^2** or 22,600,000 items/km^2. This is the only place in the province with sediment data.
- The provincial average for **waste near highways is 2.1 items/m^2** or 2,100,000 items/km^2.

Animals and plastic pollution in the province

- Fish and marine mammals have been found to **die from entanglement in fishing gear**.
- An average of **10 humpback whales and 3.2 mink whales are entangled in fishing gear annually** since the cod moratorium in 1992.
- **Terrestrial animals can become entangled in fishing gear**, such as caribou.
- While gannets incorporate plastics into nests, the **frequency and amount of plastics in nests is decreasing**, directly in proportion to the number of gillnets set around breeding colonies.
- **Species found to ingest plastics** in Newfoundland and Labrador include: American black duck (7% frequency of occurrence[1]); Atlantic puffin (7%); Black legged kittiwake (26%); Common eider (10%); Common murre (0-10%); Dovekie (0-30%); Great Black-backed Gull (75%); Great shearwater (75%); Herring gull (42-77%); Iceland Gull (100%); Leach's storm petrel (48%); Sooty shearwater (20%); Thick-billed murre (9%); Blue mussels (100%); Atlantic Cod (0-8.3%); Northern fulmar (79%); Sperm whale (100%).
- The following species are known to **not ingest plastics** (frequency of occurrence is 0%): Razorbill; Surf scooter; Atlantic salmon; Capelin; Silver hake.
- Species consumed for **human food tend to have lower plastic ingestion figures**.

[1] Frequency of occurrence (FO%) indicates the percentage of individual animals in a studied population that ingestion plastics. It does not indicate how many plastics each individual ingested, or the rate at which they ingested and egested plastics.

- Plastic ingestion figures for Newfoundland and Labrador birds are either on **par with or are lower than those in other locations** with the **exception of Northern Fulmar, Atlantic puffins, Thick-billed murres, Dovekies and Common eider ducks, which are higher**.
- **Ingestion figures for nearly all species are increasing**.

Trends over time

- Overall, trends in harms associated with macroplastics like **fishing gear have decreased since the cod moratorium** in 1992, while harms associated with microplastics have increased.
  - **Whale entanglements in fishing gear have decreased 65%** since the cod moratorium in 1992.
  - Whale entanglements since 1992 have **shifted from nearshore to offshore and from gill nets to pots**.
  - For all fishing gear combined, the average mortality of Humpback whales did not change substantially following the 1992 cod moratorium, whereas for Minke whales it did.
  - The number of gannet **nests that incorporate gillnets has decreased since the cod fisheries collapse**, directly in proportion to the number of gillnets set around breeding colonies.
  - The frequency (FO%) with which individuals of a **species ingest microplastics is higher (25.9%) than before the moratorium (10.32%)**. While figures for thick-billed murres decreased or stayed the same, **all other species increased**.
- **Plastic ingestion by Herring gulls has increased by 450%** from the 1960s to 2010s.
- **Plastic ingestion by Leach's storm petrels has increased by 940%** from the 1980s to the 2010s.
- **Plastic ingestion by Thick-billed murres decreased by 79% between 1980s and 1990s**, and more recent studies do not have large enough sample sizes to detect the changes reported.
- The **number of plastics ingested by some species is increasing** in addition to an increase in the number of individuals ingesting plastics.
- **Surface water plastics are increasing in density**.

Future directions and recommendations

- **Evaluate interventions empirically**. Evaluation of interventions using data gathered from before and after an intervention is strongly recommended. Current interventions include CPAWS' ship to shore program and effects of marine debris on species at risk program and DFO's Goodbye Plastics reusable bag initiative in Twillingate/New World Island to reduce impact on sea turtles, as well as the provincial bag ban.
- Create a **provincial-scale plastic monitoring program** to avoid the shortfalls of different stakeholders and researchers opportunistically collecting data that currently characterizes our state of knowledge.[6]
- Materials to target for intervention that account for significant sources of plastic pollution include: **fishing gear and cigarette waste**.
- Activities to target for intervention that account for significant sources of plastic pollution include: **fishing, cigarette smoking, roadside littering, and dumping by marine wharfs**.
- Encourage **studies on the impacts** of plastic pollution to help direct efforts. Most of the data on plastic pollution in the province is from monitoring studies; there are few studies that deal with the impacts and harms of plastic pollution with the exception of studies in the 1970s that investigate mortality due to entanglement.

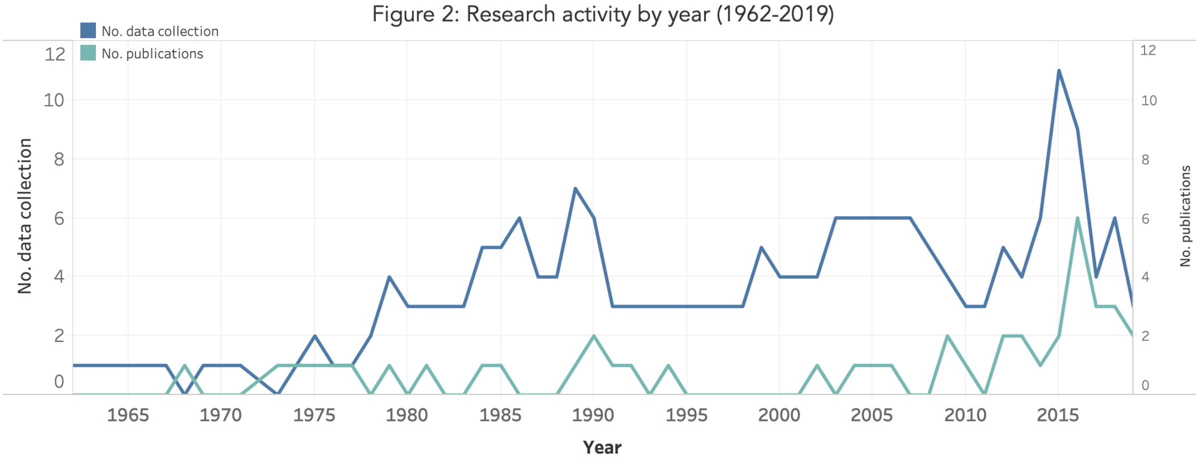
- Address **gaps in knowledge** such as: animals not yet studied or whose ingestion data are highly variable; understudied locations including Labrador and the north shore of the island, freshwater environments, and urban locations; and environmental media that is understudied including sediment and surface water.
- **Brand audits** should become a regular part of plastic pollution research.
- Foster studies on **burned and melted plastics** (their sources, prevalence, and toxicology) and lost and abandoned fishing gear are warranted.
- Study the **impact of plastic pollution on key economic drivers** in the region, including tourism and fisheries.
- Investigate **variables that affect local waste accumulation** such as: presence of harbour authorities, aquaculture, different types of fisheries and gear, condition of bays, marine traffic, recreational activities, morphology of beaches, weather, presence of sewage and stormwater outfalls and sewage management, etc.
- **Local and social science knowledge** is lacking in the literature and should be part of future studies.
- There is little high-resolution data on **urban and harbour plastic pollution**, which means we do not yet know if using harbour macro-debris collectors such as LittaTraps©, StormX© trash-collector net bags, etc. would be beneficial, nor do we have enough data to evaluate plastic levels before and after such an intervention to see if they are impactful.
- Continue **longitudinal monitoring** of animals with baseline ingestion figures and shorelines to evaluate long term trends.
- **Continue shoreline citizen science data collection** during cleanups using the Great Canadian Shoreline Clean up form and the Marine Debris Tracker app to contribute to one of the province's most comprehensive, inexpensive datasets.

CREATING A STATE-OF-KNOWLEDGE REGIONAL REPORT

Sources of data

Research into marine plastic pollution in the province of Newfoundland and Labrador has been occurring since the 1970s, with the first recorded sighting of plastics in the province in the 1960s. While publications on plastics in the province have increased exponentially in the last decade, a notable number of samples come from the 1980s and even earlier, offering a longitudinal view of plastic pollution in the region (Figure 3). The majority of this work has been opportunistic, uncoordinated, has often not used standardized methods. Much of the data is in grey literature or unpublished datasets. Local knowledge is conspicuously absent from most published work.

Figure 2: Research activity by year (1962-2019)



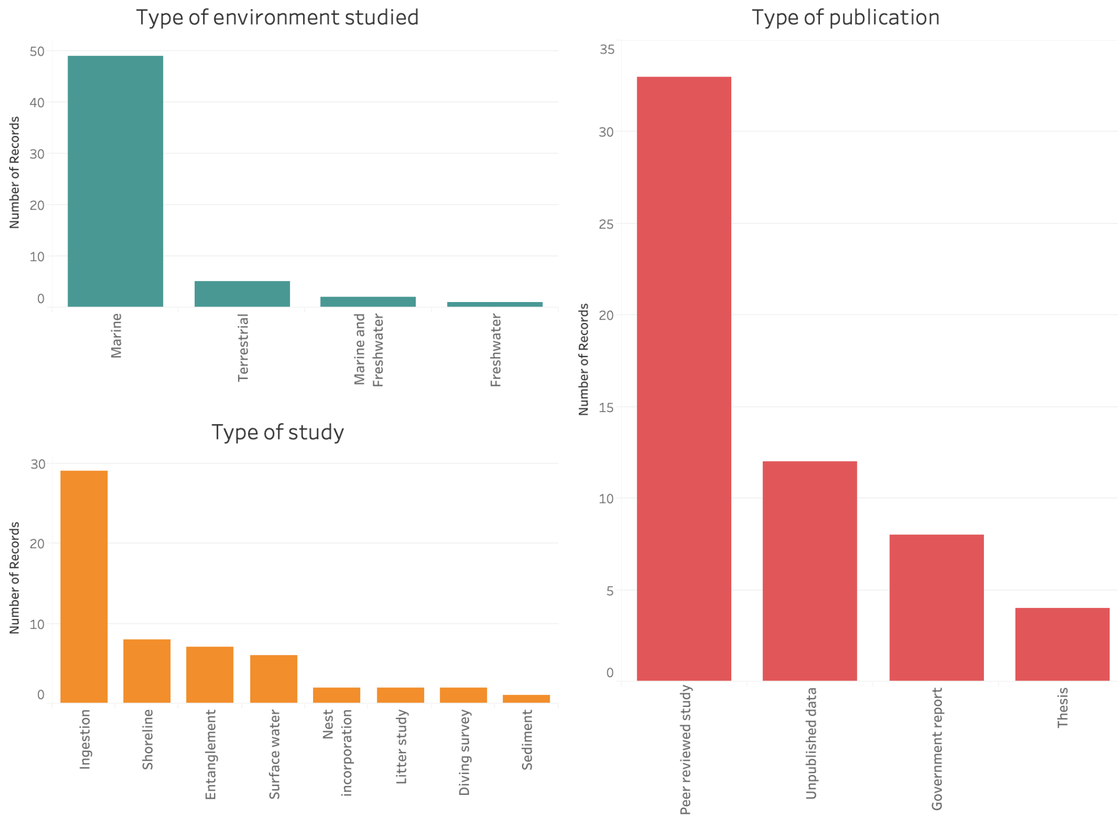
This chart shows the number of publications on plastic pollution per year (green) against the years in which data was collected in those published studies (blue). While publications are sporadic and increase in the last decade, the samples they draw from are from a wide variety of annual dates, making temporal data trends possible for many studies.

This report synthesizes 57 academic, government, NGO, and citizen group data sources to obtain a regional view on plastic pollution in the province (Appendix 1, Method 1). While there are more peer reviewed academic articles than other types of written work, the largest datasets in terms of geographical breadth and number of samples are usually from citizen and government groups. Yet these aren't mutually exclusive research domains. For example, one of the world's longest-running entanglement datasets is collected by the Whale Release and Stranding Group, which was funded by the Department of Fisheries and Oceans, founded by an academic, but run by a citizen group, and their data has been published in peer-reviewed academic journals.[7]

The two sources of provincial-scale datasets are collected by the Multi-Materials Stewardship Board (MMSB), the crown corporation that manages the province's waste, and by citizen groups and researchers doing shoreline cleanups using the Marine Debris Tracker App or the Great Canadian Shoreline Cleanup. Studies tend to cluster around the two largest cities in the province: St. John's and the Avalon Peninsula broadly, and Corner Brook (Figure 1). There are few studies in Labrador, though the Nunatsiavut Government has begun a community-based monitoring project that will increase information there.

Most studies focus on the marine environment. Of those, most are ingestion studies with a focus on birds and microplastics (Figure 2). However, by sample size, most data focus on shoreline and terrestrial cleanups and larger macroplastics (> 5mm in size), though some microplastics are included. More recent academic studies tend to focus on microplastics (< 5mm in size). In this report, "plastic" is used when studies and findings include multiple size classes of plastics or does not specify size in its methodology, "macroplastic" refer to plastics larger than 5mm, and "microplastic" refers to plastics smaller than 5mm.

Figure 3: Sources and types of data



Sources of information on plastic pollution skew heavily towards the marine environment, ingestion studies, and published peer-reviewed sources. Most authors of peer reviewed studies and theses are from Memorial University of Newfoundland, and Government reports are mainly from or for the Department of Fisheries and Oceans (DFO) and the Multi-materials Stewardship Board (MMSB).

Methods

Due to fundamentally different methods for obtaining and analyzing data in different studies, even within a type of study such as ingestion studies or entanglement studies, this report is careful not to overstate comparisons between dissimilar studies. For example, different media studies (water, sediment, ingestion) produce different metrics (density versus frequency of occurrence, for example), and different studies have focused on different sizes of plastics, making a direct comparison between studies difficult, fraught, or impossible. Moreover, even within a genre of study such as plastic ingestion by birds, methodologies vary. For example, researchers have variously sampled plastic from bird's proventriculus and gizzards;[8] gizzards only;[9] regurgitated samples;[10] stomach contents;[11] boluses;[12] or whole gastrointestinal tracts.[13] These differences dictate the types of comparisons we can make, which we can make with confidence, and these differences should always be taken to account when interpreting findings from this report.

At the same time, we undertook several comparative analyses both across existing studies and within new and existing datasets. These comparisons are noted within the report and methods for each analysis are numbered and detailed in the Appendix: Methods.

Photograph of plastic pollution research in action. CLEAR member Jacquelyn Saturno opens the gastrointestinal tract of a fish in preparation for identifying plastics in an ingestion study. PHOTO: Bojan Fürst.

WHAT ARE THE PROBLEMS WITH PLASTIC POLLUTION?

Key areas of consideration for global plastic pollution with relevance to Newfoundland and Labrador include:

- Sources, rather than sinks, of plastics are a key area of intervention.
- Plastics fragment into smaller and smaller pieces, which means accumulation of large items will eventually result in the accumulation of small items. Plastics at different sizes present different environmental harms.
- This report is almost exclusively focused on monitoring plastics (presence and characteristics in the province), not how and whether they cause harm.
- As the vast majority of global plastics are smaller than 5mm in size (microplastics), they are available to be ingested by a wide range of animals.
- Entanglement in large plastics, often fishing gear, can kill or impair animals. Significant financial and stock losses to fisheries due to "ghost fishing" have been noted in other countries.
- Marine plastics on shorelines have been shown to negatively impact tourism in other countries.

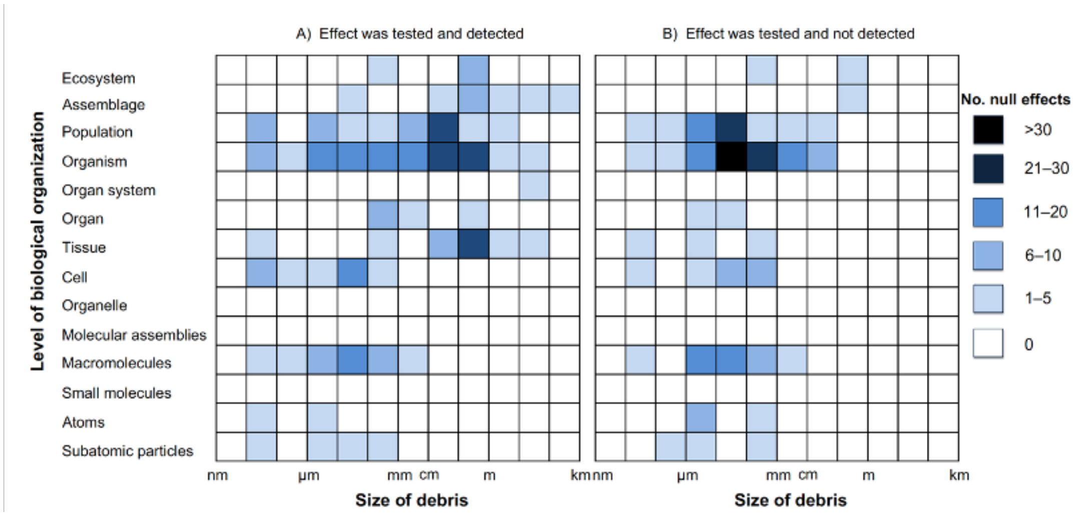
Overview of plastic pollution

Annual global plastic demand is increasing exponentially, with global production reaching 359 million tonnes produced in 2018, up from 230 million tonnes in 2009 -- an increase of over 100 million tonnes in the last decade.[14] Of this production 10% is estimated to enter the oceans each year.[15] A 1989 shoreline survey of the Halifax Harbour estimated that approximately 62% of litter could be sourced to land and recreation-based activities.[16] This pattern of production and circulation means it is essential to think of plastics as a stock and flow problem. Plastics are being continually produced and flow into the ocean, resulting in a stock of plastics accumulating in the marine environment. Attending to the flow of plastics from production and into environments is more impactful than dealing with the stock of plastics in environments, since that flow is ongoing and always producing more stock. Think of a bathtub that is running over with water. Do you turn off the tap and stop the flow first, or do you get a mop and attend to the stock of bathwater on the floor first while the tap is still running?

Once plastics have entered the environment, they tend to accumulate there. Some plastics stay in their original forms when their environments are cold, wet, dark, and still, but many larger macroplastics fragment into smaller microplastics smaller than 5mm in size.[17] Barnes et al. (2009) has reported a general decrease in the mean size of plastic debris in the global environment with a matching increase in the abundance of microplastic particles due to continuous degradation.[18] One study estimates that over 90% of marine plastics in surface water worldwide are microplastics, created through fragmentation as well as sources of microplastics that are created that size such as microbeads.[19] This shift in relative sizes of plastic pollution explains one of the trends in Newfoundland and Labrador plastics discussed below: while the province's number of whale entanglements by macroplastic fishing gear has decreased since 1992, the frequency of occurrence that animals are ingesting microplastics is increasing. Our macroplastics are turning to microplastics in the environment. As will be discussed below, different sizes of plastics cause different types of harm.

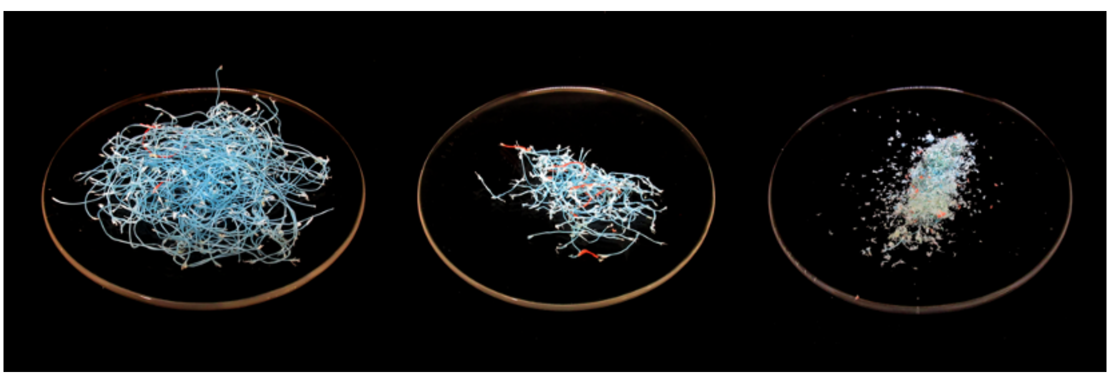
There are many types of harm associated with aquatic and terrestrial plastic pollution. There is no current comprehensive risk assessment of the impacts of plastics on biota. The text in this section details the types of harm plastic pollution can engender, contextualized for the province of Newfoundland and Labrador.

Figure 4: Detected and non-detected impacts of plastic pollution by size (from Bucci et al. 2019)



(A) Detected and (B) non-detected impacts of plastic pollution. Rows in the matrix represent different levels of biological organization. Columns represent sizes of debris from the smallest (left) to the largest (right) by order of magnitude. Shading in cells of the matrix represent the number of impacts in the peer-reviewed literature identified in a study by Bucci et al (2019). Overall, it shows that presence does not necessarily correlate to demonstrated harm, and that harms differ across sizes of plastics and biological organization.

We know that different regions globally have markedly different plastic profiles, and that different polymers at different sizes have different effects. A 2019 meta-analysis of existing plastic pollution research "found evidence that whether or not an effect is detected, as well as the severity and direction of the effect, is driven by dose, particle shape, polymer type, and particle size"[20] (see figure 4). Thus, it is imperative that interventions into plastic pollution pay particular attention to sizes of plastics and their associated harms, rather than conflate these specifics into plastic pollution in general. Whenever methodologically sound, this report details whether it is reporting results for microplastics, macroplastics, or simply "plastics" that include both size classes.



Photograph of different sizes of plastics that have fragmented off of fishing gear. From left to right: > 25mm, 5-25mm, 0.5-5mm.
PHOTO: Jacquelyn Saturno.

Most of the studies in this report do not record forms of harm. Rather, they are monitoring studies that document the presence of plastics in environments and biota. While presence of plastics does not automatically lead to harm, interventions can still address the presence of plastics. From a scientific perspective, this is called the precautionary principle where a *lack* of harm needs to be demonstrated for a contaminant to be understood as safe or not harmful, rather than waiting for *evidence* of harm. From a cultural and moral perspective, the presence of plastic in places it is not supposed to be can be understood as wrong and addressed without the need for scientific evidence or even monitoring.

Ingestion

Since over 90% of surface water marine plastics are microplastics less than 5 millimeters in size[21], they are bioavailable to a wide range of levels in the marine food web, from whales to plankton. Marine plastics are associated with contaminants that can take the form of ingredients and by-products of the plastic material itself (such as UV stabilizers, softeners, flame retardants, non-stick compounds and colourants), as well as contaminants adsorbed from the surrounding seawater (such as PCBs and DDT).[22] The accumulation of toxic chemicals in marine species can be transferred up the food chain via biomagnification, thus potentially negatively affecting apex predators like humans.[23] Industrial chemicals associated with marine plastics have been correlated to negative health effects in humans, including endocrine disruption, heart disease, and developmental disorders.[24] Despite these preliminary links further research is required to better understand the full effects that plastics consumed at lower trophic levels in the food web can have on top consumers.[25] Nonetheless, it is known that the burden of polluted wild food sources disproportionately affects rural, Indigenous, and low-income communities where country foods are relied on for sustenance.[26]

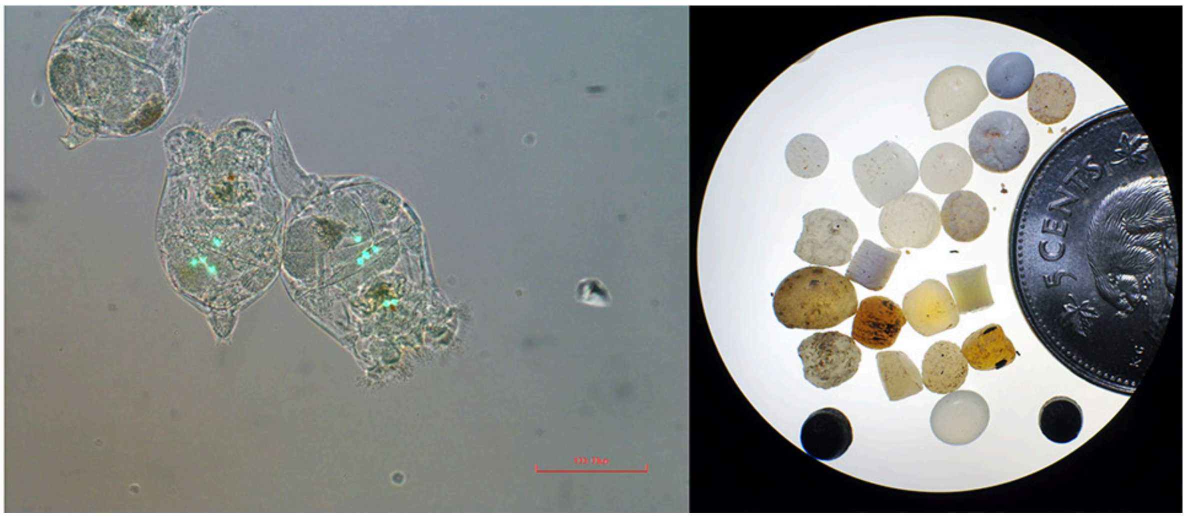


Figure 5: Plastic ingestion. Rotifer plankton (left) after ingesting fluorescing microplastic beads. Photo: Steven Hill, Memorial University. Industrial production pellets (right) with differing degrees of discolouration. The more industrial chemicals a plastic particle absorbs, darker its discolouration and the greater its erosion pattern. Photo: Max Liboiron, Memorial University.

Entanglement

Entanglement results when an animal is ensnarled in plastic and cannot free itself, which may impact mobility, ability to hunt and evade predators, ability to eat, and overall robustness. While entanglement can occur at multiple scales and with many types of plastics, in Newfoundland and Labrador fishing gear has the greatest demonstrated capacity to entangle wildlife given the extensive commercial and sustenance fishing activities in the province. These activities are expected to be significant contributors to the marine plastic landscape around the island of Newfoundland, considering the waters surrounding the island contribute over 80% of the national fisheries landings,[27] and the participation of fishers in recreational fisheries has consistently been among the highest in the country (along with the Yukon Territory).[28]

"Ghost fishing" is a term for when lost or derelict fishing gear continues to entangle fish, but without anyone retrieving the catch. This causes harm both to ecosystems and to commercial interests in those ecosystems. 92% of Scottish commercial fishing vessels have experienced economic impacts due to marine plastics, from contaminated catch to gear and propeller entanglement, amounting to a direct cost of up to $24.4 million (CAD) each year, 5% of the total revenue of affected fisheries.[29] In the US, Gilardi et al. investigated the Dungeness

Crab fishery in Puget Sound and estimated that removal of derelict gill nets yielded a cost-benefit ratio (cost of removal versus increased landings) of 1:14.5.[30] Scheld et al. estimate that the annual loss for nine species of crustacea due to derelict pots and traps amounted to US$ 2.5 billion.[31] It is likely that similar issues occur in Newfoundland and Labrador, though to what degree is unknown.

From an ecological perspective, the island of Newfoundland has the Large Whale Entrapment Program and the Whale Release and Strandings Group, one of the oldest such programs (with accompanying data) in the world. This group works to rescue whales entangled in fishing gear. The data from these efforts are discussed below.

Tourism

A unique study in South Africa found that 85% of tourists and residents would not visit a beach with more than 2 debris items per meter and 97% would not go to a beach with 10 or more large items of litter per meter.[32] Marine litter also deters recreational groups such as sailors and divers due to both the reduced aesthetic quality of an area as well as concerns about health and safety risks.[33] Annual shoreline and East Coast Trail clean ups in Newfoundland and Labrador designed to address plastics do expend resources, though we do not have figures on the amount, nor on the relationship between shoreline or trail cleanups and tourism. It is unlikely that the South African study can easily be used in Newfoundland and Labrador, since tourists do not usually bask on the cold, rocky beaches here. The relationship between plastic pollution and tourism is an area of potential future study.

WHAT ARE THE SOURCES OF PLASTIC POLLUTION IN NEWFOUNDLAND AND LABRADOR?

