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Research article

The leatherback turtle (*Dermochelys coriacea*) and plastics in the Northwest Atlantic ocean: A hazard assessment

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ABSTRACT

Atlantic leatherback turtles are faced with multiple threats, such as ship strikes, pollution and predation, throughout their annual migratory routes in the Northwest (NW) Atlantic. The risks associated with encounters with floating and submerged plastic debris are currently unknown. This study is a hazard assessment of plastics for this turtle's sub-population, using 2010–2019 data from the national Great Canadian Shoreline Cleanup (GSCS) program, therefore potential exposure, and published evidence on the interactions of plastics and leatherbacks, hence potential effects. The type of plastic items and their abundance along shorelines of three Atlantic Provinces – Nova Scotia (NS), Prince Edward Island (PEI), Newfoundland and Labrador (NL) – were evaluated and compared to plastic items known to interact with leatherbacks. During the 2010–2019 period, a total of 220,590 plastic items were collected from 578 sites, representing 1264 km of shoreline. Plastic bags and rope are in the top ten most common items found on shorelines of NS, PEI, and NL. Pot gear and trap nets are in the top ten for PEI and are the 14th most common plastic item found on all shorelines. Cigarette debris is also commonly found. From the literature, plastic bags, pot gear and trap nets, and rope are known to adversely affect leatherbacks. Assuming that a large proportion of the shoreline debris comes in from the sea, after being in coastal waters for unknown periods, the study shows that such items pose a hazard to leatherbacks through ingestion and entanglement, based on published studies. Evidence is now needed on actual exposure at sea to the most common items to establish the ecological risk of plastics to these turtles in NW Atlantic waters.

1. Introduction

Over past decades, plastic production has increased greatly in response to rising demand (UNEP, 2016). Its global production grew from 1.5 million to 368 million metric tons between 1950 and 2019 (Garside, 2020). As a result, discarded plastic of all types and sizes has increased in volume and most of it enters ocean waters from rivers, municipal wastewater outfalls, and numerous non-point land-based sources along coastlines (UNEP, 2016). Such discarded plastics are widely distributed by ocean currents but also aggregate in convergent zones, creating large patches of marine debris where animals also congregate to feed (Norén and Naustvoll, 2010). Depending on the size and density, plastic also can be found within the water column, at the sea floor, and in marine organisms (Li et al., 2016; Jamieson et al., 2019). Kukulka et al. (2012) suggests that concentrations of plastic in the North Atlantic can be between 2.5 to 27 times greater than current estimates, measured from surface tows. Consequently, the presence of plastic debris within oceanic waters can adversely impact wildlife through entanglement, ingestion, and habitat degradation (Nelms et al., 2016). The interactions of plastic and marine organisms are being investigated across the globe (Consoli et al., 2018; Fallon and Freeman, 2021; Pereao et al., 2020; Ríos et al., 2020), including Canada (Desforges et al., 2015). Canada's Atlantic bioregions, such as the Scotian Shelf, Gulf of St. Lawrence, and the Grand Banks (Dever et al., 2016), are highly productive areas that serve as spawning, nursing, and feeding habitats for many organisms. These areas are influenced by western boundary currents that may also spread plastic debris across wide areas (Greenan et al., 2018; Anderson, 2021).

The leatherback turtle (*Dermochelys coriacea*) is a migratory species widely distributed across various marine habitats, including sandy shores, that are essential for feeding, growth and development, and reproductive success (Eckert et al., 2012). Of the seven species of sea turtles, the leatherback is the only one to annually migrate from its southern nesting beaches in the Caribbean and South America to Canadian cold waters to forage on gelatinous zooplankton such as jellyfish (Ferraroli et al., 2004; James et al., 2005, 2006). Such migratory

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movement is influenced by ocean currents and nutrient-rich areas on the coastal shelves (Lambardi et al., 2008; Block et al., 2011; Greenan et al., 2018). Individual leatherbacks vary greatly in their migratory routes and temporal distribution, likely linked to body size and prey distribution (James et al., 2007). Large aggregates of the sub-adult and adult leatherbacks have often been reported in waters offshore of northern Nova Scotia (herein referred as NS), and on the Grand Banks, south of Newfoundland (herein referred to as NL) (Hays et al., 2004; James et al., 2006; Mosnier et al., 2019). Both areas are their critical feeding habitats, hence necessitating protection against potentially harmful ocean contaminants such as plastics (James et al., 2006, 2007).