Key findings:

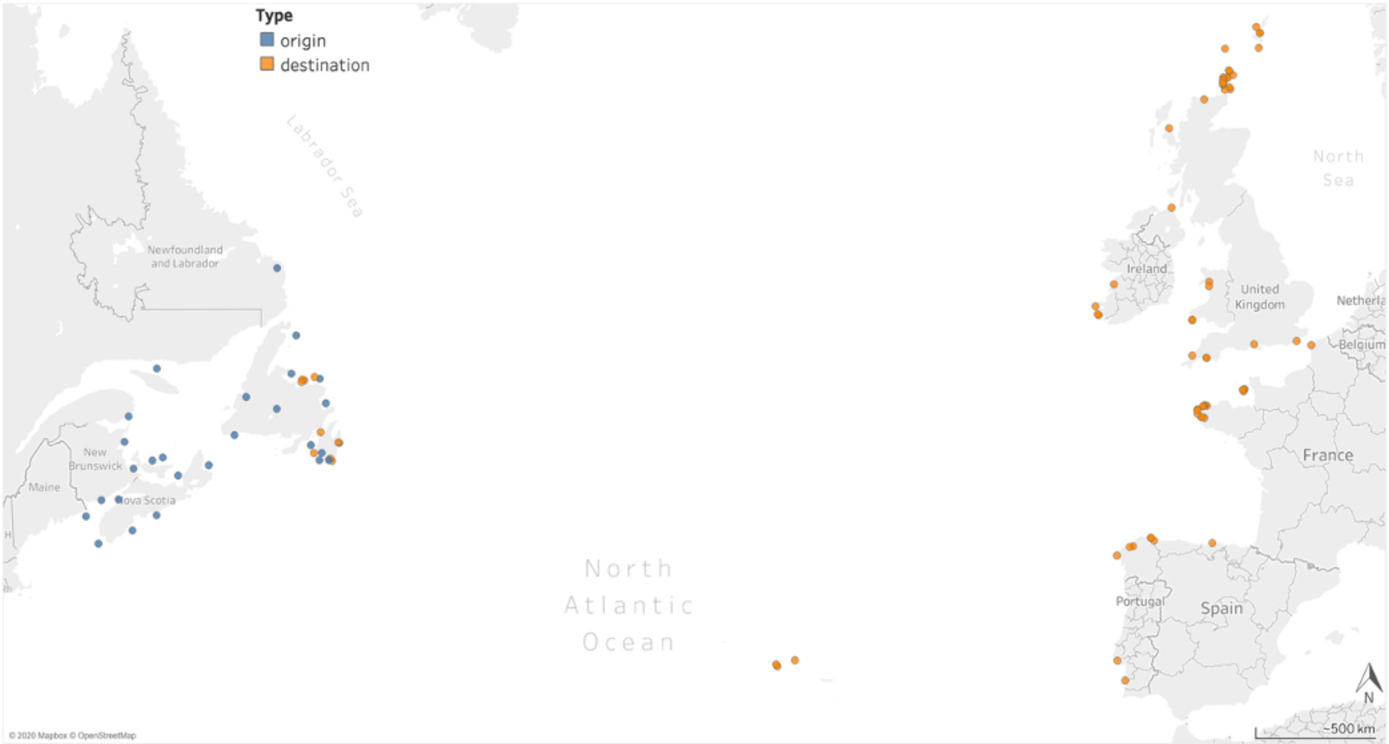
- The vast majority of plastic pollution found in Newfoundland and Labrador is expected to be from local or regional sources rather than from global sources.
- Plastics from Newfoundland and Labrador have been found in the United Kingdom, France, Ireland, Portugal, and Spain, indicating that local plastics are part of global plastic flows.
- There are relatively few industrial pellets found in Newfoundland and Labrador.
- Fishing gear accounts for an average of 37% of all shoreline plastics, but this number is quite variable, with very high peaks in Spencer's Cove, St. Bernard's/Jaques Fontaine, and Arnold's Cove, a mid-range in Ferryland, Terrenceville, Black Tickle (Labrador), and to some extent Makkovik (Labrador), and other areas having lower percentages.
- The amount of fishing gear used in a NAFO area does not appear to significantly affect the amount of fishing gear in geographically proximate beaches.
- Plastic bags are a small portion of total shoreline plastics with a provincial average of 2%, and not all of these plastic bags are from grocery carrier bags.
- Cigarette butts accounted for nearly 88% of small roadside litter items collected across the province. Of this, over half was documented in commercial areas. On average, 24% of shoreline waste is cigarette butts.
- The top brands for terrestrial roadside waste are Tim Horton's (27.3% of items), McDonald's (9.9%), and Health Canada health warnings for tobacco products (7.0%).
- Plastics and other waste accumulate at wharfs compared to non-wharf areas and low-use sites.
- Greater amounts of tourism activities near a shoreline significantly decrease the densities of fisheries plastic and plastic fragments, though does not affect plastics overall.
- For maps of types of plastic pollution in Nain, Makkovik, Terrenceville, and Arnold's Cove, see Appendix 4.

Local or Come From Away?

The vast majority of plastic pollution found in Newfoundland and Labrador is expected to be from local or regional sources rather than from global sources. In an ongoing thesis study, plastic NL fishing tags were collected from shorelines around the world and their origins and destinations were charted (Method 2). Of the 124 fishing tags that originated in Newfoundland and Labrador, 25% remained in the province. The rest were found in Europe on shorelines in the United Kingdom (19%), France (10%), Ireland (6%), Portugal (4%), and Spain (2%) (see Figure 6).

Another way we know that plastics found in the province are likely local is that relatively few plastic production pellets (also called nurdles) are recovered in local studies, as there are none produced in the province—these pellets are come from away plastics (see figure 6). While industrial pellets are commonly found in ingestion studies, all provincial studies that recorded categories of plastics found relatively low or no industrial sources of plastics save a study on Northern fulmar, a species that migrates extremely long distances (Table 1). As Bond et al. notes (2013) in an ingestion study of murres, which are known to ingest pellets in other regions, "It is also of note that the murres examined [...] showed ingestion of user plastics but lacked any industrial raw pellets."[34]

Figure 6: Origins and destinations of plastic fishing tags



Map showing the origins (blue) and destinations (orange) of plastic fishing tags retrieved on shorelines. Tags consistently moved from Atlantic Canada to shorelines in Europe. Of the 124 tags that originated in Newfoundland and Labrador, 25% remained in the province, and 75% traveled across the North Atlantic Ocean. See Method 2 for details.

Table 1: Prevalence of industrial pellets in Newfoundland and Labrador plastic ingestions studies

Species	Frequency of occurrence	#/% pellets	Citation
Northern fulmar	79%	65/7%	Avery-Gomm et al. 2018
Dovekies	30%	1/0.7%	Avery-Gomm et al. 2016
Three gull species	84%	1/0.004%	Seif et al. 2017
Common & thick-billed murres	7%	0/0%	Bond et al. 2013
Various coastal waterfowl (Atlantic Canada)	46%	0/0%	English et al. 2015
Atlantic cod	2%	0/0%	Liboiron et al. 2019

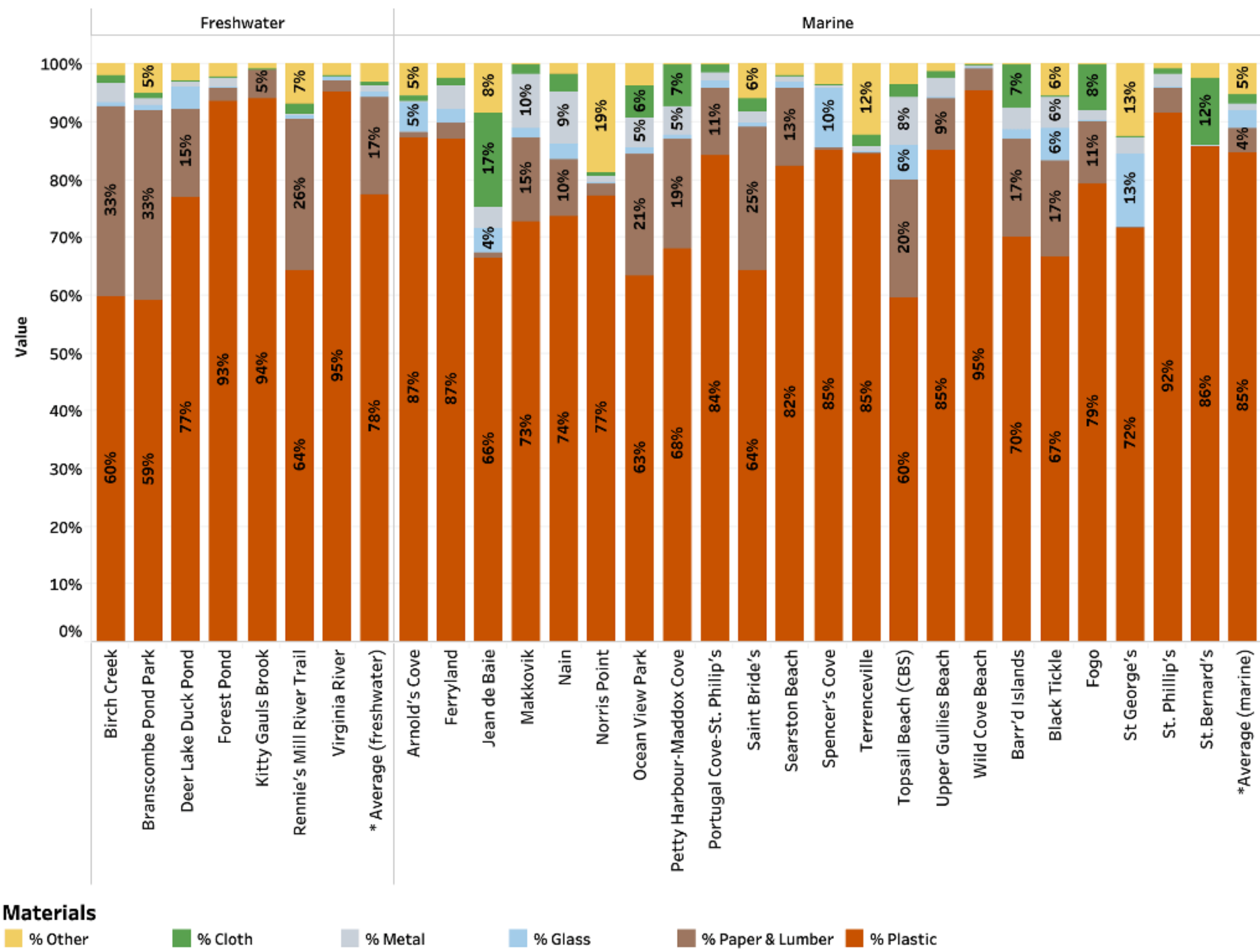
In animals that ingested plastics where the morphology of recovered plastics were recorded and the location of the animal could be determined, few or no recovered plastics were industrial pellets/nurdles. The frequency of occurrence is the percentage of individual animals of the total number studied that had ingested plastics and gives an indication of a species' likelihood of ingesting plastics of any type. The number (#) of pellets is the total number of ingested plastics that were industrial pellets. The percentage (%) of pellets is the portion of all ingested plastics that were industrial pellets. The case of the Northern fulmar stands out with 65 pellets, 7% of all plastics ingested, but they migrate long distances and these pellets may have been consumed elsewhere. For comparison, a study of Northern fulmar in the North Sea found that 51% of birds consumed an average of 2.3 industrial pellets each, which far exceeds the numbers recorded in fulmars caught in the Labrador Sea (Save the North Sea, 2005). Ingestion studies that are not included in this table either did not record industrial pellets as a district morphological category, did not disaggregate category data, or did not indicate which animals in the study were caught in Newfoundland and Labrador.

Sources of waste by material type

One of the most comprehensive datasets at the provincial scale is from shoreline cleanups conducted by citizen groups, NGOs, and municipalities that have used the Marine Debris Tracker App (MDT) or the Great Canadian Shoreline Cleanup (GCSC) to record data. Both MDT and GCSC contain comparable categories of waste, allowing the data to be directly compared (Method 3). This dataset includes 83 total clean ups at 24 sites between 2014 and 2018. This unpublished data was analyzed specifically for this report.

Shoreline citizen science data shows that plastics make up an average of 85% of marine shoreline waste with a range of 60% to 95% (figure 7). Globally, the range is between 48% and 91%.[35] For freshwater shorelines, the figures are different and more variable: 73% of waste is plastic with a range of 53% to 91% (Figure 7).

Figure 7: Material types in shoreline cleanups as precent of total waste (2014-2019)



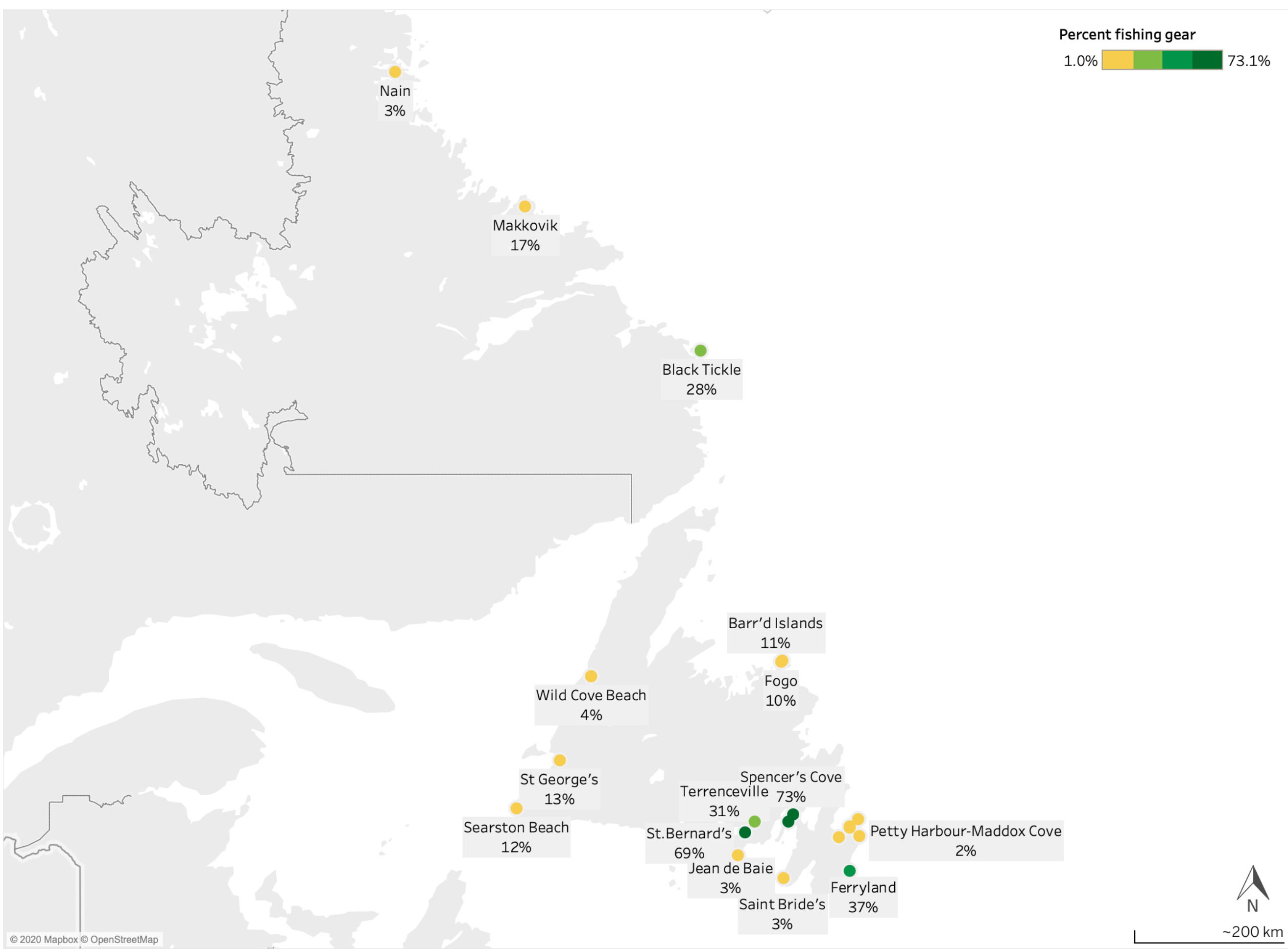
Percent of shoreline waste by material type. Plastic is orange, Paper and Lumber are brown, Glass is blue, Metal is grey, Cloth is green, and Other is yellow. Data is divided by freshwater (left) and marine (right) locations. The average for freshwater and marine locations are marked with an asterisk (*). Plastics dominate all shoreline waste. Paper and lumber is the most common material category, particularly in freshwater environments. Black Tickle contained only 27 items while others contained hundreds or even thousands, so one item accounts for a high percentage of a given category.
Data is from the Marine Debris Tracker and the Great Canadian Shoreline Cleanup. See Method 3 for details.

Within the marine plastic category, two materials were broken out for further analysis: fishing gear and plastic bags (Method 4). We investigated fishing gear because several ingestions studies of Atlantic cod have noted confirmed or suspected cases of fishing gear in gastrointestinal tracts,[36] fishing gear has been noted as a primary source of plastics in gannet nests,[37] and many of the authors have observed fishing gear during shoreline research.

FISHING GEAR

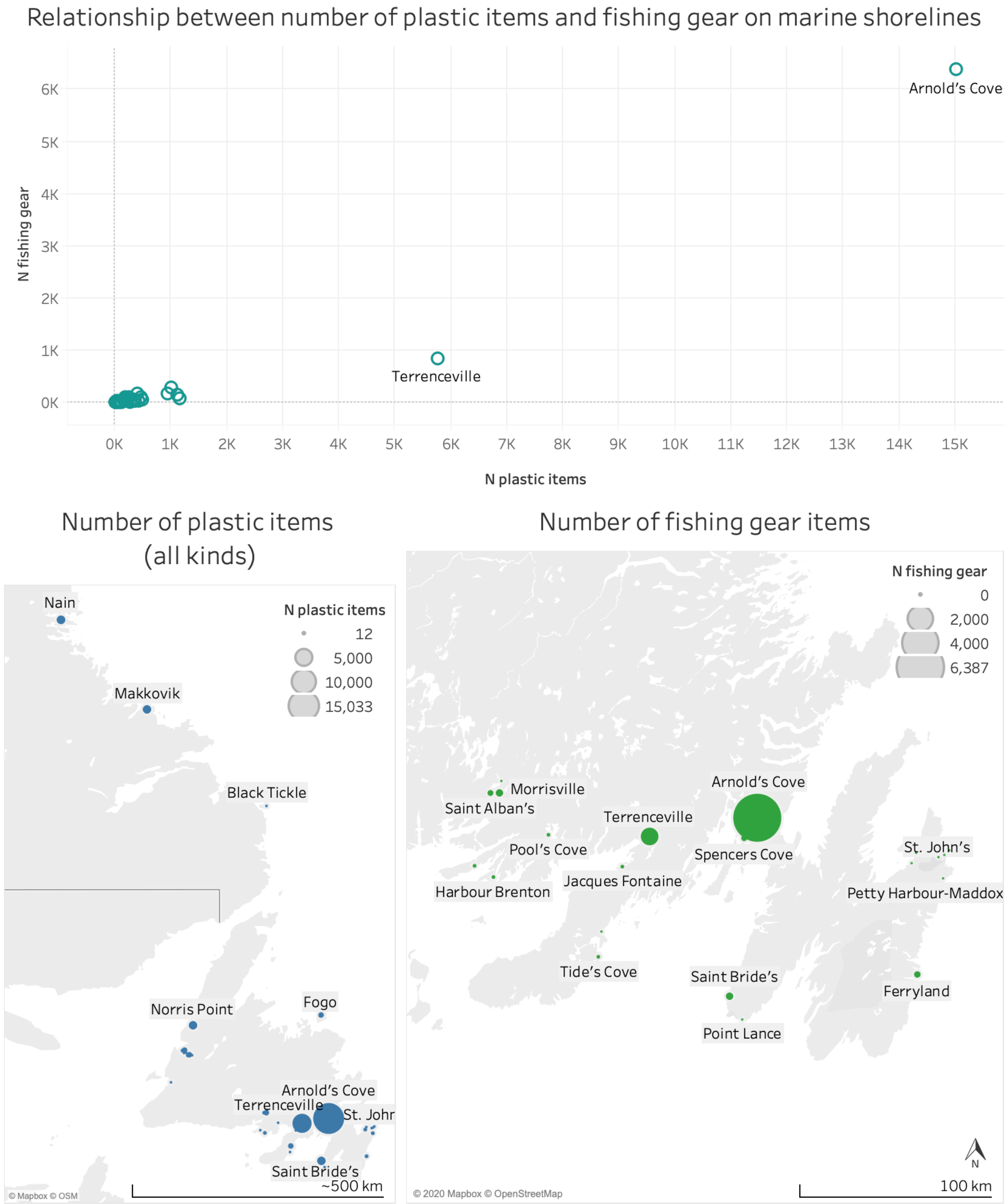
Globally, it is estimated that 5.7% of all fishing nets, 8.6% of all traps, and 29% of all lines are lost at-sea every year.[38] The percentage of total marine shoreline waste that is fishing gear varies considerably across the province (average of 37%) and does not always correspond to proximity fishing communities (Figure 8). However, the highest percentages and counts of plastics cluster around the south shore of the island of Newfoundland (Spencer's Cove, St. Bernard's-Jacques Fontaine, Arnold's Cove) and some of the lowest percentages cluster around the St. John's metropolitan region. Overall, the amount of fishing gear used in a NAFO area does not significantly affect the density of plastic overall or amount of fishing gear in geographically proximate beaches (Method 7).

Figure 8: Percentage fishing gear of total shoreline waste (2014-2019)



The percentage of fishing gear in all shoreline waste varies across the province, with higher percentages in some areas in Placentia Bay (though some of the province's lowest percentages are also in Placentia Bay), Black Tickle, and Ferryland. Black Tickle contained only 27 items while others contained hundreds or even thousands, so one item accounts for a high percentage of a given category. Freshwater and terrestrial environments have been excluded.

Figure 9: Number of plastics and fishing gear items by location (2014-2019)



The number of individual plastic (blue) and fishing gear (green) items show several loading beaches in the province. These are shorelines that attract high numbers of floating debris. While some of this variation can be explained by the number of shoreline clean ups in an area over time, the outliers of Arnold's Cove and Terrenceville indicate that these are areas with extreme accumulations of shoreline debris generally (loading beaches) and fishing gear in particular.

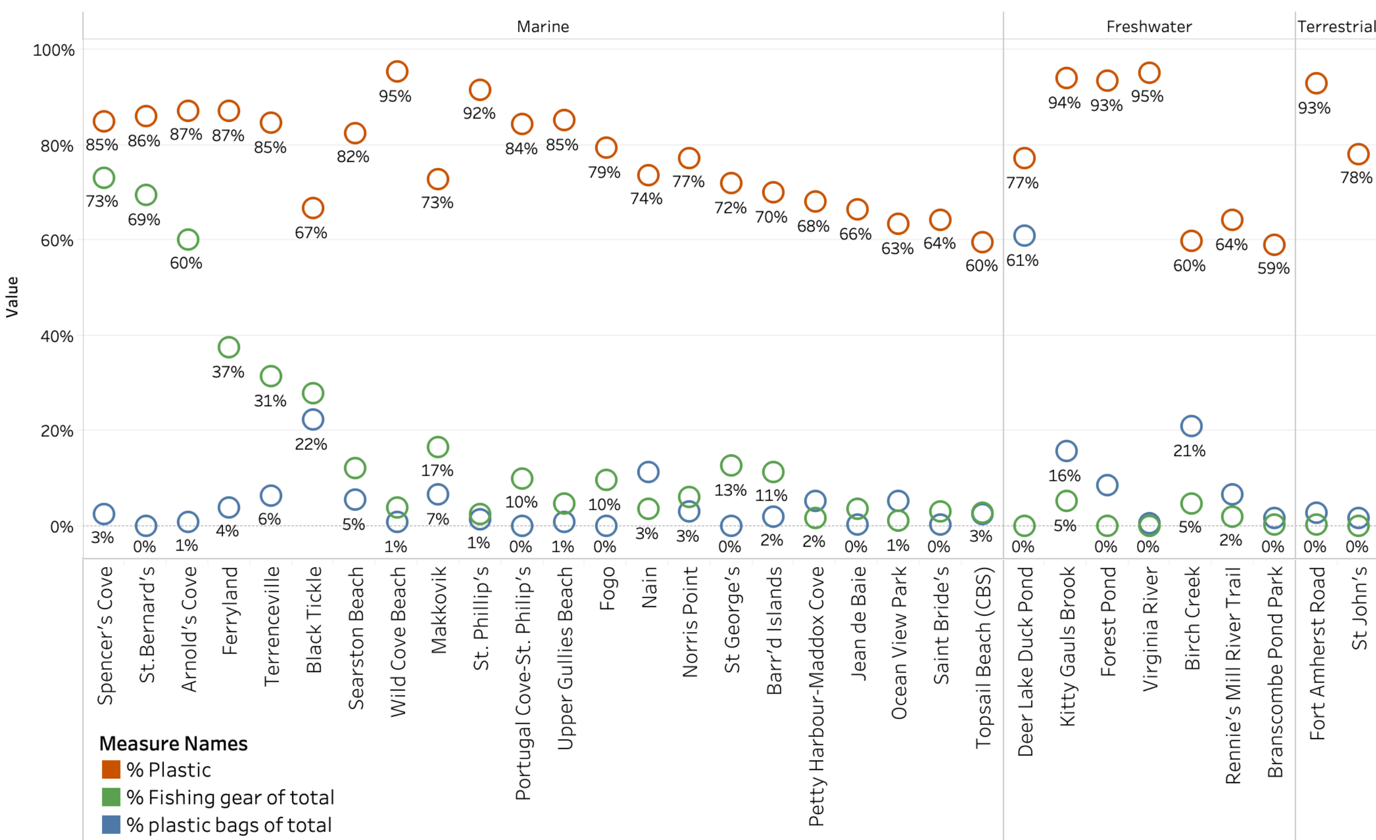
Neither MDT nor GCSC data create densities, the numbers of items per unit of space, which would allow sites to be directly compared. Thus, for a fuller picture of sources of shoreline waste we can look at both percentages of material items and total counts of material items. By count, the average number of waste items per cleanup location is 3,264. The average number of plastic items is 877 and the average number of fishing gear items is 256. However, averages are influenced by several extreme values in counts (see Figure 9, Method 8) in loading beaches in Arnold's Cove and Terrenceville.

Data collected by Intervale Associates and the Quebec-Labrador Foundation includes counts of bait bag liners. Bait bags are also a stated concern for the Canadian Parks and Wilderness Society (CPAWS).[39] Intervale collected 559 bait bag liners in 13 shoreline clean ups between 2015 and 2019, an average of 43 bait bags per clean up.[40]

PLASTIC BAGS

Plastic bags are a small portion of total shoreline plastics with a provincial average of 2% (figure 10). In data collection methods, "plastic bag" referred to all types of plastic film bags, including sandwich bags and garbage bags as well as grocery carrier bags. In marine environments, plastic bags make up an average of 2% of shoreline waste, while in freshwater environments plastic bags have much higher variability and account for 17% of shoreline waste.

Figure 10: Percentage of shoreline waste that was all types of plastic, fishing gear, and plastic bags (2014-2018)



Comparison of the percentages of different subtypes of shoreline waste. Plastics (red) includes all plastic categories, including both fishing gear (green) and plastic bags (blue). In marine environments there is usually more fishing gear than plastic bags, while in freshwater and terrestrial environments there are more plastic bags than fishing gear. Black Tickle contained only 27 items while others contained hundreds or even thousands, so one item accounts for a high percentage of any given category.

Two locations that had banned plastic carrier bags before the time of data collection (2014-2018) had plastic bags on their shorelines: 0.9% of Fogo Island (40 out of 4105 items) and 7.8% of Nain (159 out of 2046 items). The first author was present for data collection in both areas and can attest that a few of these bags were local grocery bags but most were other types of plastic bags (garbage bags, food bags), or carrier bags from non-local stores. While Fogo Island's figures seem to indicate that a bag ban can result in a lower than average prevalence of plastic bags, in Nain's case the number is above average for a marine environment. As Newfoundland and Labrador bans plastic carrier bags in October 2020, it will be important to monitor the effect of the ban and whether it decreases, increases, or does not impact the count and percentage of overall plastic bags on shorelines in reference to the baselines provided here.

The Sugarloaf trail portion of the East Coast Trail downwind of Robin Hood Bay is an area well known for the accumulation of plastic bags. The Great Canadian Shoreline Clean up inventoried waste collected there in 2018 and found that the largest single category of waste was plastic bags (1,089 items of 2511, or 43% of waste). The next significant category is plastic fragments and foam (689 items, 27%). Food wrappers (169 items, 7%) and paper materials (147 items, 6%) where the only other categories with more than a 5% share of material categories. All of these items are lightweight and likely blow out of waste infrastructure at the Robin Hood Bay Landfill.

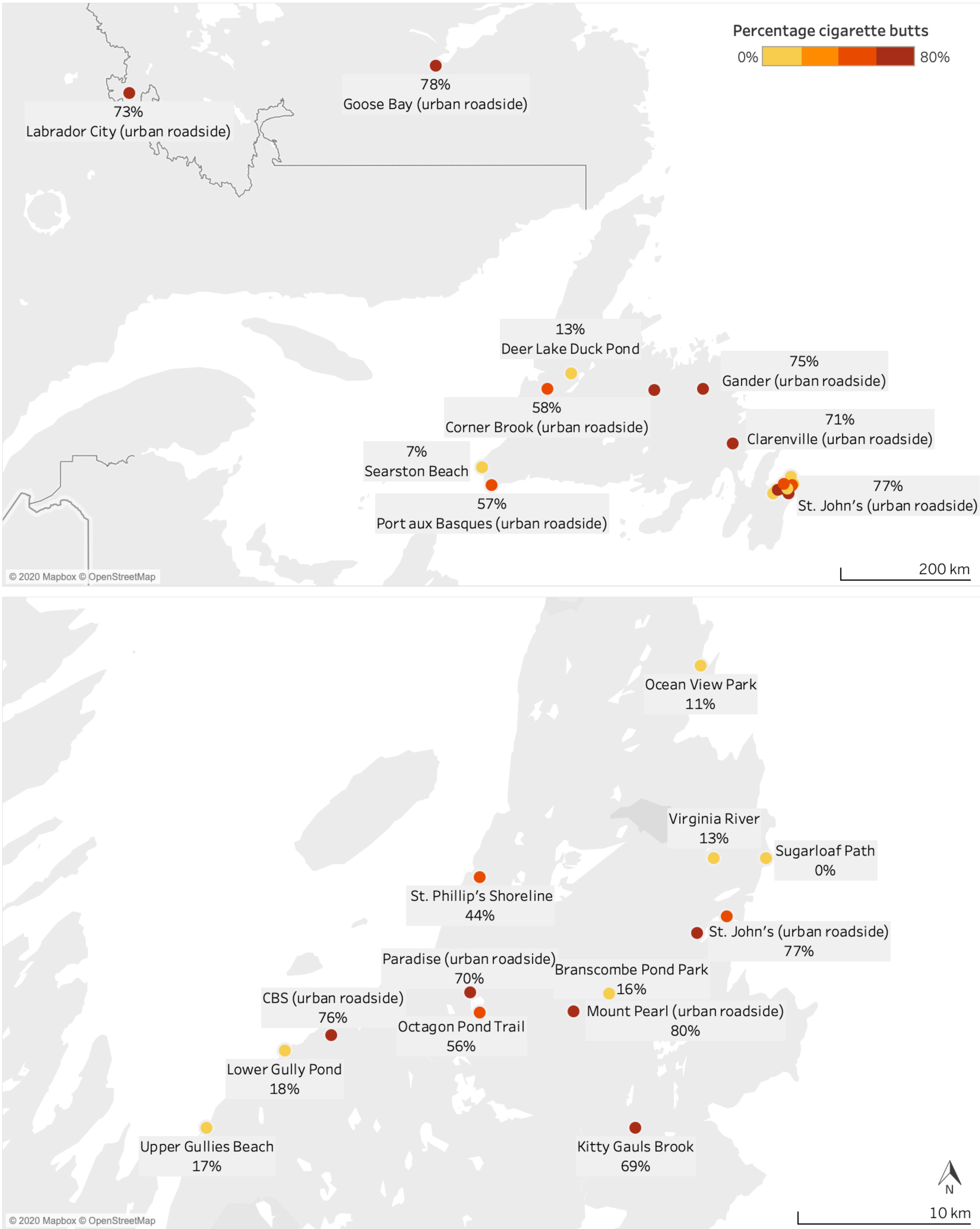
Taken together, this data indicates that plastic bags may not be a marine plastic pollution issue in the province, at least not at the scale of plastics that are observed during civic cleanup activities. Instead, freshwater and terrestrial environments may be the areas most affected by plastic bags.

CIGARETTE WASTE

The Multi-Materials Stewardship Board (MMSB), the crown corporation responsible for the province's solid waste, conducted a roadside litter audit in 2016 and found that cigarette butts accounted for nearly 88% of nearly 26,000 small litter items collected across the province (Method 5).[41] The Great Canadian Shoreline Cleanup has a subcategory for cigarette butts and found they comprised 24% of shoreline waste on average.

There is high variation of the percentage of waste comprised of cigarette butts (Figure 11), and the MMSB report argues that land use accounts for some of these differences, as "51% of cigarettes were documented in commercial areas, three times the amount found in open spaces, which contained the second highest concentrations. Industrial and school sites remained relatively large contributors at 17% and 13% respectively, while residential areas were found to have the lowest counts of cigarette butts. This distribution seems to follow that observed with large litter [generally]."[42] These figures focus only on cigarette butts and do not include other tobacco-related waste such as packaging. However, the MMSB litter audit found that the third highest brand in paper and plastic waste was Health Canada warnings for tobacco products, which accounted for 7% of all branded macro litter, and Canadian Classics, a tobacco brand, accounts for 4% of branded macro litter.[43] This means that tobacco products account for a higher percentage of waste than what is recorded in Figure 11, which only records cigarette butts.

Figure 11: Percentage of waste that was cigarette butts (GCSC 2018 & MMSB 2016)



Percentage of shoreline and roadside waste that was cigarette butts. Shoreline and walking trails had lower ratios of cigarette butts to other forms of waste. This data is only for butts, not for all forms of cigarette waste such as packaging. Data is drawn from the Great Canadian Shoreline Cleanup (2018) and the Multi-Materials Stewardship Board roadside litter audit (2016).

Sources of waste by activity

Some types of waste and activities are closely linked (cigarette butts as associated with smoking, and fishing gear is associated with fishing). As such, there will be some repetition with the section above, though with additional context and supporting data.

COMMERCIAL AND SUSTENANCE FISHING

Commercial fishing and sustenance fishing result in different types and locations of waste, but both have been found to contribute to plastic pollution. In a series of annual diving surveys conducted between 2007 and 2011 along the southeast, north, and northwest coast of Newfoundland, Morris et al. found that all forms of anthropogenic waste, including plastics (which accounted for 14% of waste), accumulated around wharfs (5.8%) compared to near wharfs (2.1%) or in areas that did not have wharfs (0.4%).[44] A similar dive survey study published by Han et al. conducted between 2007 and 2016 with many of the same researchers looked at Wharf, Nonwharf, and Low-use areas. They found, on average, that the average percent of the area containing debris was 16.5% at Wharfs, 6.5% at Non-wharfs, and 1.2% at Low-use sites, mirroring the results in Morris et al. 2016 (Method 5).[45]

Together, these studies indicate that activities on wharfs contribute to underwater marine debris. There is no breakdown in the study that allows a differentiation between commercial and fishing activities, and fishing and non-fishing activities. This data is for all waste, not just plastics.

Unpublished data by Liboiron et al. (2016) categorized the types of waste found in surface water in Petty Harbour (Table 3), a fishing community near St. John's that hosts both commercial and recreational fisheries. Over half the items found were threads: long, stiff but flexible microplastics assumed to come from polymer ropes (Figure 12). This is a much higher percentage of threads than in surface water data on multiple locations in Labrador, Nunavut, and the island of Newfoundland (Figure 17).

Table 2: Comparison of waste in surveyed diving areas

Diving location	Proportion (%) waste
Wharf	2.8%
Wharf	8.0%
Wharf	3.3%
Wharf	6.9%
Wharf	3.1%
Wharf	10.0%
Wharf	6.3%
Wharf avg	5.8%
Near wharf	4.2%
Near wharf	3.0%
Near wharf	3.9%
Near wharf	1.2%
Near wharf	0.3%
Near wharf	0.3%
Near wharf avg	2.1%
Nonwharf	0.4%
Nonwharf	0.3%
Nonwharf	0.4%
Nonwharf avg	0.4%

Comparison of the occurrence of underwater marine waste at 16 sites, including wharf, near wharf, and non-wharf sites in rural coastal Newfoundland in DFO research diver surveys between 2007 and 2011. From Morris et al. 2016

Table 3: Morphologies of microplastics on the surface water of Petty Harbour, NL (2016)

	Thread	Fragments	Microbeads	Film	Foam	Microfibers	Pellets	Toilet paper	TOTAL
#	227	122	38	33	17	12	0	55	504
%	55.0	24.2	7.5	6.5	3.4	2.3	0.0	10.9	100.0

The morphologies (physical types) of microplastics recovered from surface water in Petty Harbour, a fishing community outside of St. John's.

Threads (pink) are stiff but flexible, long fragments, often associated with fishing line or rope (Figure 12)
Fragments are hard pieces of plastic (though they can be flexible)
Microbeads are plastic spheres often found in cosmetics as an exfoliant
Film plastics are thin and flexible, like plastic bags (also called sheet plastics)
Foam plastics are characterized by air pockets in their structures that allow the plastics to flex and return to their shape easily
Fibers refer to thin fragments that come from synthetic cloth- they tend to be smaller, thinner, and more kinked than threads
Pellets refer to pre-production industrial pellets or nurdles, flattened beads used in the production of plastic goods
Toilet paper is not made of plastic, but is a form of anthropogenic debris found in sewage outfalls

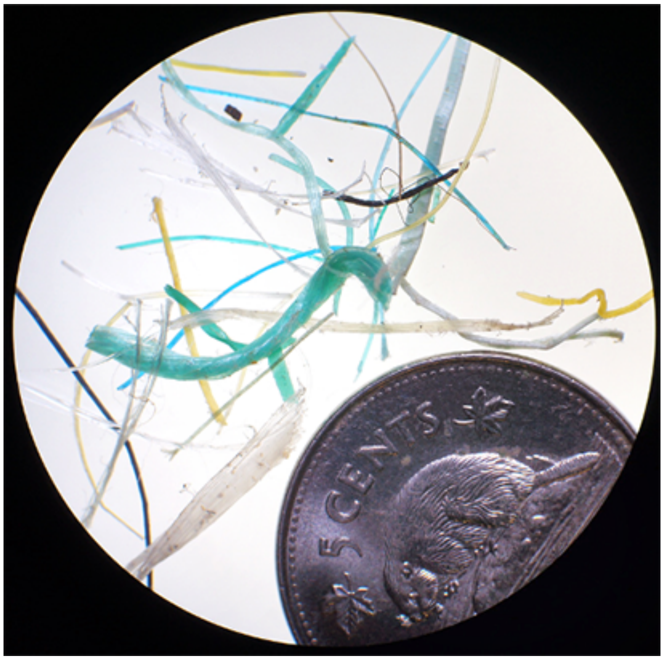


Figure 12: In microplastic morphologies, "threads" refer to stiff but flexible, intertwined fragments of plastic that are longer than they are wide. They are often from fishing gear. A forthcoming thesis by Saturno (2020) found that fishing gear abraded by seafloor conditions began shedding microplastics within the first five minutes of abrasion. Research on the role of fishing activities on plastic pollution must consider both large-scale, macro fishing gear as well as microplastic threads and related plastics. PHOTO: Max Liboiron.

In terms of commercial fishing, Newfoundland and Labrador boasts 78% of national commercial landings for fisheries (in tonnes). The province also accounts for more than 85% of the country's registered fishing vessels and has the highest number of aquaculture establishments in Canada.[46] All these activities generate polymer waste.

While an average of 37% of plastic waste on shorelines in the province is fishing-related, we investigated whether proximity to commercial fishing waters impacted the amount of fishing gear on shorelines. In our analysis of shoreline plastics recorded with the MDT, the amount of fishing gear used in a NAFO area does not significantly affect the density of plastic overall or amount of fishing gear in geographically proximate beaches (Method 6). However, the regional data at the scale of NAFO sub-units is rather coarse for comparison to specific beaches and we believe more study with different data ought to be pursued to investigate this relationship further.

An informal estimate by the Canadian Parks and Wilderness Society (CPAWS) is that of the 2000kg of trash collected in 2019 from 18 harbours, roughly half was from ocean industry.[47]

SEWAGE

While studies in other regions have found that both treated and untreated sewerage effluent contributes to aquatic microplastic pollution,[48] no such studies exist in this province to our knowledge. In 2012, 83 communities reported 222 local Sanitary Sewage Overflows (SSOs)[49] and even if that number is decreasing to bring the province in line with federal wastewater guidelines, we can assume a significant number of SSOs continue to exist and will be contributing microplastics from laundry and other sources to the aquatic environment. SSOs can release up to 100 m^3 of effluent per day without needing to be registered or monitored, so figures for the amount of sewage being released in the province (estimated at 39,000 m^3/day in one report)[50] is likely low.

In the unpublished Petty Harbour surface water study described in table 3, the presence of toilet paper (flushed from toilets), microbeads (found in personal cosmetics), and microfibers (a main component of laundry runoff), indicate many of these plastics are likely from sewage.

LANDFILL

It is estimated that the province generates 493,595 metric tonnes of municipal solid waste per year,[51] and even if that waste reaches a landfill, the light weight of many plastics allow them to flow and blow out of waste infrastructures. Indeed, the GCSC data reported above on clean up items recovered from the Sugarloaf Trail are assumed escape Robin Hood Bay waste and recycling facility in St. John's. They recorded that plastic bags made up the majority of items (1,089 items of 2511, or 43% of waste). The next significant category is plastic fragments and foam (689 items, 27%). Food wrappers (169 items, 7%) and paper materials (147 items, 6%) where the only other categories with more than a 5% share of material categories.

While landfilling is not the origin of plastic wastes, they are a source of "leakage" of plastics that have already been disposed of through municipal and commercial waste flows. This leakage persists even though Robin Hood Bay Landfill employs several technologies and techniques to defray blowing plastics, including nets, regular gravel cover, and periodic retrieval of plastics in nearby brush.[52] This suggests that merely ensuring waste reaches appropriate sites of disposal is insufficient to fully address plastic pollution in the province.

LITTER

The Multi-Materials Stewardship Board's "Newfoundland and Labrador Provincial Audit" details a province-wide roadside litter audit from 2016,[53] and a new study will release results of a 2019 litter audit. In the 2016 study, "32,190 pieces of litter were documented (139.4 per site); 5,453 as large litter, 3,356 as small litter, and an additional 23,381 in the form of cigarette butts. The most commonly identified material types of large litter were plastic and paper, making up 42.7% and 29.4% of audited litter, respectively. Significant contributions to plastic and paper litter came in the form of wrappers, straws, bags, lids, napkins, paper cups, and assorted printed materials. By material type, proportions of small litter, excluding cigarettes, were found to be consistent with large litter."[54]

While the 2019 study has not been released at the time of writing, preliminary results indicate that "close to 197 million pieces of litter exist on the provinces road network and coastlines."[55] It also indicates that there is more waste on roadsides than on shorelines. Since the ocean is "downhill from everything," roadside litter is a crucial area to target for plastic pollution of all types, including marine plastics.

The data on cigarette butts in the section above are also largely due to litter (Figure 11), as is waste around wharfs (Table 2). Taken together, this indicates that litter is a pervasive activity across different locations and activities in Newfoundland and Labrador.

BURNING WASTE

A 2017 report on municipal solid waste by the Government of Newfoundland and Labrador noted that open burning and incineration of waste is still an issue in the province despite nearly ubiquitous access to landfill services. The report estimated that 147 sites are using open burning, though only 29 waste sites in the province are authorized to burn due to operational reasons such as not having access to gravel cover.[56] These figures are for known burning sites; it is likely that there are many smaller, private sites in the province at the household or cabin scale.

Figure 13: Burned microplastics recovered from the gastrointestinal tracks of Dovekies caught on the Avalon Peninsula in 2013. PHOTO: Max Liboiron.

In a study of plastic ingestion on Dovekies, Avery-Gomm et al. (2016) noted that 37% of plastics were burned or melted, which they thought was "curious" as burned plastics do not appear often in the literature (figure 13).[57] They speculated that "burned or melted plastics in the coastal waters of Newfoundland likely originated from coastal waste disposal sites, with open burning or incineration, shoreline garbage burn piles, or from waste incinerated on fishing vessels."[58] The Marine Debris Tracker app provides a forum for commenting on individual plastics collected, and plastics collected by the Placentia Bay Ocean Debris Survey (PODS) have recorded burned and melted plastics this way. Shoreline cleanups on Topsail beach and Middle Cove beach, near St. John's, have also reported burned plastics. While large-scale burning may be a remote and rural phenomenon, burning plastics is also occurring close to urban areas with excellent access to curbside and public waste facilities.

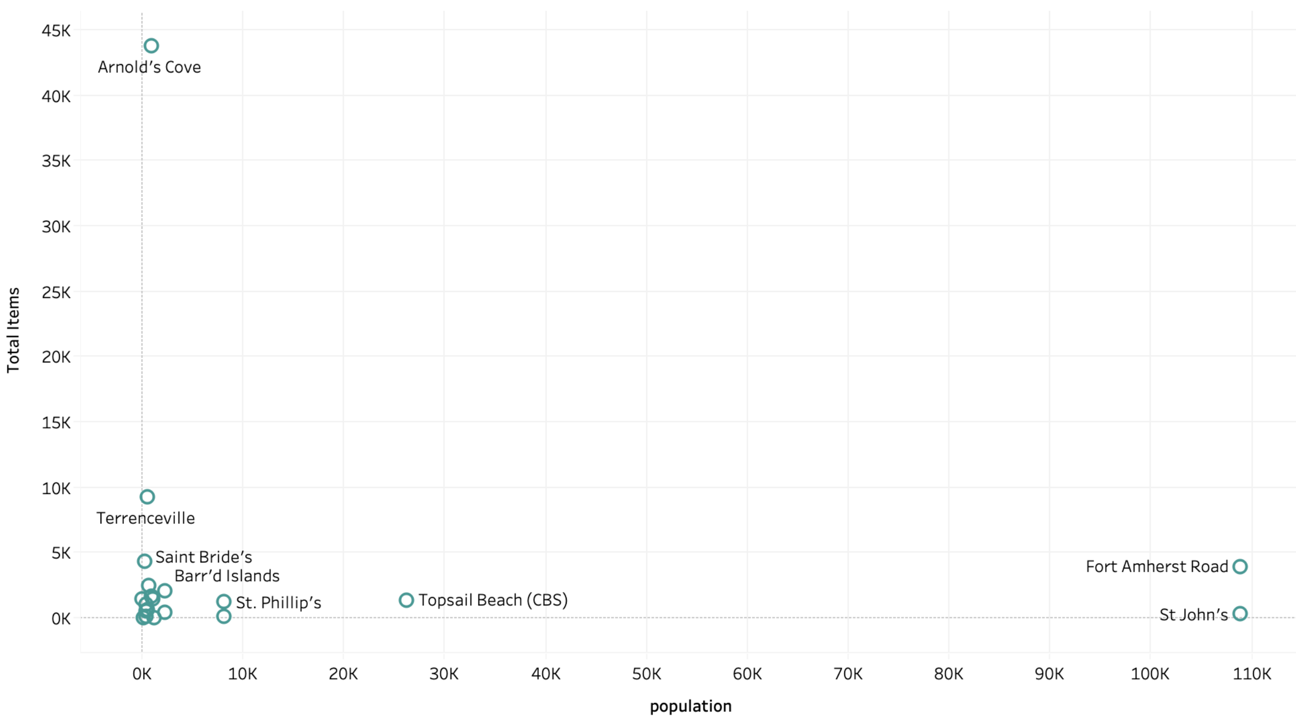
Burned and melted plastics should be considered in future studies, which should track sources and record prevalence, as well as determine post-incineration chemistry and potential toxicology of burned and melted plastics when ingested by biota or released into waterways.

POPULATION

Generally, an increase in population shows an increase in overall plastic items in shoreline waste during a shoreline cleanup, but the trend is not statistically significant (Method 6). Moreover, populations in the province are characterized by extreme values. For instance, there are high populations in places such as Conception Bay South (pop. 26,199), and extremely low populations in places such as Black Tickle (pop. 150) and these values do not result in a continuous dataset. This high variability should be kept in mind when interpreting results.
The MMSB litter audit only surveyed areas with populations over 4,000. While some areas with higher populations had more waste, the trend was uneven:

> "Of the audited sites within communities, the Community of CBS [Conceptional Bay South] was found to contribute the greatest amount of large litter, with 800 items identified within the town. As for small litter, Port aux Basques [pop. 4,067] contributed 473 items, more than any other audited community. Cigarette litter was highest within St. John's [pop. 108,860], where 3,699 butts were documented in the 20 sites. With respect to total litter, St. John's was determined to be the largest contributor to provincial litter, with 4,778 items of litter audited. In contrast, Labrador City [pop. 7,220] contained the least litter, accounting for just 1,783 items; 2.7 times fewer than St. John's."[59]

Figure 14: Shoreline waste items versus population (2014-2018)

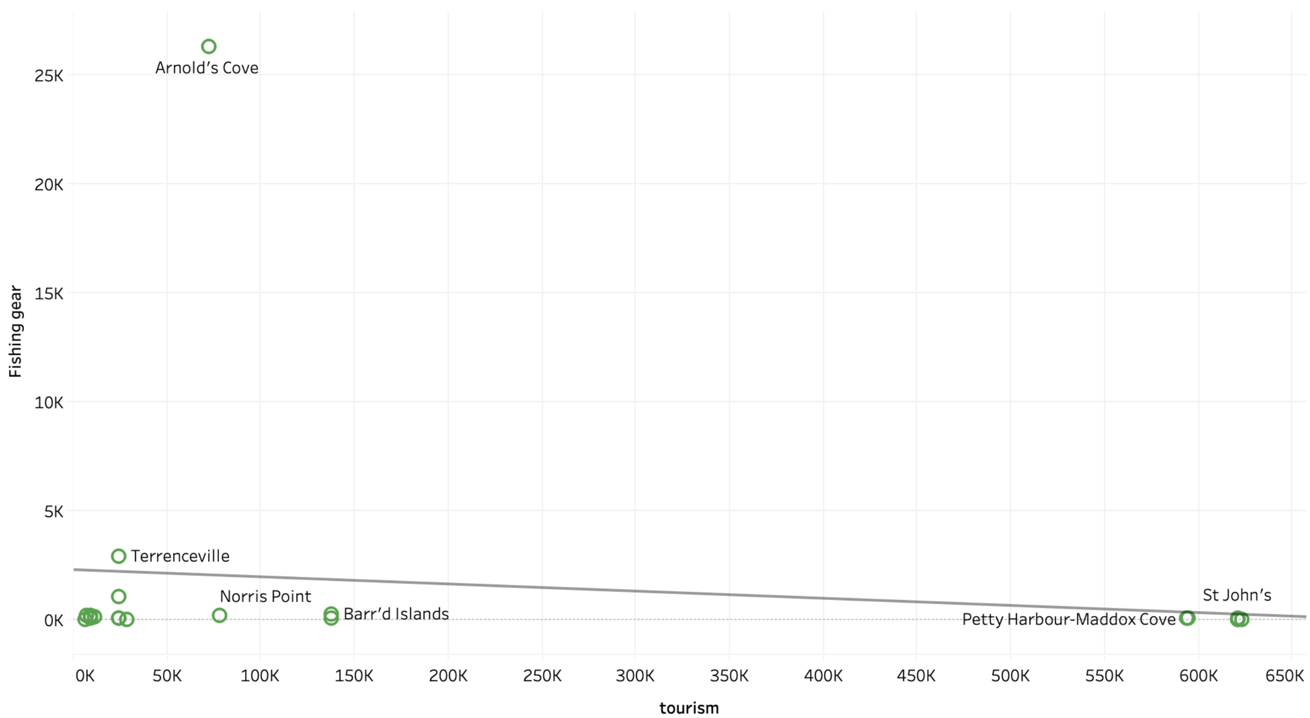


Comparison of the number of shoreline waste items and the populations of adjacent communities. Shoreline data is from MDT and GCSC (2014-2019). High population areas such as St. John's (including Fort Amherst Road, which is within St. John's city limits) and Topsail Beach in Conception Bay South did not have significantly more waste items or plastic items than areas with lower populations. Note the extreme values here: the unusually high number of waste items in the small communities of Arnold's Cove and Terrenceville, and the high population of St. John's. See Method 6 for details.

TOURISM

It appears that greater numbers of tourists near a shoreline significantly (p=0.05) decreases the densities of fisheries plastic (p=0.009) and plastic fragments (p=0.045), but not plastics overall (Method 6). The relationship might be driven by a few extreme values or other variables not tested. Increasing tourism has a general effect of decreasing all types of plastic, but not significantly. Tourism-related activities like regular shoreline cleanups or the presence of public trash bins does not likely account for the significance of the trend, since microplastics usually come from the ocean and are rarely picked up in shoreline cleanups and fishing gear is not usually placed in consumer waste infrastructure (though it is often captured in cleanups). This data is driven by several extreme values, which should be considered when interpreting the findings.

Figure 15: Shoreline fishing gear items versus tourism (2014-2018)



Comparison of the number of fishing gear items on a shoreline and the number of tourists in an area. Shoreline data is from MDT and GCSC (2014-2019). The trend line is negative, showing that the number of fishing gear items decreases significantly as the tourist population increases. No significant trend was observed between the number of plastics in total and tourist populations. As with population, these numbers are driven by several extreme values. Moreover, tourist data has a lower resolution that population data, as data from Tourism NL uses economic zones to calculate tourism (all of Nunatsiavut, for example, is one tourist region). See Method 6 for details.

THE PRODUCTION OF PLASTICS

Plastic is produced using oil and natural gas as raw feed stocks, which are purchased by primary manufacturers such as The Reynold's Group, Amcor, and Sealed Air.[60] These primary manufactures create plastic production pellets, also called nurdles, that are rarely found in Newfoundland and Labrador owing to the lack of such industries in the province (Table 1).

The primary consumers of these raw plastic materials are brand manufacturers whose names readers might be more familiar with. Brand audits are a type of metric designed to trace the account for sources of plastic pollution and be thus used to keep sources of pollution accountable.[61] Plastic waste, after all, is not produced by consumers. A brand audit focuses on recording and analyzing plastic items where brand names of items are apparent and are usually carried out in regions with high amounts of large, unfragmented plastic items. Recording counts of items by brand is designed to show the industrial origin (often called a "parent company") of plastic pollution and is often tied with extended producer responsibility (EPR), where producers of waste are responsible for the fate of their packaging products, rather than municipal or provincial governments.

The only brand audit on plastic pollution in Newfoundland and Labrador was conducted by MMSB on over one thousand items of roadside litter.[62] The top brands in the province are Tim Horton's (27.3% of items), McDonald's (9.9%), and Health Canada warnings for tobacco products (7.0%).[63] Brand audits should become a regular part of plastic pollution research in the province.

Two images of plastic pollution related to producers. Top: A plastic production pellet, the raw feedstock used to manufacture plastic items, found in the Riverhead Estuary on the south shore of the island of Newfoundland. PHOTO: Max Liboiron. Bottom: A Tim Horton's cup littered on a sidewalk, the brand that accounts for 27.3% of the province's branded roadside litter. PHOTO: Dennis Jarvis.

WHAT IS THE DISTRIBUTION OF PLASTICS IN NEWFOUNDLAND AND LABRADOR?