As discussed in the Nelms et al. (2016) review, numerous studies have evaluated the possible effects of plastic debris on individual leatherbacks or their populations (Eckert and Luginbuhl, 1988; Sadove and Morreale, 1989; Lucas, 1992; Davenport et al., 1993; Duguy et al., 2000; Barreiros and Barcelos, 2001; Bugoni et al., 2001; Russo et al., 2003; Mrosovsky et al., 2009), necessitating the need to assess the hazards, estimate ecological risk, and implement appropriate management and conservation measures. In Canadian waters, leatherbacks are also susceptible to entanglement with fishing gear such as longlines as heavily fished areas overlap critical feeding habitats; plastic ingestion (direct or indirect) may occur (James et al., 2006; Mosnier et al., 2019). As leatherbacks feed on jellyfish, they can mistakenly ingest some plastics due to its resemblance to their prey (Mrosovsky et al., 2009).

The Northwest (NW) Atlantic leatherback subpopulation is currently listed as Endangered under the IUCN red list and Canada's *Species at Risk Act* (SARA) and warrants conservation measures to prevent further population decline (Wallace et al., 2013; Government of Canada, 2019; The Northwest Atlantic Leatherback Working Group, 2019). Recently, the Canadian Department of Fisheries and Oceans (DFO) has completed the recovery action plan for the NW Atlantic leatherback subpopulation, necessitating the identification of sources and quantities of harmful contaminants such as plastics (DFO, 2020).

The hypothesis was that plastics on these shorelines largely come in from the sea and represent potential exposure to the leatherback turtles at sea, swimming and feeding in coastal and offshore waters. Hence, this study assesses potential hazard, not ecological risk. This study's goal was to conduct a hazard assessment of shoreline plastic litter to the turtles in the NW Atlantic Ocean as part of a future ecological risk assessment. The study focused on identifying the hazard only (what is in the water, what are known effects) following the risk assessment framework (Suter et al., 2003; Suter, 2016). Specific objectives were: (1) To evaluate the type and quantity of plastic debris on the shorelines of three provinces (NS, Prince Edward Island (herein referred as PEI), and NL), the debris collected annually (2010–2019) by volunteers of the Great Canadian Shoreline Cleanup (GCSC) initiative; and (2) To identify through a literature review whether such plastic debris interacts with and affects the turtles.

2. Methods

2.1. Potential exposure – shoreline data collection

The abundance of plastic items on the shorelines of NS, PEI, and NL was evaluated using the annual data provided by the GCSC from 2010 to 2019 (GCSC, 2021a,b). Collecting typically occurred on Earth Day (April), World Environment Day (June), and World Ocean's Day (June), and most commonly on International Coastal Cleanup Day (September). There was some variation in location and timing over the years, as seen in the annual comparability of the data, as it was a widespread volunteer program. The annual cleanup events are open to the public and are led by GCSC and citizen volunteers. The GCSC offers a list of locations for hosting cleanup events that are registered and that community members have previously cleaned. Participants are instructed to record data on provided Data Card or online tracker by using line tick marks next to litter items and not to use defining terms (i.e., many). Data provided by the GCSC included number of sites sampled, length (km) of the shorelines sampled and cleaned, number of participants, total weight (kg) of litter, and number of items per type of litter (e.g., plastic bags, bottles, takeout containers, etc.) for each Canadian Province.

In the present study, data provided by the GCSC was filtered according to province, number and length of shoreline sampling site, and type and number of litter item. Data collected from various sampling sites in three provinces, including NS, NL, and PEI, were evaluated, and are shown in Figure 1 (created in ArcGISPro). The type and number of litter items collected were categorized according to item use such as fishing gear, product packaging, personal hygiene, tiny trash (<2.5 cm), and items that are most likely to be found (i.e., cigarette butts, beverage cans, bottle caps, food containers, paper, etc.) (Konecny et al., 2018; GCSC, 2021a). Non plastic items such as paper were not included in the evaluation of the present study. From the filtered data, 33 categories of varying plastic item types were evaluated to determine. the abundance (items/km) of plastic items for each year and province, and to identify the top ten most common types amongst the three provinces. The abundance of all litter collected on the shorelines of NS, PEI, and NL, 2010 to 2019, are shown in Figure 2. Figure 2A is a map (created in ArcGISPro) representing the total number of items (by range) collected per site from 2010 to 2019 and Figure 2B shows the average (item/km) by year for each NS, PEI, and NL.