Key findings

- Regional-scale hotspots do not appear to exist in the province. However, specific shorelines have unusually high plastic loads, such as Arnold's Cove and Terrenceville (loading beaches).
- Densities of plastics in surface water range from 280-13,480 pieces of plastic/km^2 with an average of 5,208 pieces of plastic/km^2. This figure is higher than it was in 2008.
- Near Joe Batt's Arm (Fogo Island), the loading rate of new shoreline plastics 0.4-15 plastics/m^2 every two days.
- Near Humber Arm there is an average of 22.6 plastic items/m^2 or 22,600,000 items/km^2.
- The provincial average for all waste near highways is 2.1 items/m^2 or 2,100,000 items/km^2.

Hotspots?

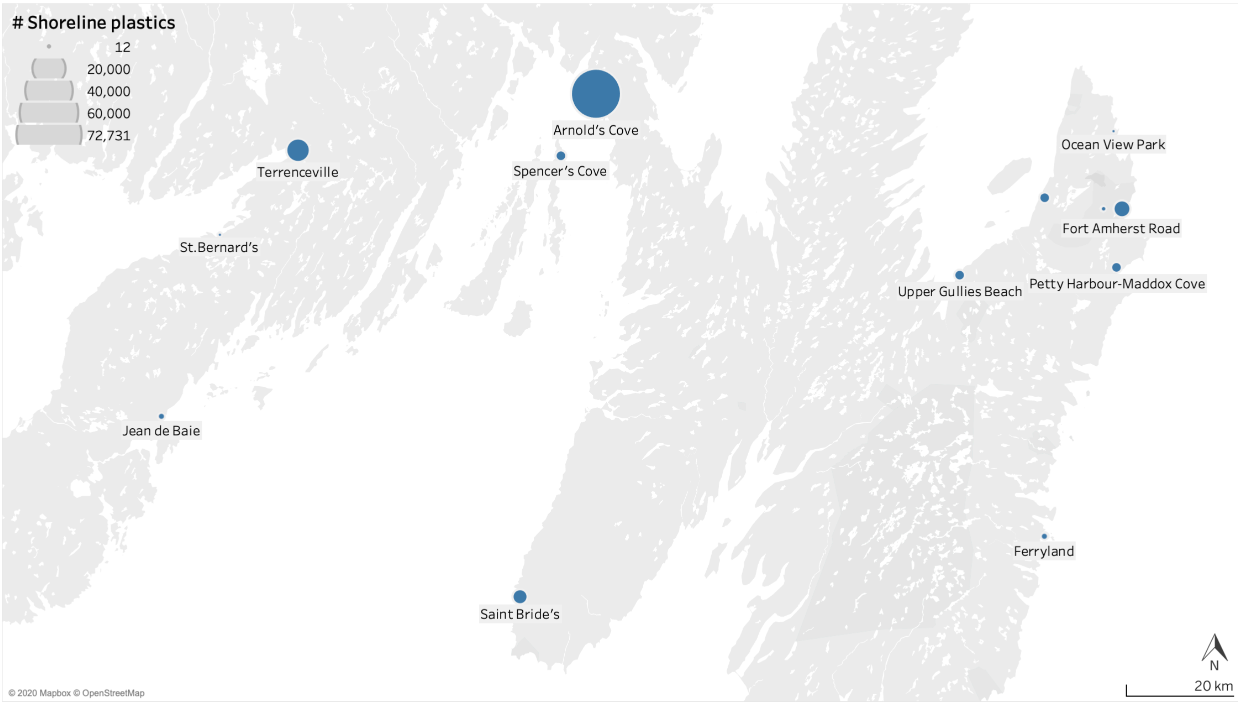
One of the goals of this report was to identify regional hotspots of plastic pollution in the province. However, there is great variability of different types of plastics within close geographic and no particular trends show a greater density in one region of the province compared to another. Much of this analysis relies on shoreline data since it has the greatest geographical breadth. Yet even when we combine all types of density or count data for plastic pollution together with their different (and incommensurate) metrics showing relative amounts, no overall trend emerges.

However, data does show some specific beaches that have unusually high plastic loads, such as Arnold's Cove, which had nearly 54,000 individual items cleaned up in 2018 and 2019, of which over 15,000 were plastic; and Terrenceville, where of over 22,000 items nearly 6,000 were plastic (Method 9). These areas are called loading beaches (Figure 16).[64] In the same bay there are locations monitored by the same group (PODS) with the same methods with much lower counts, such as Spencer's Cove and St. Bernard's-Jacques Fontaine with 653 and 147 items overall and 186 and 45 plastic items respectively. These variances are due to differences in wind, currents, tides, and topographical differences between locations.[65] Beaches that lack strong prevalent winds, for example, often possess greater abundance of beached debris accumulating during high-tide lines.[66] As such, loading and non-loading beaches can be within a kilometer or less of one another. However, one thing that both Terrenceville and Arnold's Cove have in common is that they are in the northeast corners of larger south-facing bays. It may be that other locations with similar geographies are also loading beaches.

The provincial chapter of the Canadian Parks and Wilderness Society (CPAWS) has 18 harbours in their Ship to Shore program, which aims to ensure waste that might be dumped or lost at sea is disposed of properly on shore. They have found that Musgrave Harbour and Lumpsden Harbour have loading beaches as well.[67]

At a smaller geographical scale, we know that certain types of areas are hotspots for waste from the analysis of specific types of plastic pollution above: wharfs, commercial areas and near landfills. In lieu of using regional hotspots as the locus for action or monitoring, we recommend focusing on use and types of areas, known loading beaches, as well as expanding the resolution and geographical reach of comparable data so regional hotspots might be detected in the future.

Figure 16: Number of shoreline plastic items (2014-2019)



The number of shoreline plastics (2014-2018) in the Placentia Bay and Avalon Peninsula areas showing high variability on geographically proximate shorelines. Note the difference in number of plastics in Arnold's Cove compared to Spencer's Cove just to the south, and Terrenceville compared to St. Bernard's to its south. Note that the data from the Placentia Bay area is mainly provided by the Placentia Bay Ocean Debris Survey (PODS), which uses the same methods for data collection. PODS is doing a longitudinal study of the area, and their data will highlight the local variation in counts of plastics overall as well as specific types of plastics.

Example of a "loading beach," which accumulates more debris of all types, including plastics, than neighbouring shorelines. This is Terrenceville, 2018. PHOTO: Jessica Melvin.

Figure 17: Density of micoplastics in surface water

The density of microplastics in surface water based on multiple sources of unpublished data (2013-2019). All studies used an identical method of surface water trawling with a 333 um net and visual identification. Full studies are forthcoming by Ariel Smith (Bluenose Coastal Action), Sheldon Peddle (ACAP Humber Arm), and Max Liboiron (CLEAR).

Surface water

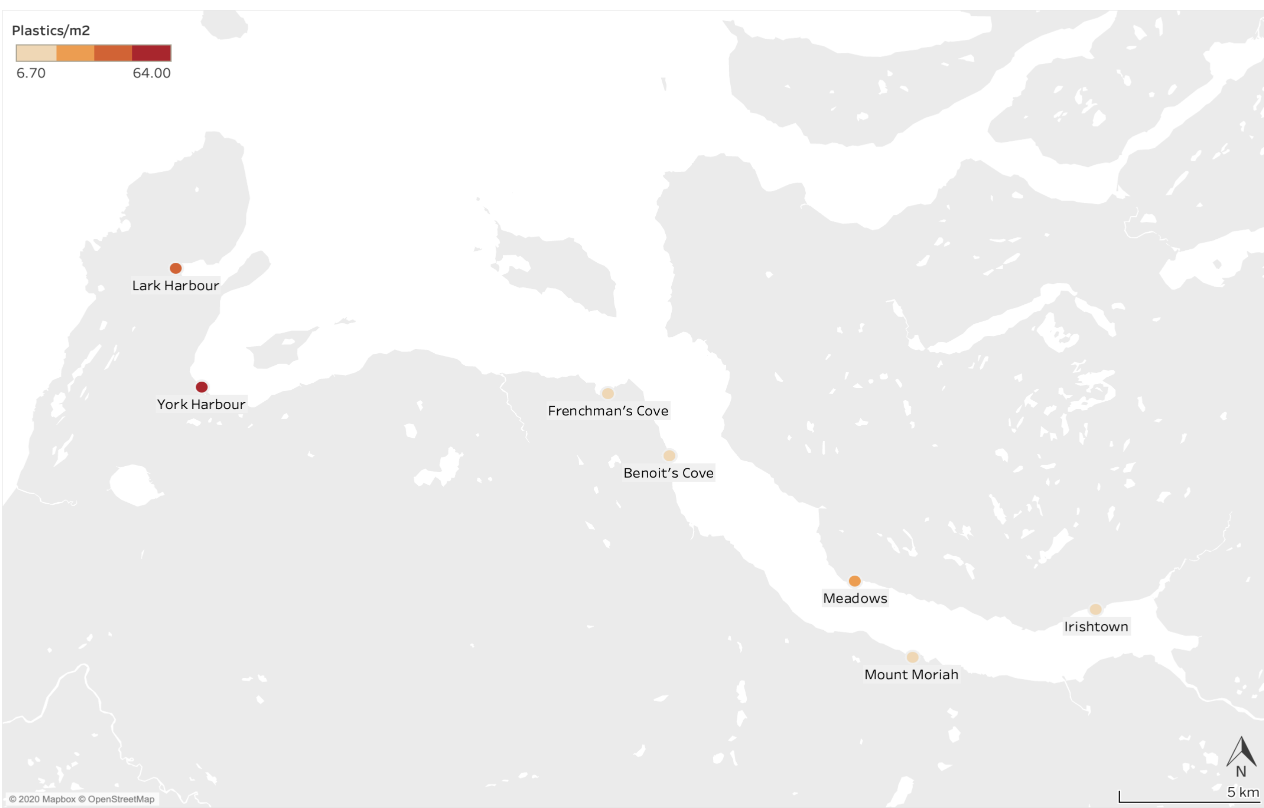
There are relatively few studies of plastics in surface water in the province, but they all use comparable methods of monitoring: a surface water trawl with a 330µm mesh net is pulled behind a boat and plastics are collected, sorted, and analyzed. Most of the sources for this data have not yet been published (see table 3 as an example). Densities range from 280-13,480 pieces of plastic/km^2 with an average of 5,208 pieces of plastic/km^2. All tows recovered plastic.

For reference, a 2010 study in the western North Atlantic Ocean and Caribbean Sea (around the North Atlantic Subtropical Gyre) of over 6,100 surface water tows from 1986 to 2008, including many tows in and around the southern shores of the island of Newfoundland and Atlantic Canada, found an average range of 0-5,000 plastic pieces per km^2 in the region around the province and Atlantic Canada generally.[68] The provincial average now exceeds those counts. A comparison from the 2010 study to the studies mentioned above, all of which were conducted in the past six years, indicates densities of surface water plastics are increasing.

Plastics in sediment

The only plastic sediment study conducted in the province is by the NGO ACAP Humber Arm, working in partnership with CLEAR and Bluenose Coastal Action Network. Their final report is forthcoming, but early access to the data shows high variation (between 7 and 64 pieces of plastic per m^2) of plastics in sediment near Humber Arm and Corner Brook, with an average of 22.6 items/m^2, or 22,600,000 items per km^2.

Figure 18: Density of plastics in sediment



The density of microplastics in shoreline sediment based on unpublished data from ACAP Humber Arm (2016). Each location used an identical method of sieving to capture plastics 333um or larger. The study will be published by Ariel Smith (Bluenose Coastal Action), Sheldon Peddle (ACAP Humber Arm), and Max Liboiron (CLEAR).

Shoreline plastics

In a rocky shoreline survey near Joe Batt's Arm on Fogo Island, 33 waste items/m^2 were recovered in a standing stock survey, meaning that upon arrival to the beach, there were an average of 33 items per square meter.[69] These items were removed and the shoreline was checked every second day for over a month to investigate how many items accumulated every day. Between 0.3 and 19 items/m^2 washed up per day, 82% of which were plastics, making the loading rate of shoreline plastics 0.4-15 plastics/m^2 every two days.

PODS, the Nunatsiavut Government, MMSB and CLEAR are currently conducting multiple shoreline plastic studies that account for both densities of micro and macroplastics over time (accumulation and loading).

Terrestrial plastics

The 2016 MMSB litter audit reports the provincial average for all waste near highways is 2.1 items/m^2 or 2,100,000 items/km^2. There is high variability within types of sites (as mentioned above), with commercial sites having higher densities of waste. Figure 19 shows the relative density of litter based on the percentage of a roadside site covered in litter. Approximately 72% of roadside litter was plastics.

Figure 19: Density of roadside litter (2016)

The density of roadside litter items based on the Multi-Material Stewardship Board's roadside litter audit (2016). Figures are for the proportion of the site area that was covered in litter. Plastics accounted for 72% of roadside litter.

WHAT ANIMALS ARE AFFECTED BY PLASTIC POLLUTION?

Key Findings:

- Fish and marine mammals have been found to die from entanglement in ghost fishing gear.
- Since the cod moratorium, an average of 10 Humpback whales and 3.2 Minke whales are entangled in fishing gear annually.[70]
- Species found to ingest plastics in Newfoundland and Labrador include:
    - American black duck (7% frequency of occurrence[2])
    - Atlantic puffin (7%)
    - Black legged kittiwake (26%)
    - Common eider (10%)
    - Common murre (0-10%)
    - Dovekie (0-30%)
    - Great Black-backed Gull (75%)
    - Great shearwater (75%)
    - Herring gull (42-77%)
    - Iceland Gull (100%)
    - Leach's storm petrel (48%)
    - Sooty shearwater (20%)
    - Thick-billed murre (9%)
    - Blue mussels (100%)
    - Atlantic Cod (0-8.3%)
    - Northern fulmar (79%)
    - Sperm whale (100%)
- We have baseline plastic ingestion figures for the following animals (Method 13), which can be used as a benchmark for future trends:
    - The 2013 baseline for plastic ingestion by Dovekies is 30.4%.
    - The 1966-1967 baseline for plastic ingestion by Herring gulls is 14.0%.
    - The 1987-1988 baseline for plastic ingestion by Leaches storm petrels is 6%.
    - The 1985-1986 baseline for plastic ingestion by Thick-billed murres is 7.7%.
    - The 2015 baseline for plastic ingestion by Atlantic cod is 2.4%.
    - The 2015 baseline for plastic ingested by Capelin is 0.0%.
    - The 2016 baseline for plastic ingestion by Silver hake is 0.0%.
- The following species exceed the EcoQO target in Newfoundland and Labrador in at least one study: Black legged kittiwake; Dovekie; Great Black-backed Gull; Great shearwater; Herring gull; Iceland Gull; Leach's storm petrel; Sooty shearwater; Northern fulmar.
- Species consumed for human food tend to have lower or null ingestion data.
- Plastic ingestion figures for Newfoundland and Labrador birds are either on par with or are lower than those in other locations with the exception of Northern Fulmar, Atlantic puffins, Thick-billed murres, Dovekies and Common eider ducks, which are higher.
- Ingestion figures for almost all species are increasing.

[2] Frequency of occurrence (FO%) indicates the percentage of individual animals in a studied population that ingested plastics. It does not indicate how many plastics each individual ingested.

Entanglement

Entanglement in macroplastics, usually fishing gear, has affected birds, fish, marine mammals, and terrestrial animals such as caribou. Species that have scientific reports of entanglement in Newfoundland and Labrador include: Seal, Cod, Turbot, American Plaice, Catfish, Skate, Crab, Humpback whale, Minke whale, Fin whale, Pilot whale, Unknown whale species, Witch, Wolffish, Lumpfish, Redfish, and Sculpin and personal communication includes reports of caribou entangled in fishing gear.[71] A summary of mortality Figures is in Table 4.

The vast majority of this data was collected before the cod moratorium in 1992. Benjamins et al. (2011), a comprehensive study on whale entanglements, reports that after the 1992 Atlantic cod moratorium total whale entanglement numbers went down by approximately 65%.[72] This may also be the case for other types of entanglement. Since the cod moratorium, an average of 10 humpback whales and 3.2 mink whales are entangled in fishing gear annually.[73] Most of these recent whale entanglements are offshore and related to pots in the case off Humpback whale entanglements and gill nets, ropes, and pots for Minke whales.

Newfoundland and Labrador are home to three of four species of Wolffish: Atlantic (Striped) which is a species of special concern, as well as Spotted and Northern Wolffish, which are threatened species. The Canadian Parks and Wilderness Society (CPAWS) Newfoundland and Labrador chapter states that for all species, the "leading cause of Wolffish decline is suggested to be incidental bycatch during fishery activities (food, small and large scale, and inshore and offshore fisheries)"[74] and provides recommendations on how to release Wolffish from entanglement in various gear.

Entanglement is likely to be underreported given that it usually occurs away from observation, particularly when fishing gear is abandoned and/or lost.

Figure 20: Caribou skeleton with polymer rope entangled in its rack. The other end of the rope is wrapped around a large log. The entanglement likely contributed, if not caused, the caribou's death. Western Indian Island near Fogo Island/Change Islands. PHOTO: Meagwin Bonar and Eric Vander Wal, 2016.

Table 4: Summary of mortality from entanglement in derelict fishing gear (1973-2008)

Species	Number dead	Dead weight (kg)	Average % mortality
American Plaice	-	49.2	40.5
Catfish	-	174.8	28.5
Cod	-	335.0	32.0
Crab	-	170.2	3.5
Fin whale	62	-	29.6
Humpback whale	935	-	21.9
Lumpfish	-	2.0	100.0
Minke whale	312.5	-	67.5
Other whales	21	-	78.3
Pilot whale	49		46.4
Redfish	-	1.0	100.0
Sculpin	-	9.0	0.0
Seal	-	68.0	100.0
Skate	-	89.1	45.5
Turbot	-	2904.4	44.0
Witch	-	6.0	100.0
Wolffish	-	5.8	4.0
Total	1379.5	3814.4	45.5

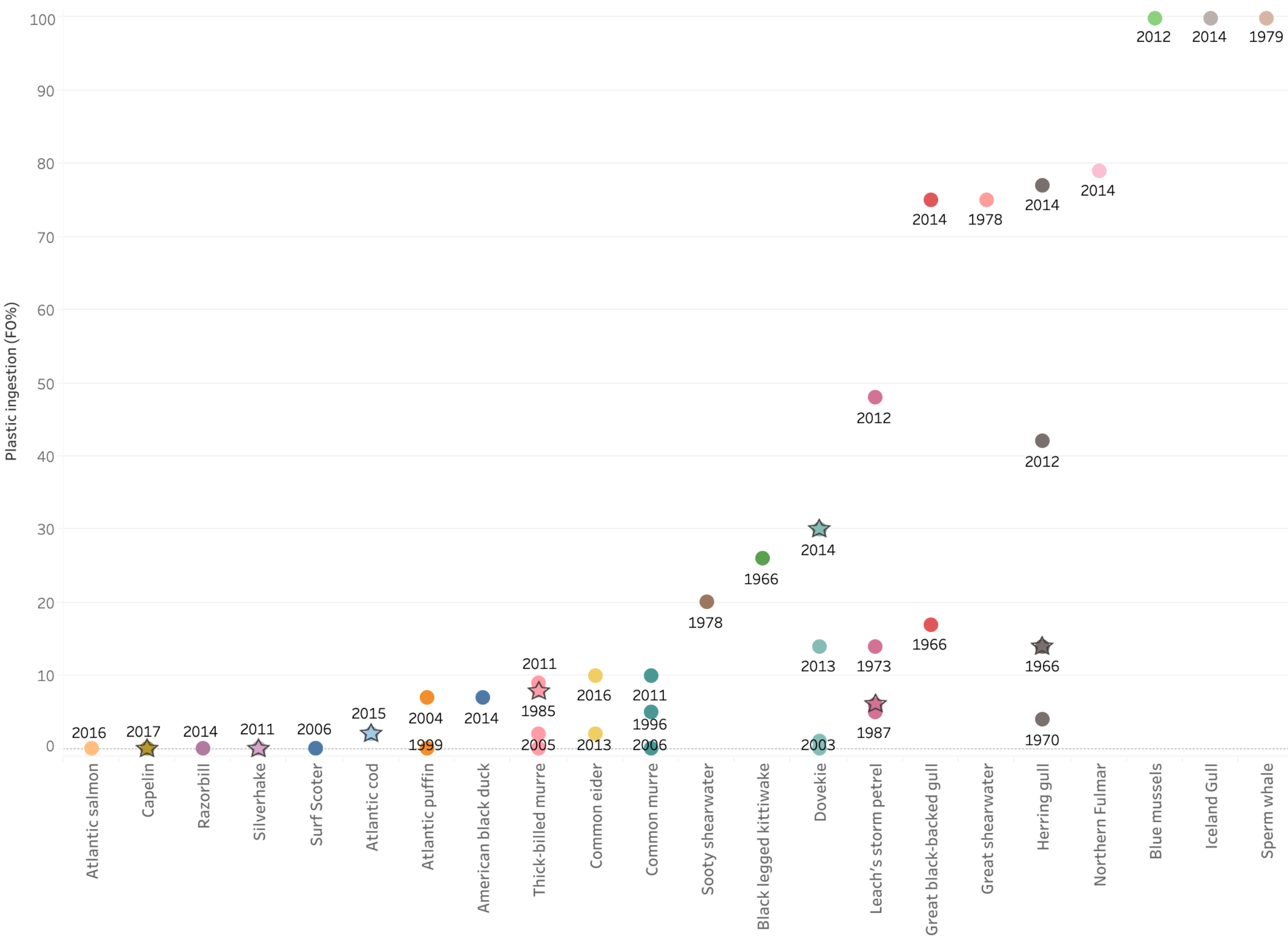
Data for Table 4 is compiled from: Way (1976), Perkins and Beamish (1979), Brothers (1992), Lien (1994) and Benjamins (2011). Terms such as seal, cod, turbot, wolfish, catfish, etc. are taken directly from studies. The species of seal, cod, etc are not specified, and "turbot" is used instead of "Greenland Halibut" in the original study.

Ingestion

When animals ingest plastics, harm may occur from gastrointestinal blockage or punctures, but many animals also appear to be healthy.[75] Yet the added weight, feeling of satiation, and pain may reduce an animal's body condition, quality of life, and ability to hunt and evade predators.[76] A key area of concern is the transfer of industrial chemicals and heavy metals (such as PCBs and methyl mercury) from plastics into animals and through food webs.[77] This is still an area of debate and study, and the relative importance of plastic pollution as a source of chemical exposure compared to other routes in the aquatic environment is unknown at this time.[78]

This report does not use plastic ingestion data to discuss plastic distribution and concentration in the province. This is because different species ingest plastics of different kinds at different frequencies because of specific feeding and foraging behaviours, meaning ingestion patterns cannot be directly compared *between* most species. However, if methods between studies are identical, this same trait allows comparison *within* a species to evaluate whether changes are occurring over time, and whether populations of the same species in different locations have different frequencies of ingestion. Of the 59 species covered in studies, 66% are birds, 31% are fish, 2% are whales and 2% are bivalves.

Figure 21: Plastic ingestion (FO%) by biota in Newfoundland and Labrador (1962-2019)



Comparison of the percentage of individuals in a sampled population that ingested plastics (frequency of occurrence, or FO%). Stars indicate baseline figures. This figure includes all studies conducted on all species in Newfoundland and Labrador, regardless of whether methods were similar. Thus, some ranges are likely due to differences in methods rather than environmental factors.

Some studies are able to produce baseline figures for plastic ingestion, meaning that we can be relatively sure that a certain number of individuals of a species will, on average, ingest plastics and we can use this figure to measure future changes (Table 5, Method 12).

Table 5: Studies that produced baseline data of plastic ingestion by key species in Newfoundland and Labrador

Species	Location	Year of collection	Sample size	FO%	Citation
Dovekie (*Alle alle*)	Conception Bay	2013	171	30.4	Avery-Gomm et al., 2016
Herring gull (Larus argentatus)	Witless Bay	1966-1967	401	14.0	Threlfall, 1968
Leach's storm petrel (*Oceanodroma leucorhoa*)	Gull Island	1987-1988	749	6.0	Hedd et al., 2009
Thick-billed murre (*Uria lomvia*)	Northeast Coast	1985–1986	124	7.7	Bond et al., 2013
Atlantic cod (*Gadus morhua*)	Northeastern Avalon Peninsula	2015	205	2.4	Liboiron et al. 2016
Capelin (Mallotus villosus)	Island of Newfoundland, multiple locations	2015	350	0.0	Liboiron et al., 2017
Silverhake (*M. bilinearis*)	South shore/Grand banks	2016	125	0.0	Liboiron et al. 2018

Baseline figures show the earliest plastic ingestion figures for species with more than 100 samples collected within a three-year period. These baselines may not generalize to areas beyond their sampled areas, but they do provide a measure against which to evaluate changes and deviations. The use of any baseline requires consideration of the methods that produced it, as methods can impact FO%, such as whether the entire gastrointestinal tract was considered, the minimum size of plastics considered, and other information.

ECOLOGICAL QUALITY OBJECTIVE

Ecological Quality Objective, or EcoQO, is a measure of plastic ingestion developed for Northern fulmar as a monitoring species. EcoQO assumes that the extra weight of ingested plastics, as opposed to their count, is the most salient measurement that would impact birds. The EcoQO measure is a threshold of 0.1g of ingested plastic per 10% of individual Northern fulmar within a studied population. EcoQO is a "target considered to reflect 'acceptable ecological quality' as used in policy documents."[79] Anything above that threshold is considered to be an indicator of unacceptable ecological quality.

The single study of plastic ingestion by Northern fulmar in Newfoundland and Labrador exceed the EcoQO target.

COMPARISON OF INGESTION FIGURES WITH OTHER REGIONS

Several studies directly compare plastic ingestion data between Newfoundland and Labrador and the rest of Canada (Table 6). Holland et al. (2016) found no statistical difference between ingestion of plastics by freshwater birds in "British Columbia (23/145, 15.9%), Nova Scotia (6/74, 8.1%), Northwest Territories (5/66, 7.6%), Newfoundland (3/29, 10.3%), Ontario (1/19, 5.3%) and New Brunswick (0/13)."[80] The sample size for Newfoundland is only 29 birds in that study.

A number of studies do comparisons between locations but do not investigate whether differences are statistically significant or not. Often this analysis is not available because of sample sizes. English et al. (2015) found that species of freshwater waterfowl in Nova Scotia had more plastics than freshwater waterfowl in Newfoundland, though this study considers only 17 birds, ten from Nova Scotia and seven from Newfoundland, across three species.[81] In a study of 2580 individual birds from 13 species in the North Atlantic, including locations in Nunavut, Greenland, South Carolina, and the Faroe Islands (Norway) as well as Newfoundland and

Labrador, Provencher et al. (2014) report a range of ingestion figures, finding that plastic ingestion figures for Newfoundland and Labrador birds are either on par with or are higher than these other locations (see table 6 for details).[82]

In a baseline study of Atlantic cod on the island of Newfoundland, Liboiron et al. (2019) found ingestion figures falling in the low rage of similar studies in other areas.[83]

Table 6: Comparison of plastic ingestion figures from Newfoundland and Labrador to other regions

Species	Location	FO%	Citation
Freshwater birds (multiple species)	British Columbia	15.9%	Holland et al. (2016)
	Nova Scotia	8.1%	
	Northwest Territories	7.6%	
	New Brunswick	0.0%	
	Ontario	5.3%	
	Island of Newfoundland	10.3%	
Freshwater waterfowl (multiple species)	Nova Scotia	6.0%	English et al. (2015)
	Island of Newfoundland	85.7%	
Shearwaters	North Carolina	71%	Provencher et al. (2014)
	Island of Newfoundland	75%	
Northern fulmar	Faroe Islands	51%	
	Newfoundland and Labrador	79%	
Atlantic puffins	Faroe Islands	0%	
	Newfoundland and Labrador	5%	
Thick-billed murres	Greenland	0%	
	Nunavut	0%	
	Newfoundland and Labrador	9%	
Dovekies	Greenland	0%	
	Newfoundland and Labrador	30%	
Common eider ducks	Greenland	0%	
	Nunavut	0%	
	Newfoundland and Labrador	10%	
Atlantic Cod	Norwegian Sea	3%	Liboiron et al. (2016)
	Baltic Sea	1.4%	Rummel et al. (2015)
	North Sea	13%	Foekema et al. (2013)
	Island of Newfoundland	2.4%	Bråte et al. (2016)

Comparison of plastic ingestion figures in Newfoundland and Labrador (pink) to other areas. Only Holland et al. (2016) conducted statistical analysis to investigate whether figures were significantly different: they were not, though species were not differentiated for the analysis.