2.2. Potential hazards or harm – known studies

A literature review of previous studies was conducted to identify whether the plastic items found on Atlantic shorelines could harm leatherback turtles if contact occurs at sea. A list of global and regional comprehensive review papers of the impacts of plastics on marine turtles (Mrosovsky et al., 2009; Schuyler et al., 2014; Nelms et al., 2016; Lynch, 2018) were examined, as well as peer-reviewed papers focusing on the impacts of plastics on marine turtles were found using Novanet Libraries, Omni database, and Google Scholar (including articles from Elsevier, Science Direct, ProQuest, Directory of Open Access Journals (DOAJ). Grey literature publications relevant to the impacts of plastics and marine turtles were also examined; these included government reports in fisheries, stock assessment and turtle migration status. Information on leatherback turtles interacting with plastics were extracted from the peer-reviewed papers cited in the global and regional review studies. Further to site, publication selection involved using keywords combination to create queries for title elements and keywords. The search was narrowed using the following keywords combination: “leatherback turtles risk assessment”, “impacts of plastics on marine turtles”, “marine turtles and fisheries”, “marine plastic ingestion”. The review was not limited to papers published in a certain period. Information gathered from these studies included the location, types of plastic item, the pathways of effect (i.e., entanglement, ingestion), and the adverse effects of plastics on the turtles. Plastic items reported to harm leatherbacks were then compared to the most common types of plastic items found in the GCSC surveys.

3. Results

3.1. Exposure - types and abundance of plastics on Atlantic shorelines

The number of shoreline plastics collected at the same locations over the 10-year period ranged up to 7622 items in all three provinces (Figure 2A). The top ten types of plastic items for each province from 2010 to 2019 are shown in Figure 3. During the period of 2010–2019, a total of 220,590 plastic items were collected from 578 sites, over 1264 km of shoreline. In NS, the most abundant plastic items were cigarettes/cigarette filters (37,787 items), followed by plastic and foam pieces (18,742 items), rope (14,436 items), food wrappers/plastic and foam takeout containers (7014 items), and plastic bags (6794 items) (Figure 3A), from 317 sites, over 654 km of shoreline. For PEI, a total of 22,049 plastic items were collected from 117 sites, over 395 km of shoreline; the most abundant items were plastic and foam pieces (5305