EVIDENCE OF HARM FROM PLASTIC INGESTION IN NEWFOUNDLAND AND LABRADOR

This report does not consider health effects associated with plastic ingestion. Most of these types of studies are based in laboratories rather than being place-based. A study by Provencher et al. (2018) looked at PCB loads on plastics ingested by Northern fulmar caught on the Labrador Sea, and found 163 PBC congeners (types of PCB) associated with the plastics. They write, "PCB concentrations in plastics in the present study were higher than plastics sampled from the North Pacific reported in Mendoza and Jones (2015), but similar to plastic PCB concentrations in Japan, Mexico, China and Portugal. This suggests that plastics in the North Atlantic and Labrador Sea region have moderate levels of associated contaminants as compared to other regions that have been examined for PCB-plastic associations."[84] The study did not find that a higher plastic ingestion load resulted in higher PCB concentrations in the bird's liver.

Park et al. (2016) fed different types of plastics to Atlantic Cod and sea urchins, and found that "all of the cod appeared in good health for the duration of the experiment, and there was no sign of intact plastic being passed at any time."[85] The same pattern occurred with sea urchins.[86] For cod larvae exposed to different types of plastics, they found that when exposed to low density polyethene garbage bags, the larvae produced an enzyme that indicated the fish had been exposed to toxins. When exposed to a polyvinyl chloride shower curtain, the fish died. For various "eco-plastics" the larvae did not show an enzyme response.[87]

IS IT GETTING BETTER OR WORSE?

Plastic pollution is assumed to increase on par with plastic production, which is increasing. Based on studies that share similar methods on the same species that span several decades and cover before and after major historical events in the province, we have found something more complex:

- Whale entanglements in fishing gear have decreased 65% since the cod moratorium in 1992.
- Whale entanglements since 1992 have shifted from nearshore to offshore, and from gill nets to pots.
- For all gear combined, the average mortality of Humpback whales did not change substantially following the 1992 cod moratorium, whereas for Minke whales it did.
- The number of gannet nests with gillnets has decreased since the cod fisheries moratorium, directly in proportion to the number of gillnets set around breeding colonies
- For nearly all species, figures for the ingestion of plastics after the moratorium is higher (25.9%) compared to before the moratorium (10.32%). While thick-billed murres decreased or stayed the same, all other species increased.
- Plastic ingestion by Herring gulls has increased by 450% from the 1960s to 2010s.
- Plastic ingestion by Leach's storm petrels has increased by 940% from the 1980s to the 2010s.
- Plastic ingestion by Thick-billed murres decreased by 79% between 1980s and 1990s, and more recent studies do not have large enough sample sizes to detect the changes reported.
- The average number of plastics ingested by some species is increasing in addition to an increase in the frequency of ingestion.
- The density of marine plastics in surface water is increasing.

These trends indicate industrial gillnet plastic pollution decreased after the cod moratorium, but other forms of plastic pollution are increasing. This can be due to more and different types of plastics entering the environment, as well as older plastics fragmenting into smaller sizes (microplastics).

Entanglement

The most robust long-term dataset on the impacts of plastic pollution in Newfoundland and Labrador is whale entanglement data. A data-rich, comprehensive report by Benjamin et al. (2011) finds:

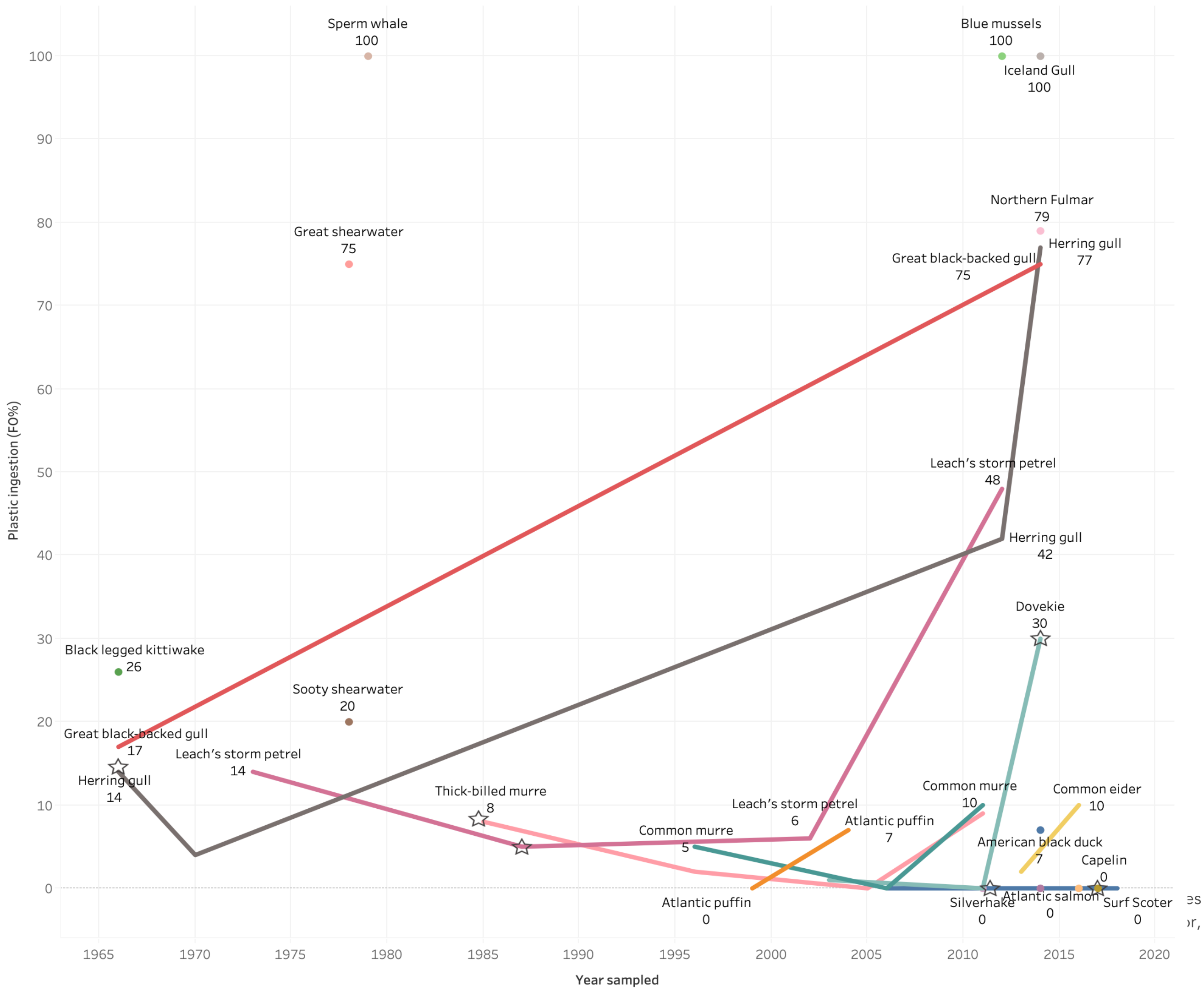
> "Reports of large whale entanglements in inshore Newfoundland and Labrador waters have clearly declined significantly following the 1992 Atlantic cod moratorium, with total reported entanglement rates down by approximately 65% from 1979–1992 to 1993–2008. This has probably been driven by significant changes in the fishing industry since the early 1990s, including (1) a reduction in overall fishing effort, particularly in inshore waters, accompanied by a concurrent shift of effort into offshore areas; (2) the disappearance of formerly widespread fishing gear implicated in many entanglements, including cod traps and salmon gill nets; and (3) a reduction of the total amount of fishing gear in the water per license, through area closures, license restrictions and shorter fishing seasons. However, the spatial distribution of entanglements also appears to have changed, with more entanglements now being reported from offshore waters. Pots, especially those used to target snow crab, have emerged as a new and potentially significant source of large whale entanglements. Because the snow crab fishery is prosecuted over such a large area, and monitoring effort is limited, the number of entanglements involving snow crab pots reported here is likely negatively biased. However, offshore reporting coverage is presently insufficient to confirm a genuine offshore shift in entanglement risk."[88]

In terms of effect, Benjamins et al. (2011) found that for all gear combined, the average mortality of Humpback whales did not change substantially following the 1992 cod moratorium, whereas for Minke whales it did.[89] The Benjamins et al. report is comprehensive, with one of the largest temporal datasets on whale entanglements in the world, and represents a state of knowledge of this type of impact from fisheries plastics, including types of gears, species affected, and mortality figures over time.

Ingestion

Overall, animals have ingested more plastic since the cod moratorium in 1992. The standard measure for describing plastic ingestion is the frequency of occurrence (FO%), which refers to the number of individuals within a sampled population that have ingested plastics, regardless of how many plastics they ingested. If one bird of 100 ingested plastic, for example, the FO% is 1%.

Figure 22: Plastic ingestion by species over time



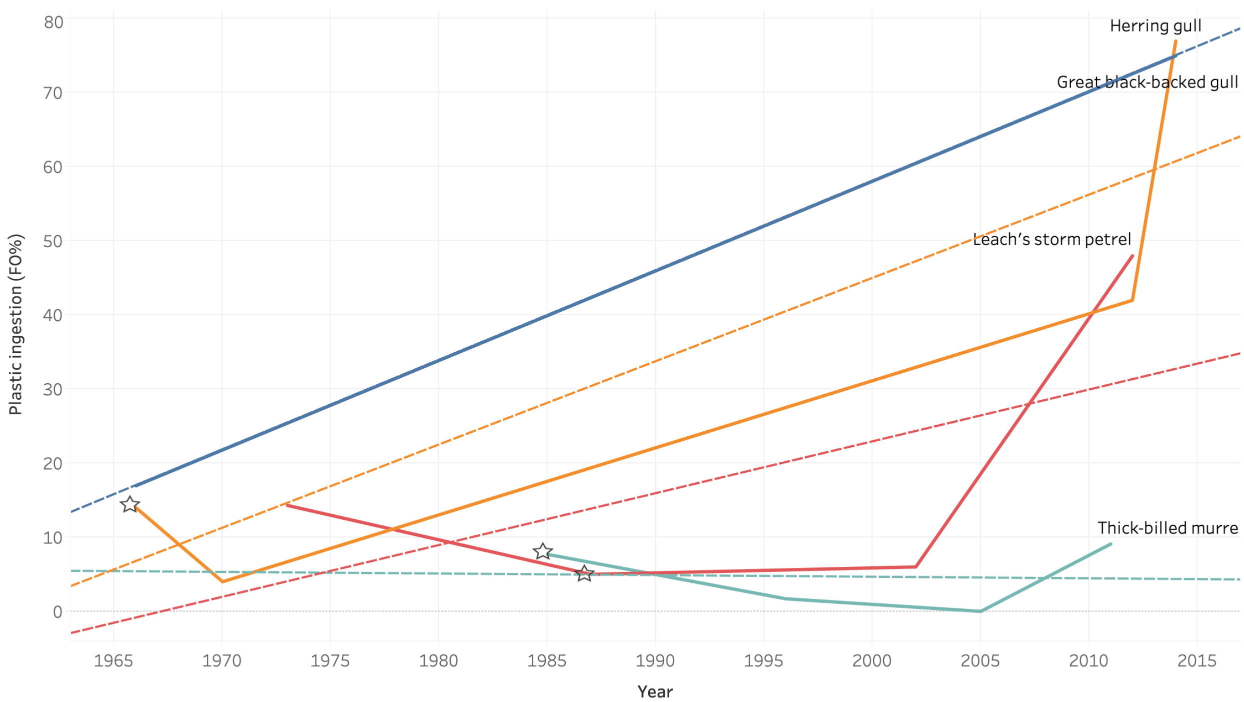
Several recent ingestion studies replicated earlier studies conducted before the cod moratorium to investigate temporal trends. Bond et al. (2013) looked at Common and Thick-billed murres (*Uria aalge* and *U. lomvia*) and found: "Approximately 7% of murres had ingested plastic, with no significant change in the frequency of ingestion among species or periods. The number of pieces of plastic/bird, and mass of plastic/bird were highest in the 1980s, lowest in the late 1990s, and intermediate in contemporary samples."[90] On average, about 7% of sampled murre populations had ingested plastics regardless of species or time.

Bond and Lavers (2013) replicated an earlier study from the 1970s[91] on Leach's storm petrels (*Oceanodroma leucorhoa*) at Gull Island and "found an increase in the proportion of birds and number of particles ingested at Gull Island between 1962 and 2012 from 14.3% to 47.6%, and from 0.3 to 1.9 pieces/individual at the population level."[92]

A third study by Bond et al. (2016) on three species of gulls compared results to an earlier study from the 1970s[93] and found an "order of magnitude increase in the proportion of garbage [ingested], from 4% in 1970-1971 to 42% in 2012. The general perception that improved land-based waste management practices have reduced the amount of garbage available to gulls does not seem to be applicable here."[94] They attribute this sharp increase in ingestion to an increasing amount of available plastics, though they do not break out plastics as a specific category of garbage in the study.

We calculated whether there was an increase or decrease in ingestion figures for species that have at least one sampling survey before and after the moratorium. These include Thick-billed murre, Herring gull, Leach's storm petrel and Great black-backed gull. The studies include those discussed above. We evaluated whether there was a statistically significant increase, decrease, or no trend across ingestion studies of the same species (Method 10).
Across studies, there is a statistically significant increase in plastic ingestion post-moratorium (average FO 26%), compared to pre-moratorium (average FO 10%) (Method 10). Though Thick-billed murres had a decrease in

Figure 23: Plastic ingestion in four species before and after the cod moratorium of 1992



Comparison of the percentage of individuals in a sampled population had ingested plastics (frequency of occurrence, or FO%) for four species sampled before and after the cod moratorium of 1992. Herring gulls are blue; Great black-backed gulls are orange, Leach's storm petrels are red; and Thick-billed murres are teal. Dotted lines show trends for each species. Baselines against which future trends can be reliably measured are marked with stars and exist for three of the four species before the cod moratorium: Herring gull, Leach's storm petrel, and Thick-billed murre. Overall, there is a statistically significant increase across all four species, with an average FO of 10.3% before 1992 and 25.9% after 1992.

plastic ingestion figures, the overall species-wide trend is an increase in the number of individuals in a population that are ingesting plastics.

The most robust determination of changes in plastic ingestion within a species over time is to compare baseline figures to figures in subsequent studies when sample sizes are large enough to detect the magnitude of change reported (Method 12). There are only three species for which this is possible: Herring gull, Leach's storm petrel, and Thick-billed murre. For Herring gulls, while there was a decrease in ingestion figures from the 1960s to 1970s, there has been a discernable increasing trend from studies conducted in 2012 and 2014-2015 showing a 450% increase in plastic ingestion between the 1960s and 2010s. Leach's storm petrels' plastic ingestion has increased from the 1980s to the 2010s by 940%. Thick-billed murres' ingestion figures decreased by 79% between the 1980s and 1990s, but more recent studies do not have large enough sample sizes to detect the changes reported.

Surface water plastics

A study in the western North Atlantic Ocean and Caribbean Sea (around the North Atlantic Subtropical Gyre) of over 6,100 surface water tows from 1986 to 2008 found an average range of 0-5,000 plastic pieces per km^2 in the region around the southern shores of Newfoundland and Labrador.[95] In the last five years, surface water trawls using comparable methods have found a range of 80-13,480 pieces of plastic/km^2 with an average of 5,208 pieces of plastic/km^2, a notable overall increase.

Plastics incorporated into nests

Scientists have found that many species of bird (especially gannets, boobies, and gulls) incorporate plastic waste into their nests. Northern gannets tend to use derelict fishing gear, which can lead to entanglement.[96] Bond et al. (2012) replicated a study on gannet nests from 1989[97] to observe trends across three gannet colonies. After examining 741 gannet nests in 1989 and 1080 nests in 2007, they found "The proportion of nests with marine debris decreased following the fishery closure, and the proportion of nests with fishing gear was related exponentially to the number of gillnets set around breeding colonies."[98] All locations in both years found some nests that incorporated plastic waste, both fishing gear and other types of plastic debris. These findings align with entanglement data, as both types of study focus on macroplastic fishing gear.

Figure 24: Northern gannet sitting on a nest that has incorporated fishing gear into it. PHOTO: © Nina O'Hanlon, University of the Highlands and Islands

Seasonal trends

While there are no seasonal studies on plastic pollution in Newfoundland and Labrador, McWilliams et al. (2017) collected shoreline plastics on Fogo Island (Barr'd Islands area) every second day from July 22, 2015 to August 28, 2015 and found

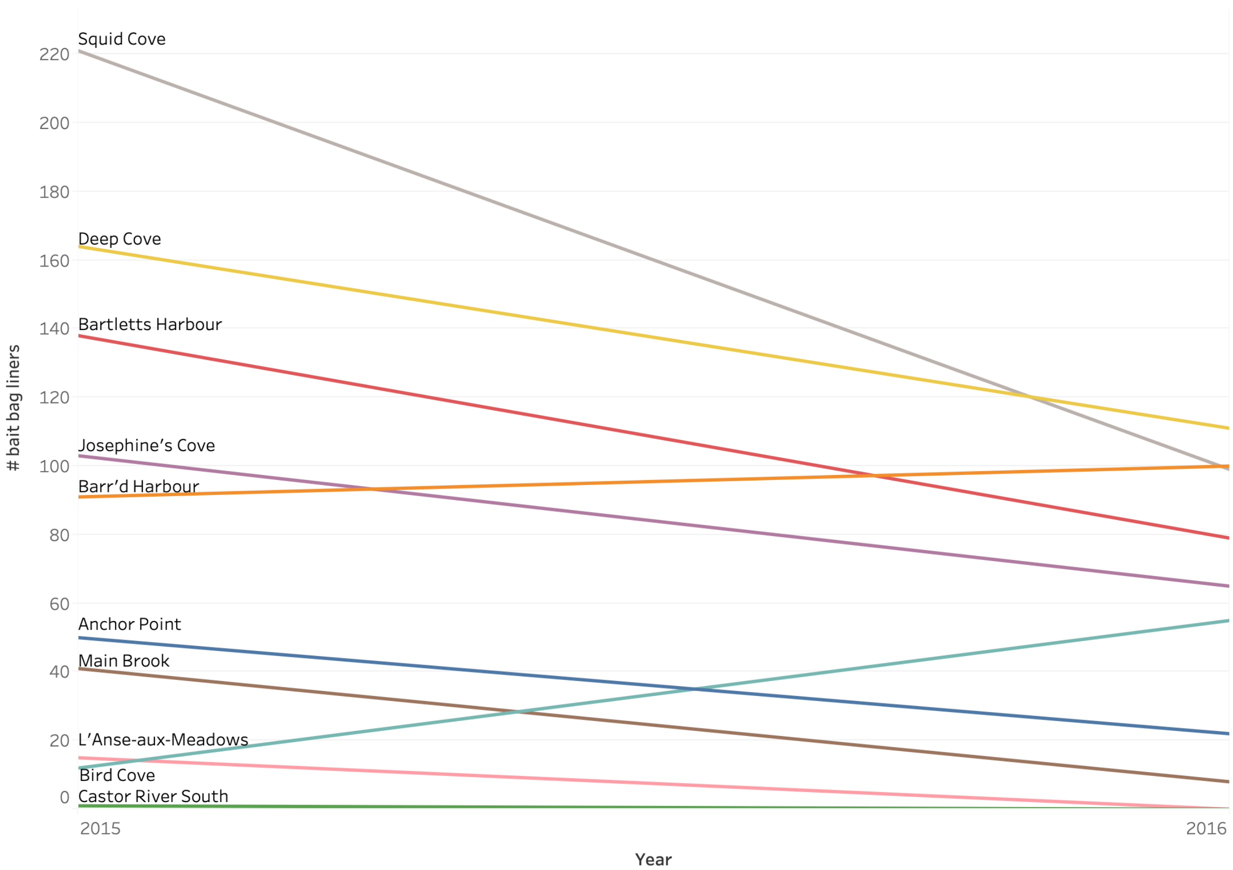
> "only temperature was significant with a significantly higher total and average volume of items when weather was colder. This is counter to our expectation that days with high wind, especially wind from the north, would yield more debris. It is possible that some of the debris we found is landward in origin. We are unable to think of a reason why temperature would be correlated, and we feel this is a spurious correlation that is not linked to any causality."[99]

Seasonal trends require more study. Almost all data collected to date has occurred during spring, summer, and fall, and there are not enough data to do a cross-study analysis of seasonal trends at this time. However, the Placentia Bay Ocean Debris Survey (PODS) and Civic Laboratory for Environmental Action Research, both based at Memorial University, are conducting studies that will provide more information on seasonal variation in plastic pollution in these areas. Due to Newfoundland and Labrador's highly variable weather patterns, longitudinal studies that sample every day/week/month while tracking weather will be necessary for data attempting to ascertain seasonal correlation.

Material snapshot: bait bag liners

In 2015 and 2016, Intervale with the Quebec-Labrador Foundation collected bait bag liners on ten shorelines on the west coast of Newfoundland island. In all cases but two, the number of bait bags decreased. We cannot discern if this temporal trend extends beyond 2016. This data highlights the importance of long-term monitoring of specific plastic pollution items to determine if changes in behaviour, policy, or infrastructure are impacting shoreline marine debris.

Figure 25: Number of Bait Bag Liners recovered at shoreline cleanups in 2015 & 2016



Comparison of the number of bait bags recovered in beach clean ups by Intervale/Quebec-Labrador Foundation on the northern peninsula of the island of Newfoundland in 2015 and 2016. There is a consistent negative (decreasing) trend with the exception of Bird Cove and Barr'd Harbour. This data is based on count, rather than density.

WHAT ARE NEXT STEPS AND RECOMMENDATIONS?

Key areas for action

Key areas to target for interventions into plastic pollution mitigation in Newfoundland and Labrador given existing data include:

- fishing gear (both lost & abandoned gear as well as fragmentation of gear into microplastics);
- cigarette waste (both butts and packaging);
- litter and marine dumping (including from wharves);
- branded take-out food containers (particularly Tim Horton's and McDonald's); and
- species of import to human food webs and species at risk, as well as species that exhibit higher than average ingestion figures (Northern Fulmar, Atlantic puffins, Thick-billed murres, Dovekies and Common eider ducks) and those that exceed the EcoQO limit (Black legged kittiwake; Dovekie; Great black-backed Gull; Great shearwater; Herring gull; Iceland gull; Leach's storm petrel; Sooty shearwater; Northern fulmar).

Future studies

- It will be imperative to create a provincial-scale plastic monitoring program to avoid the shortfalls of opportunistically collected data that currently characterizes our state of knowledge. An existing study by Melvin (2017) outlines what a provincial plastic ingestion monitoring program could look like.[100]
- Municipal, research, and citizen groups should use the Marine Debris Tracker app or the Great Canadian Shoreline Cleanup template to record beach cleanup data, thereby adding to a publicly accessible dataset that is comparable across sites.
- Create smaller scale, high resolution analyses at the size of bays or similar with existing and new data to identify local sources of plastic pollution and time trends where possible.
- Brand audits should become a regular part of plastic pollution research.
- Evaluate interventions on plastic accumulation and effects in the environment, including the efficacy of the provincial plastic bag ban, CPAWS' Ship to Shore program, and similar initiatives.
- Create studies on burned and melted plastics (sources and toxicology) and lost and abandoned fishing gear are warranted given the lack of knowledge on these issues in the province.
- We have calculated the sample sizes for future plastic ingestion studies using a power analysis (Method 11, Table M11.1 &2). This analysis tells us whether we have enough data to detect a difference or a genuine trend given how variable the data are.

While continued monitoring of existing areas is important to detect changes in plastic pollution over time, there are many gaps in our knowledge. These include:

- Locations of studies. We have scant data in Labrador, on freshwater environments, and within urban sites. Existing data is geographically patchy.
- Environmental media. Sediment and surface water studies are scarce in the province. Entanglement studies are also lacking, with the exception of the Whale Release and Stranding Group. There is a suite of diving surveys, but these are also limited regionally. There are no other types of benthic studies, including benthic sediments. There are no completed studies of plastics in ice, snow, or air, though some are underway (by CLEAR and the Nunatsiavut Government).

- Species. Terrestrial animals are absent from studies, and there are very few freshwater species considered. The effects on species used in aquaculture are also lacking, though studies by Fisheries and Oceans Canada exist in that area. There are no local studies of plastic pollution on crustaceans, mollusks, or plankton in the province.
- Variables that affect local waste accumulation. To date, most scientific studies report the presence of plastics, but not how different variables might affect the types and densities of plastics in an area, such as: presence of harbour authorities, aquaculture, different types of fisheries and gear, condition of bays, marine traffic, recreational activities, the presence of sewage and stormwater outfalls, etc.
- Local and social science knowledge is lacking in the literature, though informal conversations show that there is a wealth of knowledge and expertise available.
- Effects of plastic pollution. Both field and lab studies can ascertain the effects of plastic pollution, though we have almost no studies of this kind that focus on local cases or concerns. For example, the effects of plastic pollution on tourism, on the health of key food species, or on human health are absent, as are the toxicological effects of burned or melted plastics if they are ingested by biota.

Partnerships and collaborations

A table of some of the groups involved in plastic pollution research and mitigation in the province are listed in Appendix 3. Given the scale and complexity of plastic pollution, collaboration and coordination will be key to mitigating pollution in a meaningful way at an impactful scale. Indeed, the realization that Newfoundland and Labrador's plastic waste consistently ends up on foreign shores challenges a strictly local scale of action.[101] At the moment, the majority of both plastic pollution studies and interventions are uncoordinated, opportunistic, and funded for short periods of time. Thus, one of the most important recommendations we can make is to coordinate and scale up partnerships and collaborations so that efforts to understand and mitigate the issue are on par with the scale of the problem.[102]

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APPENDIX: METHODS

Method 1: Obtaining data sources

Published peer reviewed and grey literature, as well as unpublished datasets, were obtained by searching the following search engines and catalogues: Scopus, Web of Science, Pub Med, Science Direct, Web of Science, Elsevier, Research Gate, Google Scholar, Google search engine, Guelph University's Library Database, Memorial University's Library Database, Memorial University theses and dissertation archives, DFO archives online, ECC archives online. The bibliographies of collected texts were reviewed for relevant texts.

The following search strings were used to query these locations:

> Newfoundland and/or Labrador and/or Atlantic Canada
> and
> Plastic* and debris, or pollution, or ingestion, or entanglement, or monitor*, or shore*, or biomonitoring, or water, or trawl*
> or
> Lost fishing gear, or gillnets, or diving survey, or marine debris

Additionally, Memorial University librarians were contacted to locate additional resources, and unpublished data was sought from authors or contacts in texts as well as the authors of this report. CLEAR and our research partners and colleagues had a number of unpublished datasets. A draft of this report was circulated to key stakeholders, including DFO employees, key academic researchers, and Indigenous governments in Labrador. Their feedback, which included leads for additional grey literature and unpublished data sources, was also included.

We sought out the Marine Debris Tracker data from https://marinedebris.engr.uga.edu/
We contacted the Great Canadian Shoreline Cleanup organization for their dataset for the province. Reports were reviewed and data was disaggregated whenever possible so that specific findings could be linked to unique locations (and therefore mapped) or specific species if more than one species was in a report.

The final dataset of all compiled information is available at civiclaboratory.nl.

Method 2: Fish tag circulation

The data for this portion of the report has not yet been published and is part of a master's thesis. As such, a complete disclosure of methods is protected until publication. The dataset presented here is partial.

Samples of beached, plastic fishing tags were collected opportunistically by beach combers and shoreline cleanup efforts in Europe and Atlantic Canada from 2017 to 2019. This dataset consists of 186 observations. Maps here show the origin of tags based on the fishing area and the location it was collected from a shoreline. Time and place of collection were recorded. Using DFO archives, we interpreted the information printed in these tags regarding the province, fishing area and year of deployment.