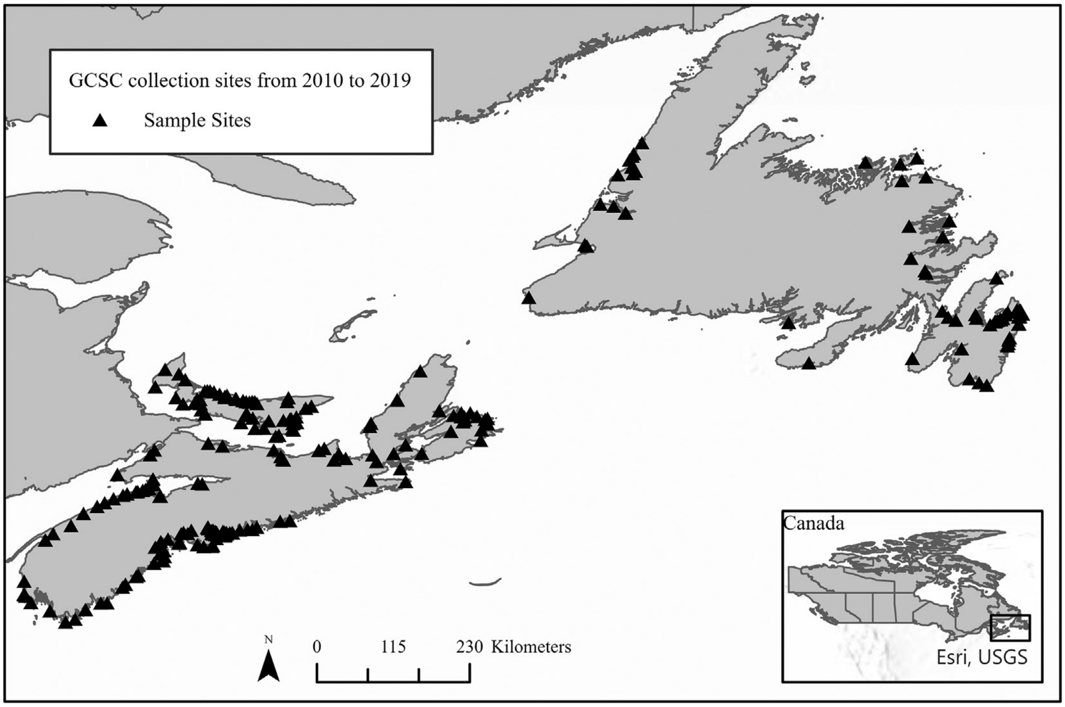

Figure 1. Great Canadian Shoreline Cleanup litter collection sites in Nova Scotia, Prince Edward Island and the island of Newfoundland and Labrador from 2010 to 2019.

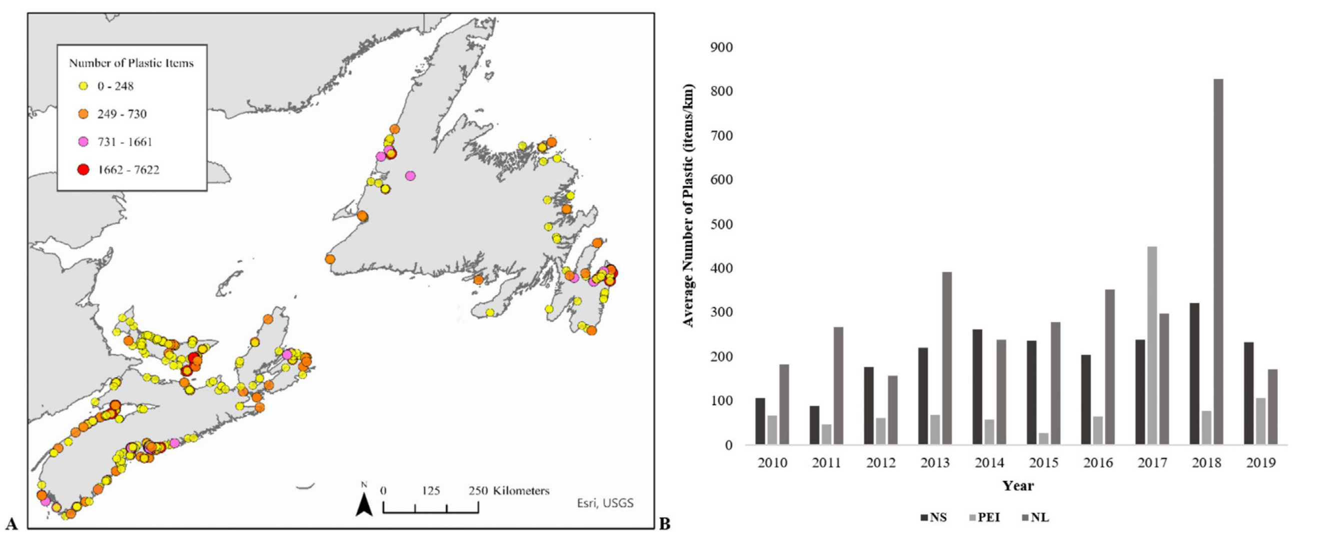

Figure 2. (A) Map demonstrating the number of plastic items collected per sample site on the shorelines of NS, PEI, and NL from 2010 to 2019. (1.5 fitting column, colour), and (B) graph representing the average number of plastics collected on the shorelines (items/km) of NS, PEI, and NL during the Great Canadian Shoreline Cleanup events from 2010 to 2019.

items), rope (3,055 items), fishing buoys, pots, and traps (2084 items), and cigarettes/cigarette filters (1860 items) (Figure 3B). For NL, a total of 70,115 plastic items were collected from 144 sites, over 215 km of shoreline. The most abundant items were cigarettes/cigarette filters (18,192 items), plastic and metal bottle caps (8602 items), plastic and foam pieces (7293 items), and plastic bags (5295 items) (Figure 3C).