Example of a plastic fish tag collected by citizen scientists for the Fish Tag Project with the code clearly displayed.

INTERPRETATION OF THE FISH TAG

In the example above, which is a common format, the markings mean:
99 = 1999. The year of issue and deployment.
DFO =Department of Fisheries and Oceans. The government department of issue.
LOB = Lobster. The fishery for which the tag is issued.
NFLD = Newfoundland. The location for where the tag is issued. Other tags often have LFA ("Lobster Fishing Area") and a number, which corresponds to a designated DFO fishing area.
899296 = a unique number that can indicate the fisher's license, trap number, etc. depending on the type of tag.

The future publication by Nadia Duman should be available in 2021 with complete methods, analysis, and datasets. A report with summary data was distributed to DFO in the spring of 2020 as per funding directives.

Method 3: Shoreline data

Shoreline data came from two comparable datasets produced by citizen science beach clean-up efforts recorded by the Marine Debris Tracker phone app (MDT) and the Great Canadian Shoreline Cleanup (GCSC).

THE MARINE DEBRIS TRACKER

Screenshots from the Marine Debris Tracker (MDT) where shoreline waste can be logged. The app geotags the information and creates a public dataset at https://marinedebris.engr.uga.edu/.

The Marine Debris Tracker (MDT) app allows citizen scientists to log individual items or groups of items they identify on the beach according to Material Description categories (Plastic, Glass, Metal, Cloth, Fishing Gear, Rubber, Paper and Lumber, and Other) and subcategories (plastic bags, straws, plastic utensils within the Plastic material, for example). This design allows the material category to be very trustworthy, as most users are able to identify the main material an item is made of, even if it is fragmented. The secondary categories are more subjective. The app automatically tags the data with latitude and longitudinal, place name, and the date. This information can be freely downloaded from their website at https://marinedebris.engr.uga.edu/. The cleaned dataset we used for this project can be downloaded at civiclaboratory.nl.

We downloaded all data for the province between January 1, 2014 and December 31, 2018. There was no data for the region prior to January 1, 2014.

Microsoft Excel was used to view and clean the data. The criteria for excluding data included: entries with no temporal or spatial (ie. lat/long or location) information; entries that occurred outside of the province; any cleanup event with fewer than 10 samples (to avoid instances of people testing the app); any clean up event with more than 25% "other" material category items (which make it inappropriate for plastic analysis as 1 in 4 items would be without a material category); any items marked "test item," which is used when learning how to use the app. Additional data clean up included reverse geocoding for areas that had a lat/long but no place name, using Google maps by inputting lat/long and using the named location. Local knowledge was also used for place names so that the common name of places was used whenever possible (e.g. "Conception Bay South" rather than "subdivision D"). We also combined the following material categories into a single Plastic Material Description category: Plastics, Rubber, Fishing Gear.

The MDT dataset includes 83 clean ups at 24 sites. For the purposes of this analysis, sites with multiple cleanups were analyzed for their total numbers and changes over time were not analyzed. After removing clean up events with 10 items or fewer, the lowest count of items in one clean up event is 27 items and the highest is 9176, with an average of 1727. This represents significant variation. The MDT does not give a density measurement—it only records the number of items collected, not the amount of space that was covered. As such, we compared sites to one another based on the percentage of material categories (and two subcategories—plastic bags and fishing gear) of the total collected waste. This means that shores with close to one thousand items cleaned up can be compared to one with 27 items cleaned up. Note that the location with 27 items is a remote location in Labrador called Black Tickle and have information about that data collection at that site that indicates it is representative (via Patricia Nash, NunatuKavut Community Council).

This cleaned MDT dataset for Newfoundland and Labrador from 2014 to 2018 is available at civiclaboratory.nl.

THE GREAT CANADIAN SHORELINE CLEANUP

The Great Canadian Shoreline Cleanup (GCSC) is a national conservation program operated by Ocean Wise and WWF- World Wide Fund for Nature. GCSC uses paper datasheets with material categories similar to the MDT to record individual items—similar enough that we can group them into identical material master categories and accurately extract plastic bags and fishing gear, both standalone categories in the GCSC dataset. We requested GCSC's raw data from Newfoundland and Labrador. All clean ups occurred in 2018 in 24 locations that included both marine shorelines and freshwater ponds and parks. Data cleaning was identical to that used for MDT data, with the addition of the separation of terrestrial and freshwater locations so they would not be conflated with marine areas, since patterns of waste are different. In several cases, both the MDT and GCSC covered the same location, and the data were analyzed together.

Both datasets are counts, rather than density metrics; the area cleaned is unknown. As such, percentages of each Material Description and occasionally item categories (see Method 4) were used to compare sites to one another, allowing for differences between sizes of shoreline, length of time cleaning, etc. This also obfuscates the differences between loading beaches and sparsely polluted beaches. Instead, it focuses on the relative material sources of shoreline waste. To create a percentage per Material Description, the count of each Material Description category (e.g. Plastic, Metal) was divided against the total number of items in a cleanup.

Note that there is no minimum size of item in these datasets, and while there may be mostly macroplastics, it is possible that microplastics were also collected.

Method 4: Isolating fishing gear, plastic bags, and cigarette butts as percentage of total waste within shoreline data

Both the MDT and GCSC contain subcategories within their larger material categories, including fishing gear, cigarette butts, and plastic bags. Both contained individual counts that, along with other subcategories (personal care items, cigarette butts, food packaging, etc.) make up the counts for plastics, wood, and other material categories.

Raw datasets already contained unique categories for fishing gear, cigarette butts and plastic bags. These counts were compared against the *total* waste count not just the plastic material category. For example, if there were 2000 items collected overall, 1500 of which were plastic, of which 60 were fishing gear, then: 60/2000 = 0.03, or 3% of that shoreline waste was fishing gear.

Note that though “microplastics” and “small plastics/plastic fragments” are both subcategories in the datasets, we chose not to break them out because of the range of interpretations that citizen scientists could bring to those items. For instance, we noticed some citizen scientists using the small plastics subcategory for items that simply were not in another category such as plastic whistles. As such, we only use categories where identification of items is expected to be consistent and accurate.

Method 5: Diving survey study comparison

There were two multi-year diving surveys in the literature: Morris et al. (2016) and Han et al. (2019). Both use a similar design, including comparisons between wharf and non-wharf areas. While Morris et al. (2016) publish a table with findings from each site (which we reproduce in this report as table 2), Han et al. (2019) do not. However, Han et al. write that, “for a standardized average survey area of 692 m^2 per site, the average area containing debris was 114 m^2 at wharfs, 45 m^2 at non-wharfs, and 8 m^2 at low-use sites.”[1] To make these two studies comparable, we used the proportion (%) of area with waste present metrics published in Morris et al. (2016) and calculated the same for the Hans et al. (2019) by dividing the survey area (692 m^2) by the average area containing debris. This allows a comparison between the studies.

[1] Han, Victoria, Corey J. Morris, Robert S. Gregory, Daniel Porter, and Philip S. Sargent. 2019. *Incidence of Plastic and Other Marine Debris on the Seabed, Disposed in Rural Coastal Harbours.* Fisheries and Oceans Canada/ Pêches et Océans Canada: 4.

Method 6: Relationship between marine shoreline plastic data and population, tourism and fishing effort

Using a type 3 ANOVA model, we evaluated the potential relationship between (1) population density, (2) fishery activities, and (3) tourism on the spatial distribution of (i) plastic, (iii) fishing gear, (iv) plastic bags, and (v) microplastics from the Marine Debris Tracker App (MDT) from January 1st, 2014 to December 31st, 2018.

Note that St. John's is not part of this analysis because the shoreline categories are too different, since one clean-up is on land, one is by an urban freshwater lake, and one is by a roadway.

The variables under study are:

(1) Plastic
(2) Plastic Fishing gear
(3) Plastic bags
(4) Microplastics

All of these variables are tracked as stand-alone categories in the MDT app. The variables were standardized for comparison purposes into "effort," defined as the number of items/time of clean up. This is as close to a density calculation as the data allows. Our assumption is that the search effort (in minutes) is consistent across beaches and individuals.

The exploratory variables under study are:

(1) Population density – a metric of how many people live in the area, i.e. population data per town. We gathered population data from the 2016 Canadian survey from the community nearest to the beach. The survey's data corresponds to communities one to one, meaning that the population of Petty Harbour was used for the beaches in Petty Harbour, for example.
(2) Fishery activities – a metric of the amount of fishing gear used in an area = Number of gear used per NAFO sub-division. Data from DFO (statistics division, NL).
(3) Tourism – a metric of the importance of tourism in the area = Number of rented rooms in the economic zone where the beach is located from NL tourism.

A variance inflation factor (VIF) was calculated between variables, and was < than 5 (2.07, 2.07 and 1.01 for Tourism, Population, and Fishery, respectively), hence no collinearity was expected.

The tested model was: Y~ Population + Tourism + Fishing Gear
The response was sometimes log-transformed to meet the assumptions of normality, homogeneity and independence.
A type 3 ANOVA was calculated to account for the unbalanced design.

```
#Plastics
summary(Plastic)

Call:
lm(formula = log(Effort.Plastic) ~ Tourism + Population + Fishery,
   data = MDT)

Residuals:
    Min      1Q  Median      3Q     Max
-3.1696 -0.4242  0.0671  0.6641  2.1799

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.235e+00  2.236e-01   5.521 1.14e-06 ***
```

```
Tourism     -1.242e-06  1.205e-06  -1.030    0.308
Population   1.792e-05  4.106e-05   0.437    0.664
Fishery      6.182e-07  7.554e-07   0.818    0.417
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.027 on 51 degrees of freedom
Multiple R-squared:  0.03796,	Adjusted R-squared:  -0.01863
F-statistic: 0.6708 on 3 and 51 DF,  p-value: 0.5739

#Fisheries Plastics

summary(fisheries)

Call:
lm(formula = log(Effort.Fishing + 1e-04) ~ Tourism + Population +
    Fishery, data = MDT)

Residuals:
    Min      1Q  Median      3Q     Max
-8.8571 -1.1505  0.8797  1.6497  3.0453

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.118e-01  4.856e-01  -0.230   0.8188
Tourism     -6.959e-06  2.618e-06  -2.659   0.0105 *
Population   7.568e-05  8.917e-05   0.849   0.4000
Fishery      1.797e-06  1.640e-06   1.095   0.2786
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.231 on 51 degrees of freedom
Multiple R-squared:  0.176,	Adjusted R-squared:  0.1275
F-statistic:  3.63 on 3 and 51 DF,  p-value: 0.01887

                Microplastics

summary(microplastic)

Call:
lm(formula = log(Effort.Microplastic + 1e-04) ~ Tourism + Population +
    Fishery, data = MDT)

Residuals:
    Min      1Q  Median      3Q     Max
-9.1451 -0.0048  0.5172  1.1937  3.5856

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.294e-01  5.722e-01  -0.576    0.567
Tourism     -6.111e-06  3.085e-06  -1.981    0.053 .
Population   1.648e-04  1.051e-04   1.569    0.123
Fishery      1.830e-06  1.933e-06   0.947    0.348
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.629 on 51 degrees of freedom
Multiple R-squared:  0.09191,	Adjusted R-squared:  0.0385
F-statistic: 1.721 on 3 and 51 DF,  p-value: 0.1744

#Plastics bags

summary(bag)

Call:
lm(formula = log(Effort.Bag + 1e-04) ~ Tourism + Population +
    Fishery, data = MDT)
```

```
Residuals:
    Min      1Q  Median      3Q     Max
-5.1271 -3.2254  0.8054  2.3635  5.0695

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.301e+00  7.190e-01  -5.981  2.2e-07 ***
Tourism     -3.599e-06  3.876e-06  -0.929    0.357
Population   9.362e-05  1.320e-04   0.709    0.482
Fishery      2.814e-07  2.429e-06   0.116    0.908
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.303 on 51 degrees of freedom
Multiple R-squared:  0.01732,	Adjusted R-squared:  -0.04049
F-statistic: 0.2996 on 3 and 51 DF,  p-value: 0.8255
```

Interpretation

Based on the results, it appears that Tourism activities significantly impact fishing gear plastics. The impact is negative (slope is negative), meaning that increasing tourism activities, decrease fishing gear's presence. The correlation might be driven by a few extreme values. Also, other variables not tested might be creating this trend (such as beach clean ups, the direction the beach is facing relative to normal winds, etc.).

Tourism activities also impact microplastic, but not significantly (p-value = 0.053). The trends are similar to fishing gear plastics (negative slope).

Due to issues with what citizen scientists might count as "microplastics" in the app, we did not include this as a category in the final interpretation, though it is left in the data analysis here.

It is important to note:

- The variance in Tourism, Population, Fishing Gear and the different effort of plastic are not really consistent and wide – i.e. most of the values are tightly grouped, with a few extreme values (e.g. Large population in St John's and small population anywhere else, with almost no middle range). This is not a limitation of the data—it is how Newfoundland and Labrador population and tourism trends exist.
- Two of our explanatory variables (tourism and fishing gear) are very coarse (e.g. NAFO Sub-Unit encapsulate many communities that were surveyed) and this coarseness could have failed to explain more fine-grained variance at specific and different shorelines.
- The plastics dataset has large amounts of data from a few areas that were surveyed heavily (e.g. Arnold's Cove, Avalon peninsula generally) and it does not provide a lot of variation in our explanatory variable (all in the same population bracket, same subunit and same economic zone). It would be interesting to have a geographically broader survey in future years to fill in the gaps and increase the explanatory power (e.g. more in Labrador or Northern Peninsula.)

These limitations should be kept in mind when interpreting results.

Method 7: MMSB study

This text is taken directly from MMSB's *Newfoundland and Labrador Provincial Litter Audit* (2016) and has been simplified to meet the needs of readers of this report. For full methodological details see the original report.

> 20 sites were chosen to be surveyed in 11 communities across the province, with 11 additional sites along the TransCanada Highway (TCH) to assess highway litter. Sample communities distributed along the TCH and TLH with populations greater than 4,000 were chosen to reflect littering practices throughout the province.[2]
> Sites were 200 x 200 feet, starting 1.5 feet from the road. Large litter was assessed by surveyors throughout the entire survey area and was defined as all litter larger than 1 inch^2. It was broken into 13 major categories and 57 sub-categories, while also being defined as a function of material type and brand when clearly visible. Small litter was defined as anything smaller than 1 inch^2 and was separated into 14 categories based on material type. All material categories map on to both MDT and GCSC categories.[3]

The MMSB data provides density measures, as their study uses regularly sized sample grids. The MDT and GCSC data only records counts of items in an unknown sized area so data from that source is presented here as types of waste that are percentages of total waste, not the amount of waste in an area or waste items per unit of space. The MMSB data is turned into percentages of total waste when compared to MDT and GCSC data.

The MMSB study does not use statistics to determine when differences are statistically significant. For example, the claim that commercial sites have more cigarette butts than public sites is based on a higher count, not statistical significance.

Method 8: Count of items on shorelines

Datasets were those used in Method 3 above. Rather than using percentages of Material Descriptions, raw count data was used. Note that counts do not reflect the number of cleanups that occurred at one location. One location could have several cleanups over several years, or a single clean up. Moreover, it does not account for geographies of cleanup sites. The data for Ferryland, for example, looks like it could be for a loading beach, but the geotagged data show that the cleanups occurred over a very long strip of shoreline.

See Appendix 4 for detailed maps of geotagged counts of items on specific shorelines.

Method 9: Comparison of ingestion figures within species, over time

We calculated whether there was an increase or decrease in ingestion rates for species that have at least one sampling survey before and after the moratorium (n= number of datasets). These include Thick-billed murre (n=6), Herring gull (n=4), Leach's storm petrel (n=4) and Great black-backed gull (n=2). The studies include those already discussed above. We used binomial generalized mixed models with the frequency of occurrence (%FO) and the sample size of species to evaluate whether there was a statistically significant increase, decrease, or no trend across ingestion studies of the same

[2] MMSB, 2016: 7.
[3] MMSB, 2016: 8.

species. The model included Year (indicated by PP, as a pre-/post-moratorium variable), species, and the interaction between them.

Results

Frequency of ingestion occurrence in function of pre-/post-moratorium

```
> model.ingestion<-glm(FO.100 ~ PP, family=binomial, weights=Sample, data=Ingest.bino)
> summary(model.ingestion)

Call:
glm(formula = FO.100 ~ PP, family = binomial, data = Ingest.bino,
    weights = Sample)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-10.2350   -2.6610   -0.5282    3.5860    8.2090

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.34144    0.07856  -17.07   <2e-16 ***
PPPre       -1.17510    0.10612  -11.07   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 462.52  on 15  degrees of freedom
Residual deviance: 344.30  on 14  degrees of freedom
AIC: 405.86

Number of Fisher Scoring iterations: 5

> anova(model.ingestion, test="Chisq")
Analysis of Deviance Table

Model: binomial, link: logit

Response: FO.100

Terms added sequentially (first to last)


     Df Deviance Resid. Df Resid. Dev  Pr(>Chi)
NULL                    15     462.52
PP    1   118.23        14     344.30 < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Frequency of ingestion occurrence in function of pre-/post-moratorium and species

```
> model.ingestion<-glm(FO.100 ~ PP*Name, family=binomial, weights=Sample, data=Ingest.bino)

> anova(model.ingestion, test="Chisq")
Analysis of Deviance Table

Model: binomial, link: logit

Response: FO.100

Terms added sequentially (first to last)

        Df Deviance Resid. Df Resid. Dev  Pr(>Chi)
NULL                       15     462.52
PP       1   118.23        14     344.30 < 2.2e-16 ***
Name     3   122.31        11     221.99 < 2.2e-16 ***
```

```
PP:Name  3   119.47        8     102.52 < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Interpretation

The analyses demonstrate that there is a significant effect of species and pre-/post-moratorium in explaining the variance in plastic ingestion.

The model that includes the interaction between year and species shows a significant difference between the interaction term, meaning that species did not react similarly pre- and post-moratorium – i.e. Thick-billed murres had a decrease in plastic ingestion, while the other species had an increase.

When looking at year alone (without considering species), we can observe a significant effect of year (pre-/post-moratorium) in explaining the variation in plastic ingestion. Hence, as a general effect, there was an increase in plastic ingestion post-moratorium (mean=25.88%), compared to pre-moratorium (mean=10.32%).

The total number of studies included is 16: 6 pre-moratorium and 10 post-moratorium. This is not a large sample size, especially when separated by species, but it does show a trend. This type of analysis will become more robust with an increase in studies on species that were also studied for plastic ingestion before the cod moratorium. Note that for many (though not all) of these studies, differences in methods can impact findings. Future studies that seek to evaluate ingestion trends over time should take care to replicate methods as exactly as possible.

We compared rates within species over time rather than across all species over time because ingestion figures are highly species-dependent; some species do not ingest plastics at all (such as silver hake) while other species are known to ingest plastics ubiquitously (such as mussels). A temporal analysis that blends all species is more likely to reveal more about which species are studied over time than trends in ingestion over time.

Method 10: Power analysis for sample sizes in future studies

A power analysis calculates the statistical power of a comparison, and is based on sample size, and variability. It tells us whether we have enough data to detect a difference or a genuine trend given how variable the data are.

Here, we are interested in whether repeated sampling of the same species or site was sufficient to detect a change in plastics over time, and if so, how big or small a change can we detect reliably. In this analysis, each study is weighted equally as a single point in time. We then calculated the mean, standard deviation, and coefficient of variation (CV = SD/mean) for each species. The higher the CV, the more variable the data are, and the more samples that are needed to detect a given trend. This variability can come from several sources, such as natural variability in the environment or as the result of different sampling methods. If we assume that a species or site will be sampled using different methods in the future, and that this will therefore increase the variability, then we can include studies that used different approaches in our calculation (e.g., Leach’s Storm-petrels that regurgitated spontaneously or when given an emetic), even though the proportions themselves may not be directly comparable. This is crucial for a regional study over time where consistently in methods is unobtainable.

Methods

We must first define two parameters for our analysis: the reliability (**α**; probability of a false positive), and the discriminating power (**β**; probability of a false negative). Based on the OSPAR EcoQO study of Northern Fulmars in the North Sea (van Franeker & Meijboom 2002), we set **α** = 0.05 (i.e., a 95% probability that any trends over time are real), and **β** = 0.90 (i.e., a 90% probability that we detect any real trends that are present). These values have been used in other studies to estimate statistical power.[4]

For 15 species (3 fish and 12 birds), there was >1 data point, which meant we could calculate the mean and CV (Table M11.1). Of these, two fish (capelin, silver hake) and two birds (surf scoter, razorbill) had no plastic detected in any study, so we could not calculate a CV; these species will be addressed later. For the remaining 11 species, we calculated the sample size needed per sampling event to detect changes ranging from 5-100% in 5% increments. It is important to note that these relative percent changes (i.e., changing from 5% to 10% is a 100% increase), not changes in the absolute percentage of birds ingesting plastic. Data for great and sooty shearwater were supplemented by previously published studies from the non-breeding grounds in the North Atlantic Ocean, which is the same population as occurs off Newfoundland and Labrador and was reviewed by Bond et al. (2014).[5]
We also repeated this analysis using data only from 1992-present, as the amount of plastics in the ocean changed markedly following the groundfish moratorium and could therefore reduce the variability among sampling events.

Results

In general, the variability in plastic ingestion was high relative to the mean value, resulting in high CVs (several > 1), which means a large sample is required to detect smaller changes (Table M11.1). For example, to detect a 5% change in plastic ingestion by common murres (e.g., from 10-15%) would require >20,000 individuals, which is not practical.

For species where the rate of ingestion is low (such as both murre species), then a larger percent change (e.g., 100%, or a doubling) is more relevant than for highly-impacted species, like Great shearwaters, where a 20% change (e.g., from 60% to 72%) is more useful when monitoring trends.

Species & CV	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Atlantic Puffin (1.414)	18,541	5,087	2,471	1,514	1,051	789	625	515	437	378	334	299	271	248	229	213	199	187	177	168
Cod (0.958)	8,512	2,335	1,134	695	483	362	287	236	200	174	153	137	124	114	105	98	91	86	81	77
Common Eider (0.949)	8,345	2,290	1,112	681	473	355	282	232	196	170	150	135	122	112	103	96	90	84	80	76
Common Murre (1.494)	20,690	5,677	2,758	1,689	1,173	881	698	575	487	422	373	334	302	277	255	238	222	209	198	188
Dovekie (1.237)	14,188	3,893	1,891	1,158	804	604	479	394	334	290	256	229	207	190	175	163	152	143	136	129
Great Black-backed Gull (0.893)	7,386	2,026	984	603	419	314	249	205	174	151	133	119	108	99	91	85	79	75	71	67
Great Shearwater (0.517)	2,476	679	330	202	140	105	84	69	58	51	45	40	36	33	31	28	27	25	24	22
Herring Gull (0.955)	8,463	2,322	1,128	691	480	360	286	235	199	173	152	136	124	113	104	97	91	86	81	77
Leach's Storm-petrel (1.103)	11,284	3,096	1,504	921	640	480	381	313	266	230	203	182	165	151	139	130	121	114	108	102
Sooty Shearwater (0.683)	4,327	1,187	577	353	245	184	146	120	102	88	78	70	63	58	53	50	46	44	41	39
Thick-billed Murre (1.360)	17,152	4,706	2,286	1,400	972	730	579	476	404	350	309	277	251	229	212	197	184	173	164	156

Table M11.1: Power analysis for 11 species with more than one data point that had ingested plastics showing the sample size needed per sampling event to detect changes ranging from 5-100% in 5% increments.

[4] E.g. Lavers and Bond, 2016; Provencher, Jennifer F., Alexander L. Bond, and Mark L. Mallory. 2015. "Marine Birds and Plastic Debris in Canada: A National Synthesis and a Way Forward." *Environmental Reviews* 23(1):1–13.

[5] Bond, Alexander L., Jennifer F. Provencher, Pierre-Yves Daoust, and Zoe N. Lucas. 2014. "Plastic Ingestion by Fulmars and Shearwaters at Sable Island, Nova Scotia, Canada." *Marine Pollution Bulletin* 87(1):68–75.

Species with no plastic recorded

Four of the 15 species that had multiple studies had consistently recorded no ingested plastics - capelin, silver hake, surf scoter, and razorbill. In some cases (e.g., razorbill), the two studies had a very low sample size (2 and 8 individuals), which suggests inadequate sampling. If we assume that the rate of ingested plastics would be similar to common or thick-billed murres (i.e., <10%), then the fact that no plastics were detected in these two studies is not surprising. The same can be said of surf scoter (n = 3 and 38), where if an ingestion rate of 10-15% is expected based on data from common eider, these are not large enough sample sizes to detect plastics if they were indeed present.

For silver hake, and particularly capelin, sample sizes are large (>100), so we can be reasonably confident that had plastics been present, they would have been detected, even at low frequencies. For these species, regular monitoring of 50-100 individuals per sampling unit would be needed to detect plastics at such a low frequency.

Using data from after 1992, results for dovekie, common murre, Atlantic puffin, common eider, and cod were unchanged. The required sample sizes decreased for herring gull, Leach's storm-petrel (marginally), and great shearwater, and increased for thick-billed murre (Table M11.2). Analyses for sooty shearwater and great black-backed gull were no longer possible as only 1 study occurred after 1992.

Species & CV	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Great Shearwater (0.677)	4,255	1,167	567	347	241	181	144	118	100	87	77	69	62	57	53	49	46	43	41	39
Herring Gull (0.416)	1,604	440	214	131	91	68	54	45	38	33	29	26	23	21	20	18	17	16	15	15
Leach's Storm-petrel (1.100)	11,216	3,077	1,495	916	636	478	378	312	264	229	202	181	164	150	138	129	120	113	107	102
Thick-billed Murre (1.828)	30,983	8,501	4,129	2,529	1,756	1,319	1,045	861	729	632	558	500	453	414	383	356	333	313	296	281

Table M11.2: Power analysis for the sample sizes required to detect a 5-100% change in the rate of ingested plastics, only for species where values changed using data after 1992.

The datasets for these calculations are posted on civiclaboratory.nl.

Method 11: Plastic ingestion baselines

Baseline studies provide information against which to monitor and assess change. In the case of plastic ingestion studies, baseline studies must be conducted within a species given known differences in how species forage and hunt for food. These baselines provide a metric to measure changes in the frequency of occurrence (FO%) that individuals within a studied population ingest plastics. Ideally, baseline figures have large sample sizes and sample from the area the baseline is meant to represent (such as the scale of the province). While some studies are designed to be baseline studies, other studies can be used as baselines if they have certain characteristics.

A handful of plastic ingestion studies in the plastic pollution literature in Newfoundland and Labrador were designed as baseline studies (Liboiron et al. 2017; Liboiron et al. 2018; Liboiron et al. 2019), while others can be interpreted as baselines or multiple studies can be brought together to be used as a baseline.

The following parameters were used to determine if an existing study could be used as a baseline:

- Contained equal to or greater than 100 samples of a species
- Contained disaggregated data on those samples where a FO% could be determined

The following parameters were used when multiple study results could be aggregated to create a baseline:

- Studies used comparable methods for plastic detection
- Studies together contained equal to or greater than 100 samples of a species
- Studies contained disaggregated data on those samples where a FO% could be determined.
- Samples were collected within three years of one another.

When using multiple studies to create a baseline, frequency of occurrence across studies was then calculated using the total sample size divided by the total number of individuals that had ingested plastics.

In all cases, the earliest instance of this data is used as the baseline.

A table detailing studies used in this calculation is in Appendix 2.

Method 12: Changes in plastic ingestion over time, using baselines and power analysis

Determining whether a change has occurred in a species' plastic ingestion depends on the sample size as well as how often that species usually ingests plastic. A power analysis tells us whether we have enough data to detect a difference or a genuine trend given how variable the data are (Method 10). We looked at species for which there is a baseline figure (Table 5, Method 11), factored in the sample sizes of subsequent studies, and whether and to what degree changes in plastic ingestion could be determined for those studies. Power analysis determines the sample size required to determine change given the variability within a dataset, and this includes variation due to methods, making it a suitable method for comparing different studies. The datasets for power analyses calculations are posted on civiclaboratory.nl.