3.2. Potential hazard (harm)

Previous studies show that the recurring interactions between plastics and leatherback turtles are entanglement with fishing gear and plastic ingestion, and both may cause a range of harmful effects (see references included in Table 1). The types of fishing gear reported include nets, sink gillnet gear, trawler nets, pelagic longlines, rope, and other fixed-fishing gear such as pots, trap nets, and buoy lines (see references included in Table 1). The types of plastic documented to interact with leatherbacks include pieces of soft plastic, bags (trash bags, rice mesh bags), sheeting, nylon fragments, rope, balloons, and packaging () (see references included in Table 1). Plastic bags, pot gear and trap nets, and rope are the three plastic items described most frequently in the literature to cause harm (Table 2), plastic bags and rope through ingestion, such as partial intestinal blockage leading to secondary impacts (see references included in Table 1). Pot gear and trap nets as well as rope have been documented to entangle leatherbacks, causing external injury, asphyxiation, and

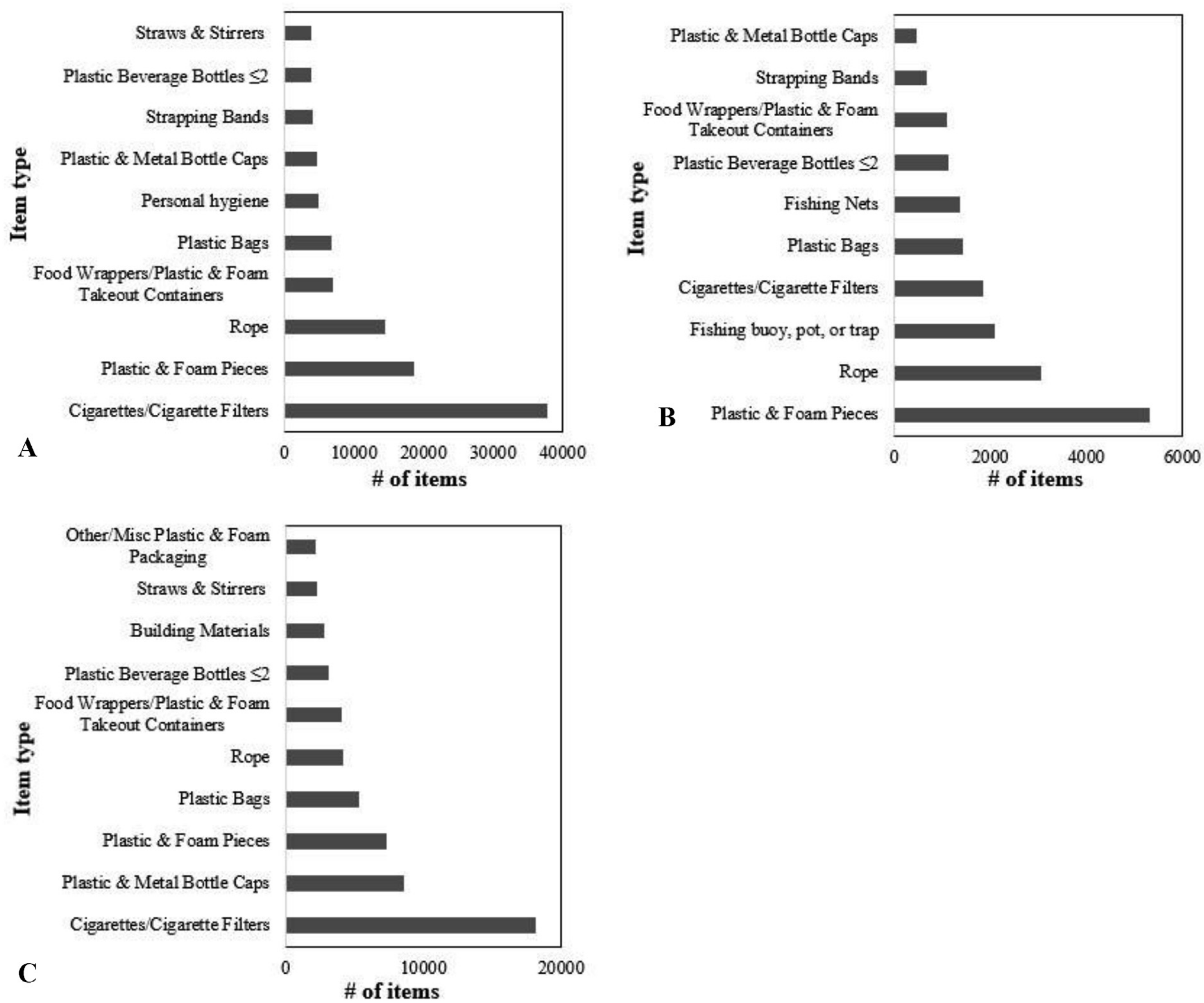

Figure 3. (A) Total number of items for the top ten common type of plastic in NS, (B) total number of items for the top ten common type of plastic in PEI, and (C) total number of items for the top ten common type of plastic in NL. Plastic items were collected on the shorelines from 2010–2019 by the Great Canadian Shoreline Cleanup.