Table M12.1: Determination of whether change in ingestion rates between studies was detectable

	Baseline		Subsequent study						
Species	Year	FO%	Year	Sample size	FO%	% Δ*	Power analysis¥	Δ detectable	Citation
Herring gull (Larus argentatus)	1966-1967	14.0%[6]	1970-1971	405	4%	71%	113	YES	Haycock and Threlfall, 1975
			2012	292	42%	200%	77	YES	Bond, 2016
			2014-2015	31	77%	450%	32	YES	Seif et al., 2017
Leach's storm petrel (*Oceanodroma leucorhoa*)	1987-1988	5.0%[7]	2002-2006	224	6%	20%	921	NO	Hedd & Montevecchi, 2006
			2012	63	48%	940%	32	YES	Bond & Lavers, 2012
Thick-billed murre (*Uria lomvia*)	1985-1986	7.7%[8]	1996-1997	310	1.7%	79%	197	YES	Bond et al., 2013
			2005	11	0%	-	-	NO	Muzaffar, unpub. data in Provencher et al. 2014
			2006	15	0%	-	-	NO	Muzaffar, 2009
			2011-2012	32	9.1%	316%	83	NO	Bond et al., 2013

* Percentage change (%Δ) equals the change in value divided by the absolute value of the original baseline, multiplied by 100.

¥ Power analysis refers to the sample size needed to detect the % of change between the baseline and the subsequent study (from Table M11.1, Method 11)

[6] Threlfall, 1968
[7] Hedd et al., 2009
[8] Bond et al., 2013

APPENDIX: SUPPLEMENTARY DATA

Appendix 1: Data sources on plastic pollution in Newfoundland and Labrador

Year of collection	Type of study	Source	Citation (short)
2007-2011	Diving survey	Published study	Morris et al., 2016
2007-2016	Diving survey	Government report	Han et al., 2019
1969	Entanglement	Published study	Perkins and Beamish, 1979
1979-1990	Entanglement	Published study	Lien, 1994
1979-2008	Entanglement	Published study	Benjamins et al., 2011
1975	Entanglement	Government report	Way, 1976
1985*	Entanglement	Published study	Mate, 1985
1989*	Entanglement	Government report	Brothers, 1989
1990*	Entanglement	Published study	Breen, 1990
1962	Ingestion	Published study	Rothstein, 1973
1978	Ingestion	Published study	Brown et al., 1981
1966-1967	Ingestion	Published study	Threlfall, 1968
1970-1971	Ingestion	Published study	Haycock and Threlfall, 1975
1979	Ingestion	Published study	Walker and Coe, 1989
1984-1986	Ingestion	Published study	Elliot et al., 1990
1985*	Ingestion	Published study	Mate, 1985
1985–2012	Ingestion	Published study	Bond et al., 2013
1987-1988	Ingestion	Published study	Hedd et al., 2009
1999	Ingestion	Unpublished data	Muzaffar, unpublished data in Provencher et al., 2014
1999-2001	Ingestion	Published study	Joyce, 2002
2002-2006	Ingestion	Published study	Hedd and Montevecchi, 2006
2003	Ingestion	Unpublished data	Robertson et al., 2006
2004-2006	Ingestion	Unpublished data	Muzaffar, unpublished data in Provencher et al., 2014
2006	Ingestion	Published study	Muzaffar, 2009
2011	Ingestion	Unpublished data	Rosing-Asvid et al., 2013
2012	Ingestion	Published study	Bond and Lavers, 2013
2012	Ingestion	Published study	Bond, 2016
2012	Ingestion	Published study	Mathalon and Hill, 2014

2013	Ingestion	Published study	Avery-Gomm et al., 2016
2013	Ingestion	Published study	Fife et al., 2015
2013-2014	Ingestion	Published study	English et al., 2015
2014-2015	Ingestion	Published study	Avery-Gomm et al., 2018
2014-2015	Ingestion	Published study	Seif et al., 2017
2015	Ingestion	Published study	Liboiron et al., 2016
2015	Ingestion	Published study	Liboiron et al., 2017
2015-2016	Ingestion	Graduate thesis	Melvin, 2017
2015-2016	Ingestion	Graduate thesis	Richárd, 2018
2015-2016	Ingestion	Published study	Liboiron et al., 2019
2016*	Ingestion	Published study	Holland et al., 2016
2020[§]	Ingestion	Published study	Saturno et al., 2020
1989	Nest incorporation	Published study	Montevecchi, 1991
2007	Nest incorporation	Published study	Bond et al., 2012
1975	Shoreline	Government report	Way, 1976
2015	Shoreline	Published study	McWilliams et al., 2018
2003-2004	Shoreline	Graduate thesis	Pink, 2004
2005	Shoreline	Government report	DFO, 2005
2014-2018	Shoreline	Unpublished data	Marine Debris Tracker
2018	Shoreline	Unpublished data	GCSC, 2018
2014-2019	Shoreline	Unpublished data	Intervale/QLF, 2020
2017-2019	Shoreline	Government report	Duman, 2020
1984	Surface water	Government report	Barney, 1984
1976-1990	Surface water	Government report	Brothers, 1992
1986-2009	Surface water	Published study	Law et al., 2010
2016	Surface water	Unpublished data	Liboiron, 2016 (report forthcoming)
2017	Surface water	Unpublished data	Liboiron, 2017 (report forthcoming)
2018	Surface water	Unpublished data	ACAP Humber Arm, 2018
2016	Terrestrial	Government report	MMSB, 2016
2019	Terrestrial	Unpublished data	MMSB, 2020 (report forthcoming)
2018	Sediment	Unpublished data	ACAP Humber Arm, 2018 (article forthcoming)

[§] This study was not published before 2019, and so is not included in the report analysis.
* Year of collection not specified in the study. Year of publication substituted.

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Appendix 2: Plastic ingestion frequencies of occurrence for animals in Newfoundland and Labrador, disaggregated by species, location, and year collected

Year[ϕ]	Env't	Location	Animal	Species	N[γ]	FO%	Citation
2014	Freshwater	St. John's	Bird	American black duck *Anas rubripes*	87	6.9	English et al., 2015
1999	Marine	Gull Island	Bird	Atlantic puffin *Fratercula arctica*	2	0	Muzaffar, unpub. Data in Provencher et al. 2014.
2004	Marine	Bay of Exploits	Bird	Atlantic puffin *Fratercula arctica*	14	7	Muzaffar, unpub. Data in Provencher et al. 2014
1966-1967	Marine	Witless Bay	Bird	Black legged kittiwake *Rissa tridactyla*	69	25.9	Threlfall, 1968
2013-2014	Marine	Northeast coast	Bird	Common eider *Somateria mollissima*	48	2.1	English et al., 2015
2016*	Marine	Little Fogo Is.	Bird	Common eider *Somateria mollissima*	29	10.3	Holland et al., 2016
2006	Marine	Gannet Islands	Bird	Common murre *Uria aalge*	15	0	Muzaffar, 2009
2006	Marine	Renews	Bird	Common murre *Uria aalge*	13	0	Muzaffar, 2009
2006	Marine	St. Mary's Bay	Bird	Common murre *Uria aalge*	15	0	Muzaffar, unpub. Data in Provencher et al. 2014
1996–1997	Marine	Northeast Coast	Bird	Common murre *Uria aalge*	60	4.8	Bond et al., 2013
2011–2012	Marine	Avalon	Bird	Common murre *Uria aalge*	11	9.7	Bond et al., 2013
2003	Marine	Cape Shore	Bird	Dovekie *Alle alle*	73	1.4	Robertson et al., 2006 (unpub.)
2011	Marine	Placentia Bay	Bird	Dovekie *Alle alle*	50	0	Rosing-Asvid et al., 2013 (unpub.)
2013	Marine	Conception Bay	Bird	Dovekie *Alle alle*	171	30.4	Avery-Gomm et al., 2016
2013	Marine	White Bay	Bird	Dovekie *Alle alle*	65	13.8	Fife et al., 2015
2014-2015	Terrestrial	St. John's	Bird	Great black-backed gull *Larus marinus*	8	75	Seif et al. 2017
1966-1967	Marine	Marystown	Bird	Great black-backed gull *Larus marinus*	32	16.96	Threlfall, 1968
1978	Marine	Placentia Bay	Bird	Great shearwater *Puffinus gravis*	20	75	Brown et al., 1981
2012	Marine	Gull Island	Bird	Herring gull *Larus argentatus*	292	42	Bond, 2016
1966-1967	Marine	Witless Bay	Bird	Herring gull *Larus argentatus*	401	14	Threlfall, 1968
1970-1971	Marine	Gull Island	Bird	Herring gull *Larus argentatus*	405	4	Haycock and Threlfall, 1975
2014-2015	Terrestrial	St. John's	Bird	Herring gull *Larus argentatus*	31	77	Seif et al. 2017
2014-2015	Terrestrial	St. John's	Bird	Iceland Gull *Larus glaucoides*	2	100	Seif et al. 2017

1962	Marine	Gull Island	Bird	Leach's storm petrel *Oceanodroma leucorhoa*	7	14.3	Rothstein, 1973
2012	Marine	Gull Island	Bird	Leach's storm petrel *Oceanodroma leucorhoa*	63	48	Bond and Lavers, 2013
1987-1988	Marine	Gull Island	Bird	Leachs storm petrel *Oceanodroma leucorhoa*	749	5	Hedd et al., 2009
2002-2006	Marine	Baccalieu Island	Bird	Leachs storm petrel *Oceanodroma leucorhoa*	224	6	Hedd and Montevecchi, 2006
2014-2015	Marine	Labrador Sea	Bird	Northern Fulmar *F. glacialis*	70	79	Avery-Gomm et al.,2018
2004	Marine	Bay of Exploits	Bird	Razorbill *Alca torda*	2	0	Muzaffar, unpub. data
2011-2012	Marine	Notre Dame Bay	Bird	Razorbill *Alca torda*	8	0	Bond, unpub. data
1978	Marine	Placentia Bay	Bird	Sooty shearwater *Ardenna grisea*	5	20	Brown et al., 1981
2006	Marine	Nain	Bird	Surf Scoter *Melanitta perspicillata*	38	0	Muzaffar, unpub. Data Provencher et al. 2014
2005	Marine	Harbour Breton	Bird	Thick-billed murre *Uria lomvia*	7	0	Muzaffar, unpub. Data Provencher et al. 2014
2005	Marine	St. Mary's Bay	Bird	Thick-billed murre *Uria lomvia*	4	0	Muzaffar, unpub. Data Provencher et al. 2014
2006	Marine	Gannet Islands	Bird	Thick-billed murre *Uria lomvia*	15	0	Muzaffar, 2009
1985–1986	Marine	Northeast Coast	Bird	Thick-billed murre *Uria lomvia*	1249	7.7	Bond et al., 2013
1996–1997	Marine	Northeast Coast	Bird	Thick-billed murre *Uria lomvia*	310	1.7	Bond et al., 2013
2011–2012	Marine	Avalon	Bird	Thick-billed murre *Uria lomvia*	32	9.1	Bond et al., 2013
2012	Marine	West Coast of Newfoundland	Bivalve	Blue mussels *Mytilus edulis*	10	100	Mathalon and Hill, 2014
2015	Marine	Avalon Peninsula	Fish	Atlantic cod *Gadus morhua*	205	2.4	Liboiron et al., 2016
2015-2016	Marine	Bauiline East	Fish	Atlantic Cod *Gadus morhua*	114	0.88	Melvin, 2017
2015-2016	Marine	Brigus South	Fish	Atlantic Cod *Gadus morhua*	35	5.71	Melvin, 2017
2015-2016	Marine	Petty Harbour	Fish	Atlantic Cod *Gadus morhua*	44	0	Melvin, 2017
2015-2016	Marine	Portugal Cove-St.Phillips	Fish	Atlantic Cod *Gadus morhua*	56	1.79	Melvin, 2017
2015-2016	Marine	Quidi Vidi	Fish	Atlantic Cod *Gadus morhua*	12	8.33	Melvin, 2017
2015-2016	Marine	Witless Bay	Fish	Atlantic Cod *Gadus morhua*	87	2.3	Melvin, 2017

2016	Freshwater	Campbellton	Fish	Atlantic salmon *Salmo salar*	69	0	Liboiron et al., 2017
2015	Marine	Bonavista Bay	Fish	Capelin *Mallotus villosus*	50	0	Liboiron et al., 2017
2015	Marine	Conception Bay	Fish	Capelin *Mallotus villosus*	50	0	Liboiron et al., 2017
2015	Marine	Lawn	Fish	Capelin *Mallotus villosus*	50	0	Liboiron et al., 2017
2015	Marine	Notre Dame Bay	Fish	Capelin *Mallotus villosus*	100	0	Liboiron et al., 2017
2015	Marine	Trinity Bay	Fish	Capelin *Mallotus villosus*	50	0	Liboiron et al., 2017
2015	Marine	White Bay	Fish	Capelin *Mallotus villosus*	50	0	Liboiron et al., 2017
2016	Marine	Burgeo Bank	Fish	Silverhake *M. bilinearis*	9	0	Liboiron et al., 2018
2016	Marine	Southern Grand Bank	Fish	Silverhake *M. bilinearis*	40	0	Liboiron et al., 2018
2016	Marine	St. Pierre Bank	Fish	Silverhake *M. bilinearis*	85	0	Liboiron et al., 2018
1979	Marine	Purgatory Bay	Whale	Sperm whale *Physeter macrocephalus*	1	100	Walker and Coe, 1989

ϕ Indicates year sample was collected

* Indicates no year for collection was given. Year of publication used instead

γ "N" is for sample size

FO% refers to the frequency of occurrence—how many individuals within the sampled population had ingested plastic. It is a measure of prevalence

Appendix 3: List of groups involved in plastic pollution initiatives and data collection that provided data or were consulted for this report

Name	Type of plastic initiative
Atlantic Health Oceans Initiative	Beach cleanup
Canadian Parks and Wilderness Society, Newfoundland and Labrador (CPAWS-NL)	Beach cleanup & Ship to shore program
Boy Scouts Canada	Beach cleanup
East coast Trail Association	Beach cleanup
Friends of Topsail Beach	Beach cleanup
Great Canadian Shoreline Cleanup	Beach cleanup
Intervale/Quebec-Labrador Foundation	Beach cleanup
Nature Conservancy of Canada - NL	Beach cleanup
Nature NL	Beach cleanup
Northeast Avalon ACAP	Beach cleanup
Petty Harbour Mini Aquarium	Beach cleanup
WWF Canada	Beach cleanup
The Town of Terranceville (with PODS)	Beach cleanup
Multi-Materials Stewardship Board (MMSB)	Beach & roadside cleanups
Conservation Corps NL	Community litter clean up
The Bee's Knees (eco-friendly store)	Community litter clean up
Civic Laboratory for Environmental Action Research (CLEAR), Memorial U	Ingestion studies, surface water, shoreline, snow, urban waterways
Nunatsiavut Government	Ingestion studies, surface water, shoreline, snow
Fisheries and Oceans Canada	Ingestion studies, impact studies
OceanQuest	Underwater surveys
Avalon Pond Cleanups	Underwater cleanups
Clean Harbours Initiative	ocean/underwater clean-ups
ACAP Humber Arm	Sediment, surface water
Placentia Bay Ocean Debris Survey (PODS), Memorial U*	Surface water, shoreline
Department of Fisheries and Oceans	Various, usually in partnership
Environment and Climate Change Canada	Various, usually in partnership

These groups are in addition to individual researchers at universities and government agencies referenced in this report. This is not an exhaustive list by any means.

Appendix 4: Detailed analysis of twinned locations for comparisons of shoreline waste (Nain & Makkovik, and Arnold's Cove & Terrenceville)

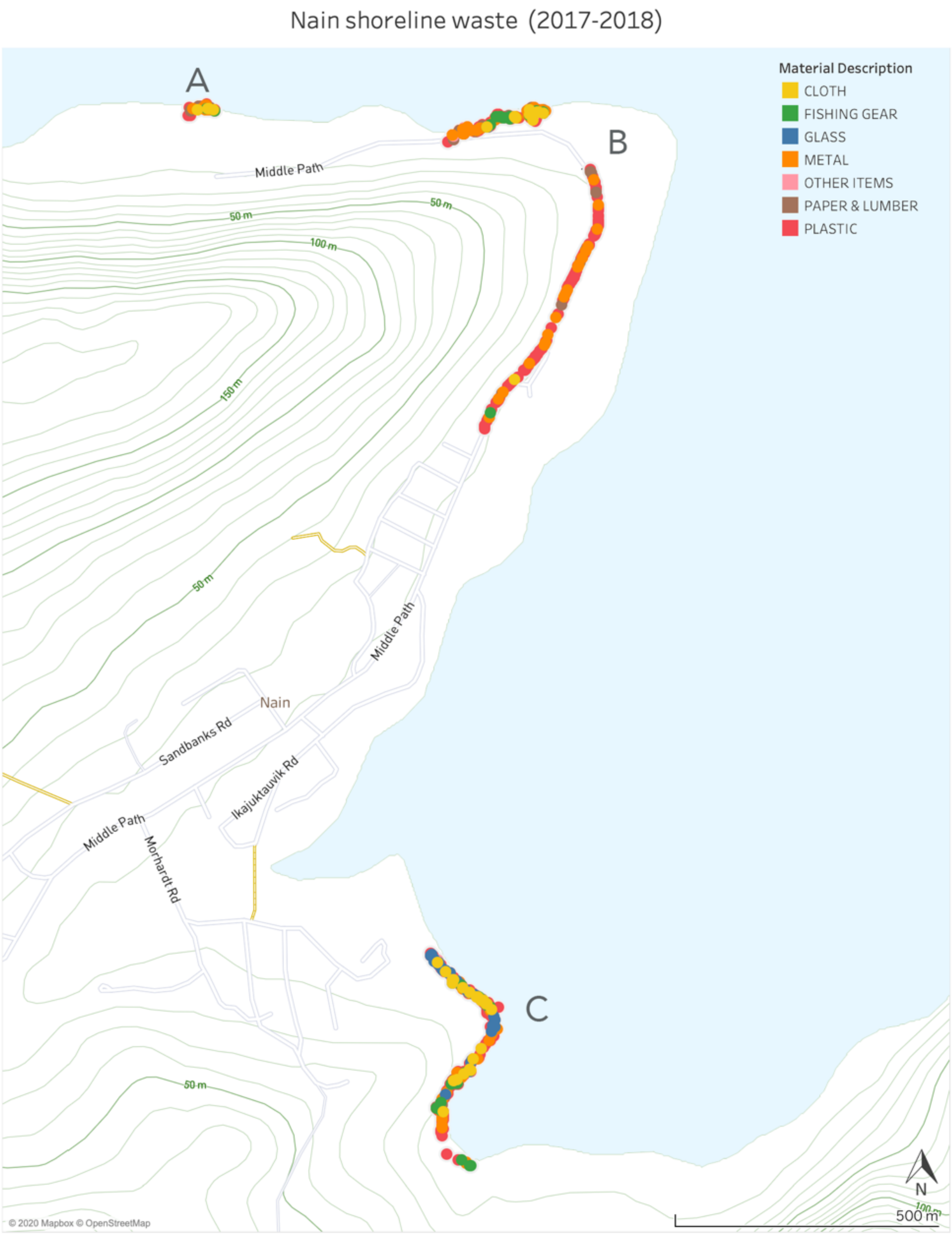
Given that sources and accumulations of plastics vary even within proximate locations, the following maps and figures are examples of the type of analyses that can be done to compare locations of interest. Here, two Inuit communities in Nunatsiavut, Nain and Makkovik, were compared because of their shared jurisdiction under the Nunatsiavut Government and because both are relatively remote locations in Labrador bordered by the Labrador Sea. Terrenceville and Arnold's Cove are compared because of their proximity in Placentia Bay and because both are outlier loading beaches that accumulate more waste than their neighbouring shorelines (see Figure 9).

Data for these types of analyses are publicly available via the Marine Debris Tracker app (https://marinedebris.engr.uga.edu/). The cleaned dataset for this analysis, which also includes all sites in Newfoundland and Labrador that use the Marine Debris Tracker app until 2019, are at civiclaboratory.nl.

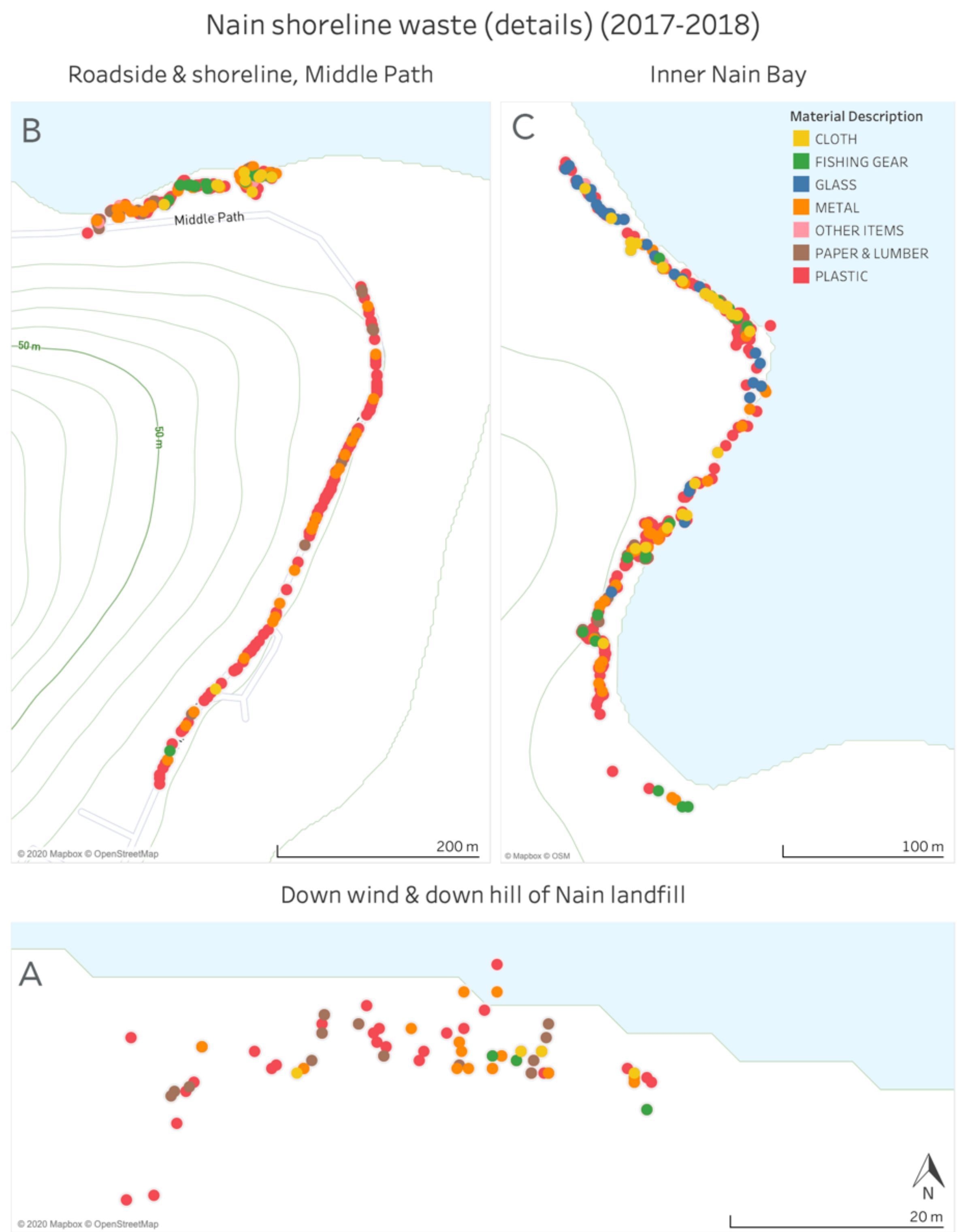
Note that for material categories, fishing gear is broken out as a unique material (green) even though it is plastic (red). This is to aid in evaluation of sources of plastics within and across locations.

List of figures:

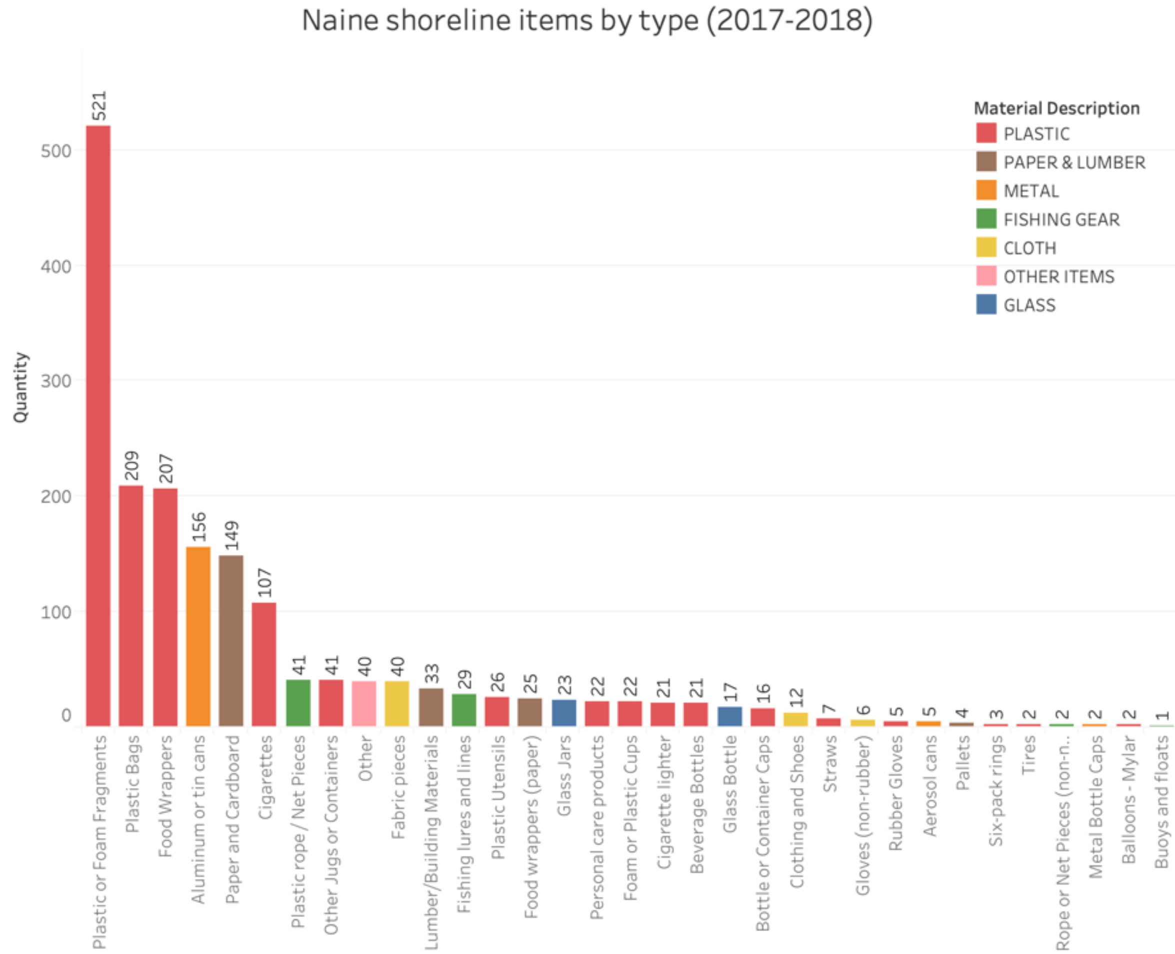
Two locations in Makkovik (town and Ranger Bight) were monitoring for all shoreline waste using the Marine Debris Tracker app in the spring of 2019. In town, plastics were consistently pushed into the grassy areas bordering the water. Fishing gear collected closer to the water. In Ranger Bight, the highest number of plastics was observed near the recreational area, and few items accumulated around the point. Total items include items from both locations.

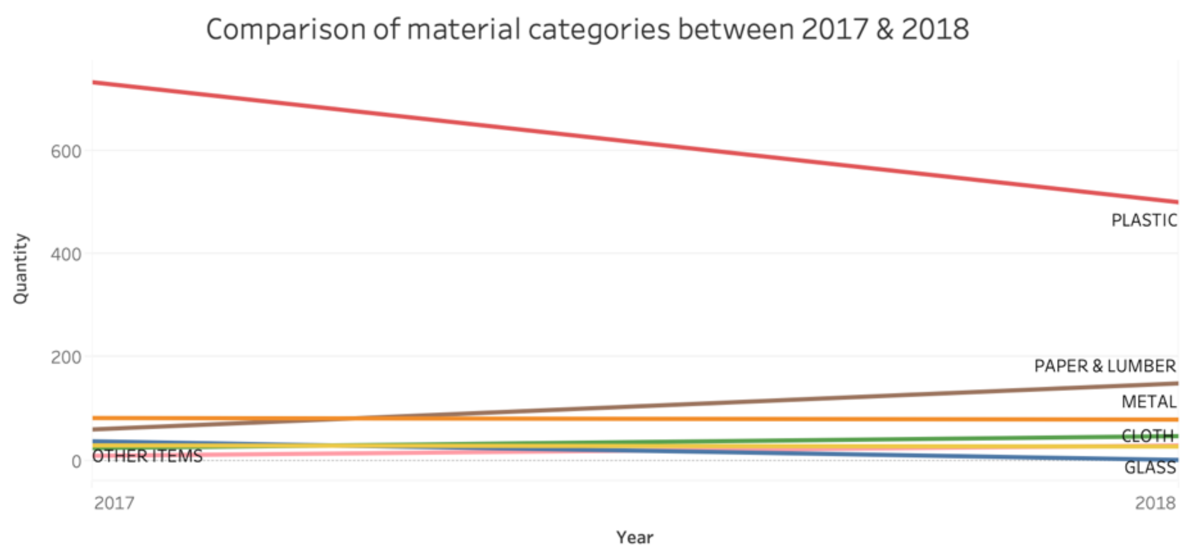


Three locations in Nain (A: downhill from the landfill, B: along the road and on the shore by Middle Path, and B: in Nain Bay, and the south side of Unity Bay where Anainaks Brook emerges) were monitoring for all shoreline waste using the Marine Debris Tracker app in 2018 and 2019.

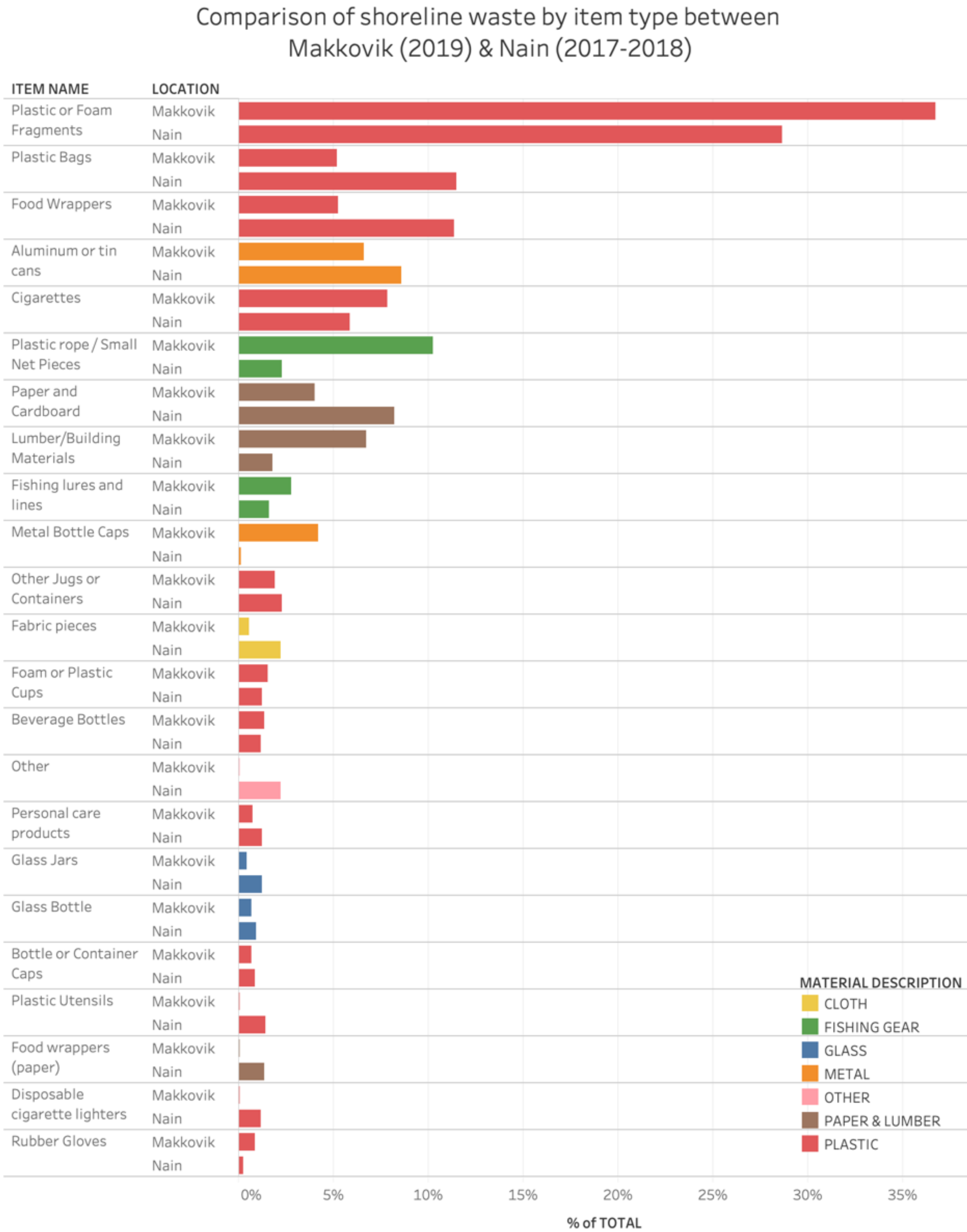


Details of three locations in Nain. A: downhill from the landfill, where items are scattered from the wind. Nearly all items downhill from the landfill appeared to have blown from the landfill. B: along the road and on the shore by Middle Path. The roadside had much higher amounts of plastics and cigarette waste. B: In inner Nain Bay, on the south side of Unity Bay where Anainaks Brook emerges. This area had a much higher incidence of glass, much of it older. Glass is likely to stay in the rocks and not degrade, allowing it to accumulate more in areas adjacent to town. The further from town, the more plastics and fishing gear was observed.

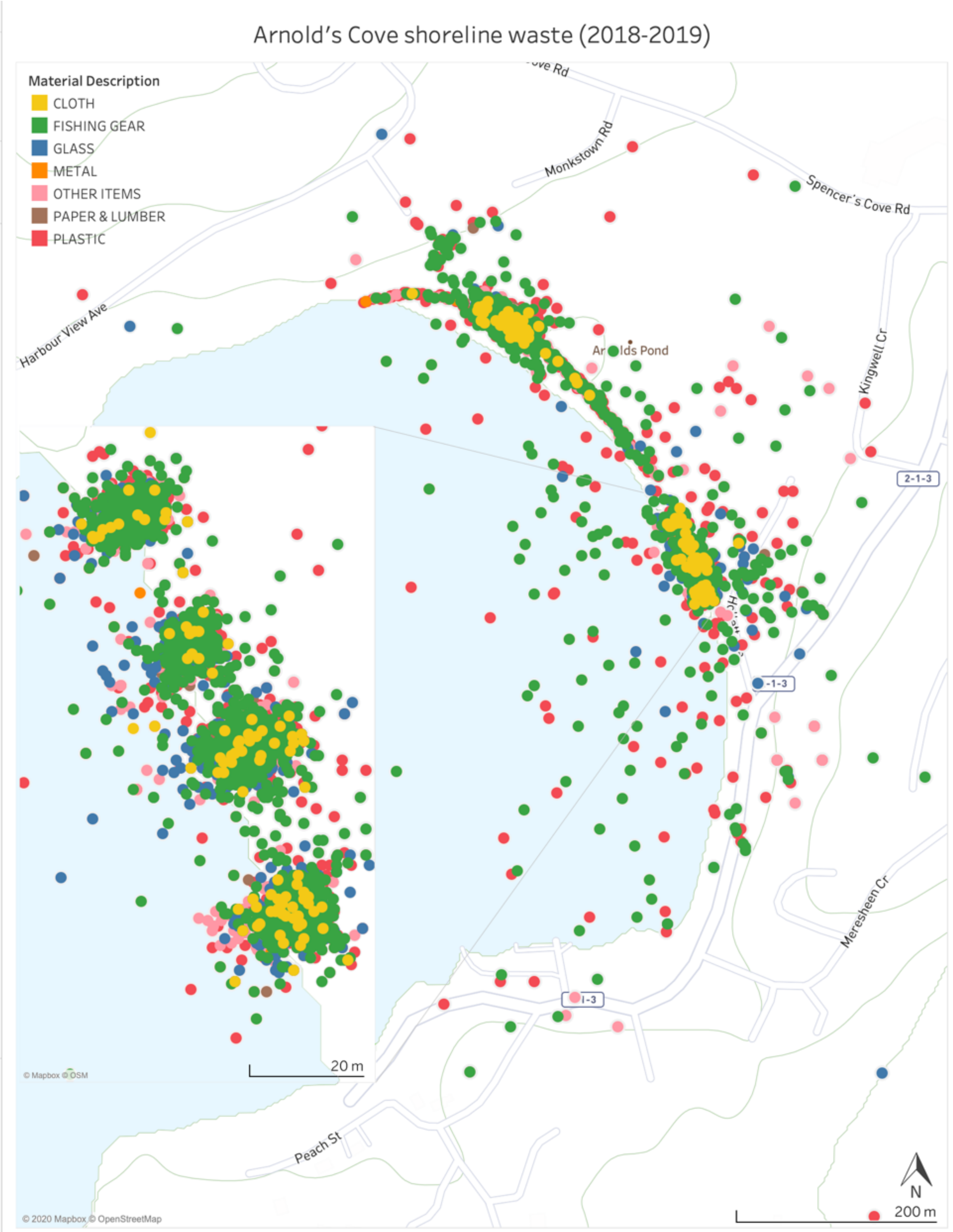




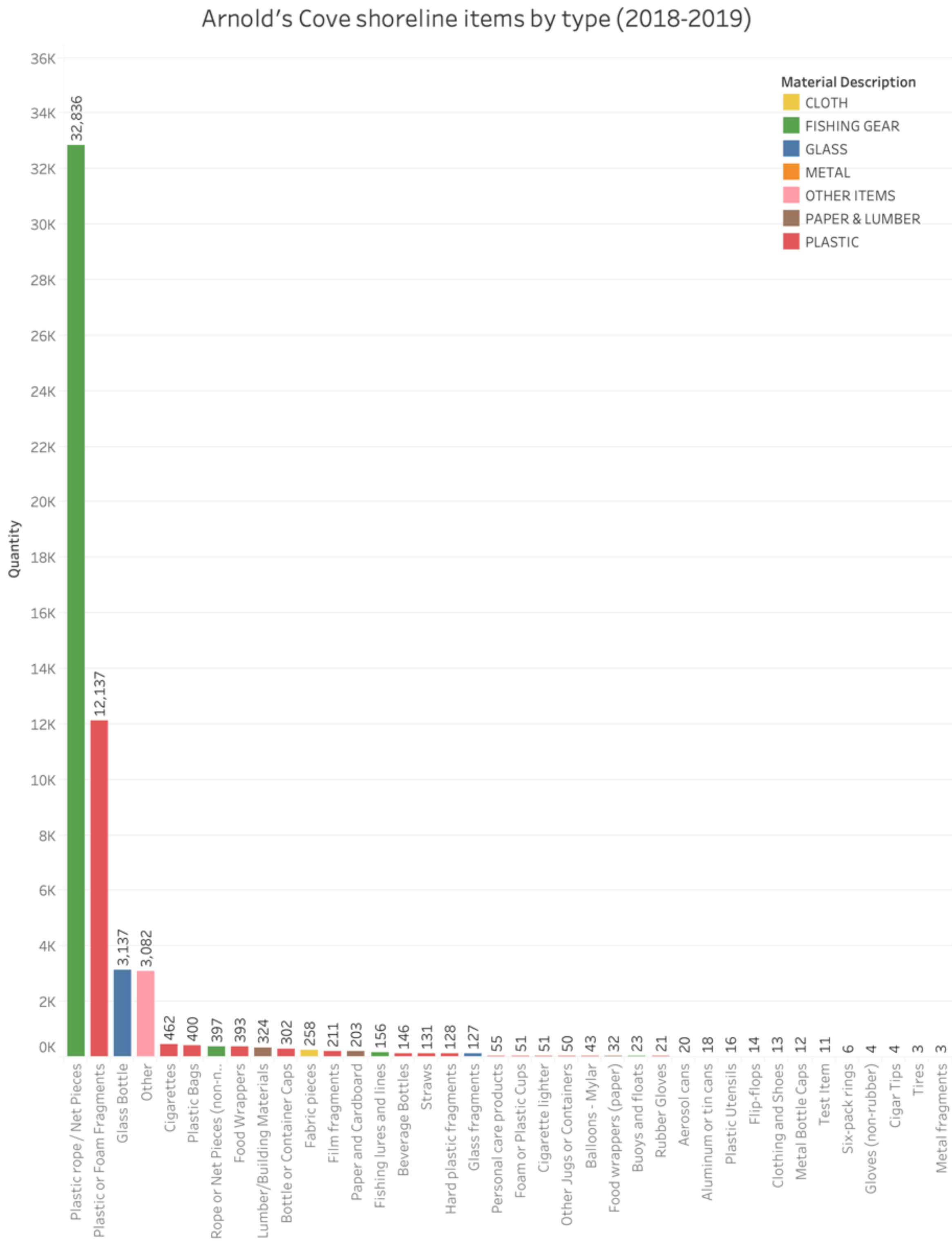
Total items include items from all locations, all years. Plastic items (fragments, bags, and food wrappers, cigarettes) dominate the materials observed. Nain has one of the highest observations of metals (aluminum or tin cans) in the province, a material with a uniquely steady recycling market. Paper and cardboard found indicate that these items were likely in the environment for little time and came from local sources, as paper tends to disintegrate quickly in the elements. The comparison between 2017 and 2018 is by count, and variation may be due to differences in locations surveyed and time spend surveying. Most material counts stayed steady, while plastics decreased and paper and limber increased.



Total items include items from all locations, all years, and compare those in Makkovik to Nain for each type of waste item. To adjust for differences in the number of items surveyed in each location and ensure direct comparison, items have been listed according to percentage of the total shoreline waste. Plastic fragments were the most numerous type of shoreline waste in each location. Notable differences are in the higher percentages of fishing gear, lumber/building materials, and metal bottle caps in Makkovik, while Nain has a noticeably higher percentage of plastic bags, food wrappers, and paper and cardboard. Items with less than 1% representation in both locations have been omitted.

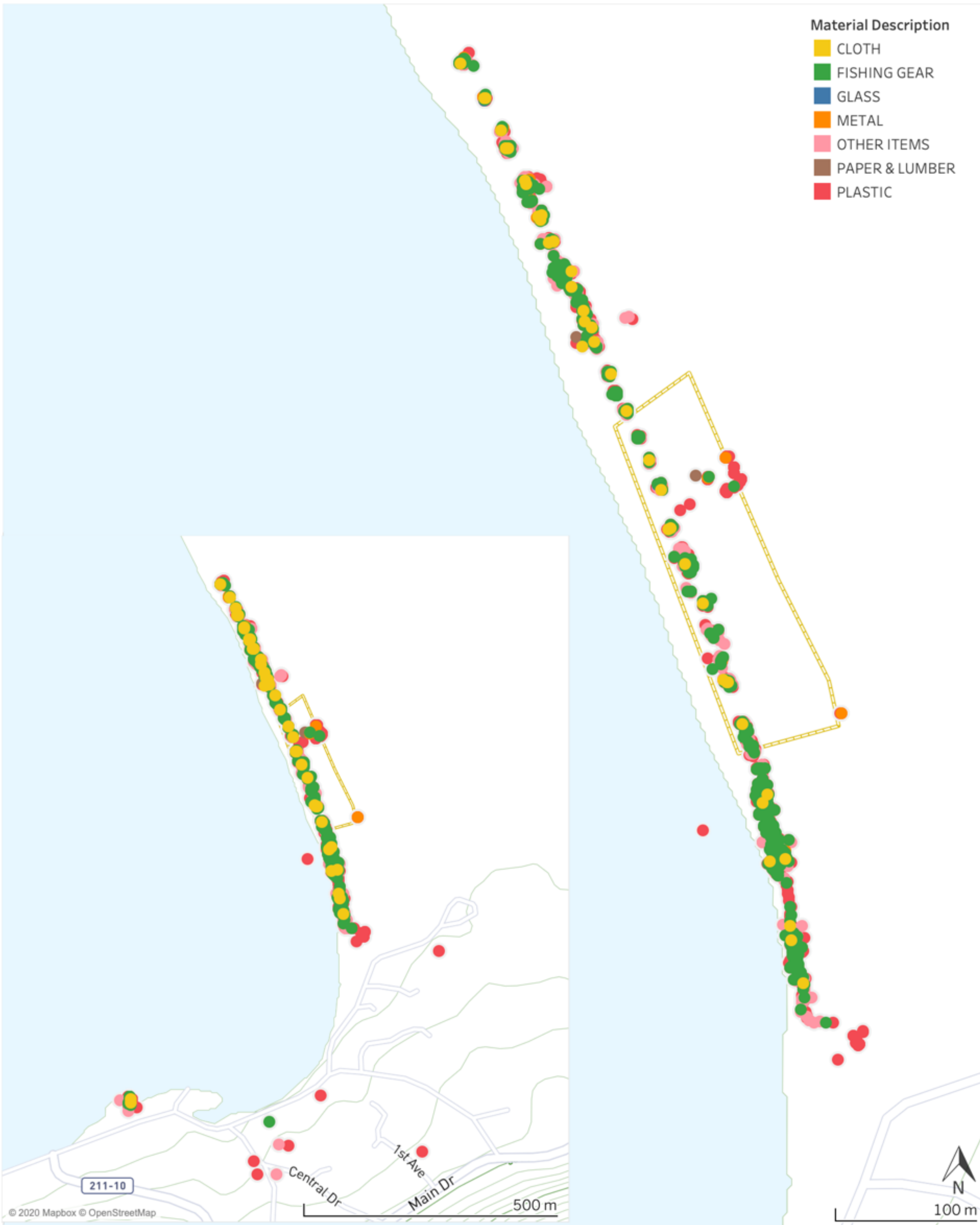


Shoreline waste was collected in Arnold's Cove using the Marine Debris Tracker along the inner bay shoreline, in the intertidal zone (dots in the blue area), and between the shoreline and the roads. All forms of waste accumulated on the shoreline itself, with additional densities occurring in dense clumps (see the inset map). Fishing gear is particularly prevalent on this shoreline.

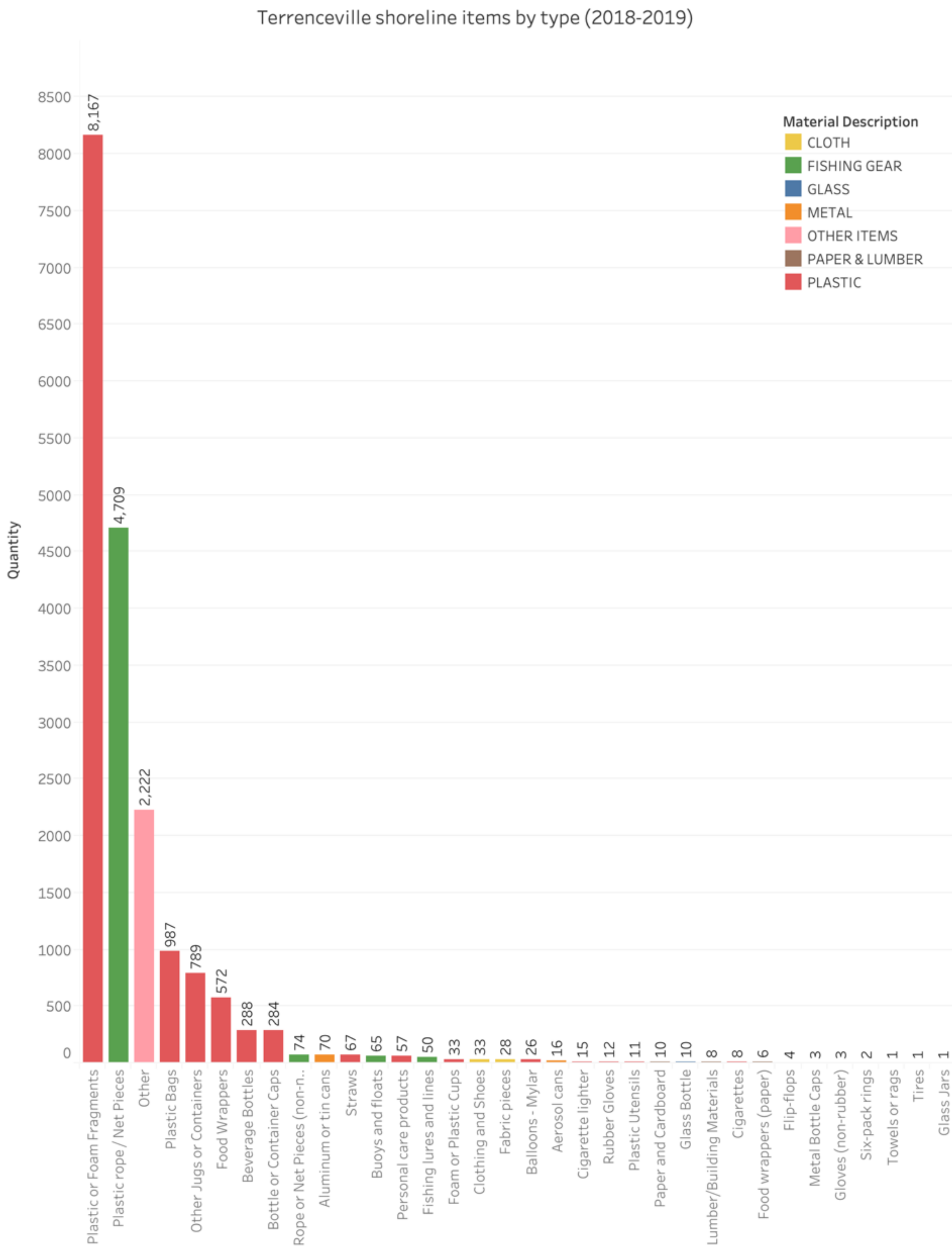


Total shoreline waste items include items from all years across all cleanups. Uniquely, fishing gear is an order of magnitude more prevalent than other types of items. Plastic fragments are also numerous. Glass bottles likely stay in the rocky shoreline over time, as they do not wash away as readily as other lightweight materials and they do not degrade in time. Future studies should remove the glass bottles to see whether they are legacy waste items or whether they are accumulating anew.

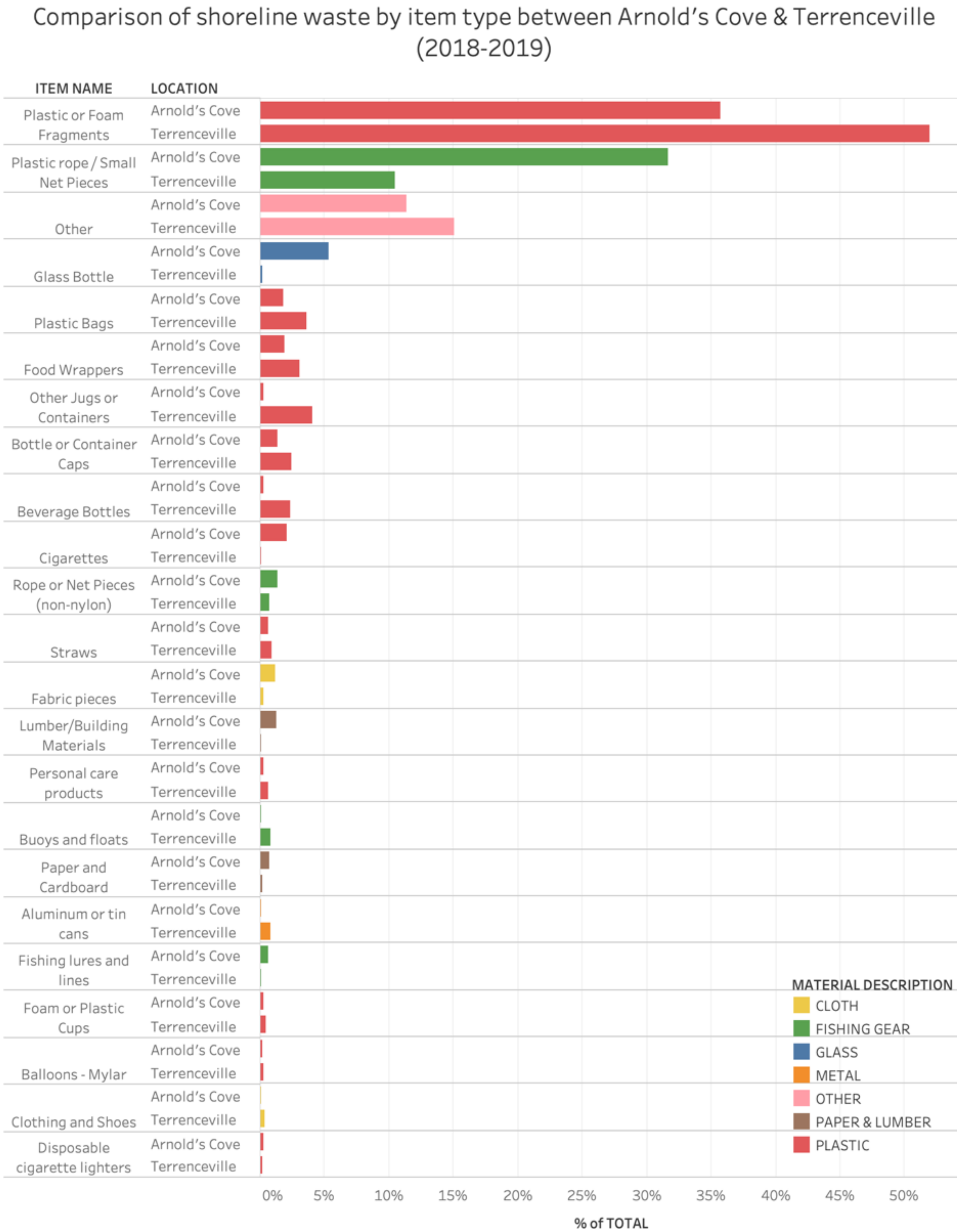
Terrenceville shoreline waste (2018-2019)



Shoreline waste was collected in Terrenceville using the Marine Debris Tracker. The inset map is the overall area, and a detail of the shoreline shows where most of the waste accumulates. Items accumulate mainly along the west edge of the spit, unevenly.



Total shoreline waste items include items from all years across all cleanups. Plastic fragments, including fragments of fishing gear, characterize this shoreline. The high percentage of fragmented plastics likely indicate that waste in these categories is not local, but brought by tides after having been in the marine environment for some time. Plastic bags and wrappers are more likely to come from more proximate sources.



Total items include items from all locations, all years, and compare those in Arnold's Cove to Terrenceville for each type of waste item. To adjust for differences in the number of items surveyed in each location and ensure direct comparison, items have been listed according to percentage of the total shoreline waste. Plastic fragments were the most numerous item of shoreline waste in each location. Notable differences are in the higher percentages of fishing gear and glass bottles in Arnold's Cove, while Terrenceville was a broader distribution of waste types overall. Items with less than 1% representation in both locations have been omitted.