death by drowning (see references included in Table 1). Plastic bags and rope are commonly found on Atlantic beaches, after undermined time in open waters. Interestingly, no published data on the possible effects to turtles of ingesting cigarette remains and filters was found.

4. Discussion

This study shows that there are huge quantities of plastic litter on Atlantic shorelines, and that whatever has been at sea is a hazard to leatherback turtles if contact occurs. Given the location and length of the shorelines, it is not unreasonable to hypothesize that much of the litter found along the shorelines was in open waters for unknown times, with contact likely occurring with marine organisms, including turtles.

Evidence on the interactions of marine plastics and leatherback turtles has been documented since the late 1960s (Brongersma, 1969; Den Hartog and Van Nierop, 1984; Lucas, 1992; Davenport et al., 1993; Levy et al., 2005; James et al., 2006; Mrosovsky et al., 2009; Hamelin et al., 2017; Archibald and James, 2018; Upite et al., 2018; Hurtubise et al., 2020; Santos-Costa et al., 2020). Although not as prevalent as leatherback entanglement, occurrence of plastic ingestion by leatherbacks has been reported in different regions of the world including, Central Mediterranean Sea, Central-north Pacific, Southwestern Atlantic, and North-eastern and western Atlantic (Sadove and Morreale, 1989; Davenport et al., 1993; Duguy et al., 2000; Bugoni et al., 2001; Russo et al., 2003). In the NW Atlantic, leatherbacks are faced with multiple hazards, including certain types of plastic debris as shown by this study. For the period of 1998–2014, Hamelin et al. (2017) show that the number of reported incidences of leatherback entanglement in fixed fishing gear occurred most frequently in waters surrounding NS and NL. The most common fishing gear to entangle leatherback turtles consisted of pot gear and trap nets attached by polypropylene lines (Hamelin et al., 2017). Furthermore, a recently published study evaluated sea turtle bycatch in fixed-gear fisheries in Massachusetts from 2005 to 2019 (Dodge et al., 2022). Findings from a 15-year dataset show that 272 out of 280 confirmed cases of sea turtle entanglement involved leatherback turtles. From this study, pot gear and trap nets are more commonly found on the shorelines of PEI rather than NS and NL, suggesting that this type of item remains in surrounding waters of NS and NL. Based on the assumption that these items originate from the ocean and the evidence of reported cases on leatherback entanglement in the NW Atlantic during the similar period, fixed pot gear and trap nets are currently a hazard to the turtles. Entanglement in fishing rope causes external injury to neck, shoulders, and limbs of leatherbacks (Innis et al., 2010; Archibald and James, 2018). Rope is in the top five most common type of item found on the shorelines of the three provinces, suggesting that this item is a hazard to leatherbacks in Atlantic coastal waters.

As leatherbacks feed on gelatinous prey, direct ingestion of plastic can occur as some items may not be readily visible in the water column

Table 1. Classification of reported evidence, type of plastic item, and their effects on the interaction of plastic and leatherback turtles according to location and pathway of effects.

Location	Type of plastic item	Pathway of effect	Effect (s)	Reference
NW Atlantic (FL, MA, PEI)	Trawler net, heavy line/or fishing gear	Entanglement	Drowning, ligature wounds, one found with metabolic derangement, trauma (shark bite), susceptibility to predation	Stacey et al. (2016)
NW Atlantic (FL, MA)	Pieces of soft plastic, 84 × 35 cm piece of plastic sheeting	Ingestion	Underweight likely due to partial gastric obstruction, gastric foreign body obstruction resulting in death	Stacey et al. (2016)
NW Atlantic, Canary Islands	Plastic bag	Ingestion	Intestinal obstruction, edema	Orós et al. (2021)
NW Atlantic (CA, Trinidad)	Fishing rope, lines, nets	Entanglement	External injury to neck and shoulders	Archibald and James (2018)
NW Atlantic	Pot gear and trap nets, gill nets, bait nets	Entanglement	Drowning, asphyxiation, injury to front flippers, neck, and head	Hamelin et al. (2017)
South Atlantic, Brazil	Fishing nets	Entanglement	Abrasions, lacerations on neck and flippers, cardiorespiratory collapse by asphyxia	Santos-Costa et al. (2020)
NW Atlantic French Guiana NW Atlantic Mediterranean Sea Mediterranean Sea	Pot, trap gear Plastic bags (rice mesh bag, trash bag) Linear fishing rope Plastic bag Fishing gear nets	Entanglement Ingestion Entanglement Ingestion Entanglement	Cloacal obstruction causing secondary effects on egg deposition Physiological changes (impaired kidney function likely resulting from reduced food intake), generalized stress response and inflammatory response Partial occlusion to stomach lumen causing secondary mucosal damage Myopathy, abrasions and fractured front limb, plastron damage	Upite et al. (2018) Plot and Georges (2010) Innis et al. (2010) Levy et al. (2005) Levy et al. (2005)
Hawaii NW Atlantic, Sable Island British waters, New Zealand	Plastic bags, plastic sheeting, -plastic-coated prescription label, plastic fragments, nylon line Rope, balloons, plastic bags Plastic in sheet- linear form, packaging, monofilament nylon	Ingestion Ingestion Ingestion	Partial intestinal obstruction Found deceased on shoreline, cause of death unspecified Gastric blockage	Davenport et al. (1993) Lucas (1992) Den Hartog and Van Nierop (1984)

*FL: Florida, MA: Massachusetts, NC: North Carolina, NW: Northwest, CAN: Canada, PEI: Prince Edward Island.

Table 2. Occurrence of reported cases on plastics impacting leatherback turtles and the pathway of effect based on the number of times the plastic item known to affect leatherbacks appears in literature.

Plastics known to affect leatherbacks	Pathways	Times appearing in literature
Plastics bags	Ingestion	5
Pot gear and trap nets (linear fishing rope)	Entanglement	5
Rope	Ingestion/entanglement	3
Plastic pieces/fragments	Ingestion	2
Nylon line	Ingestion	2
Plastic sheeting	Ingestion	2
Gillnets	Entanglement	1
Food/cigarette wrapping/packaging	Ingestion	1
Balloons	Ingestion	1

and mimic their prey (Mrosovsky et al., 2009). At least one third of adult leatherbacks have ingested plastic in past decades (Mrosovsky et al., 2009). Ingestion of plastic bags alone has resulted in intestinal obstruction of leatherback turtles found in waters off Florida and Massachusetts (Orós et al., 2021). Additionally, nylon line has been reported in earlier studies to be in the gastrointestinal tracts of leatherbacks and was found, along with various plastic items, to cause gastric blockage and partial intestinal obstruction (Den Hartog and Van Nierop, 1984; Davenport et al., 1993; Mrosovsky et al., 2009). Evidence of nylon ingestion and potential effects have yet to be documented for leatherbacks in Canada's NW Atlantic. This may be due to the constraint in sampling and evaluating gastric contents of live leatherback turtles.

5. Conclusions and recommendations

As plastic litter continues to enter the ocean from Atlantic coastlines, leatherback turtles remain at risk of exposure and harm. This study described the plastic litter found on these coastlines and the known hazards of such litter to turtles. The actual open ocean exposure of the turtles to these plastics is of yet unknown, precluding an estimate of actual risk for individual turtles at sea. However, the large amounts of plastic debris found on the shorelines warrants immediate action to prevent and reduce possible harm to these animals, including additional research in the study area and raising awareness of the impacts in surrounding Canadian waters.

Additional research and actions needed to help prevent and reduce the possible harms as follow:

- Identify whether the commonly found cigarettes/cigarette filters are ingested by leatherbacks at sea, and if so, with what effects.
- Conduct a detailed necropsy of turtles found deceased.
- Examine all turtles found stranded, captured incidentally, or captured in tagging studies.
- Share all relevant data on leatherback turtles and plastics on a single communication platform open to all engaged researchers.
- Raise awareness about the presence of leatherback turtles in Canadian waters through ocean literacy programs.

Declarations

Author contribution statement

Noémie Blais: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Peter G. Wells: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

The authors do not have permission to share data.

Declaration of interest's statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

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