Are Atlantic Leatherback Turtles (*Dermochelys coriacea*) at Risk of Plastic Pollution in the Northwest Atlantic Ocean?

by

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DEDICATION

I dedicate this work to my father, Richard Blais. I am forever grateful that you encouraged me to dream, allowed me to try new things even though I didn't stick to them for long and that you accepted that I saw the fun in life. I will continue to live my dream of protecting the ocean and what was once your dream of becoming Jacques Cousteau.

"You can do anything – Dad"

… à ma mère, Sylvie Samson Blais. Merci d'avoir encourager mon amour pour les animaux. Merci infiniment pour le support et l'amour inconditionnel.

"Je t'aime, je t'adore, tu es mon cœur et je suis folle de toi - Maman"

…and to Tim. I carry you in my heart. We did it, we got another one.

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ABSTRACT

The production of plastic has greatly increased since the early 20th century resulting in an overwhelming abundance on land and in the sea. The solid waste pollution found in the ocean poses sublethal to lethal threats to marine turtles through ingestion, entanglement, and habitat degradation. The leatherback turtle is a migratory species that inhabits terrestrial and marine environments and is better known for its migrations from mid to higher latitudes. Out of the seven species, it is the only marine turtle to migrate in Canadian cold water for the sole purpose to forage on gelatinous zooplankton (i.e. jellyfish) which are easily mistaken with plastic bags. Their movements frequently overlap the fishing industry, increasing their exposure to entanglement with fishing gear. Throughout its life cycle, leatherback turtles (*Dermochelys coriacea*) are exposed to the multiple threats from contact with plastic debris. This project explores the exposure, possible pathways of exposure, and the effects of plastic debris on the endangered Northwest Atlantic Leatherback subpopulation through a comprehensive literature review and an analysis of data on plastic litter found on the shorelines of Canadian Maritime provinces. A comparison of the effectiveness of current waste management strategies and leatherback conservation efforts are discussed in the context of the Northwest Atlantic regions, with the aim of assess the risk of plastics to the turtles.

Keywords: Leatherback turtles, *Dermochelys coriacea*, Northwest Atlantic Ocean, plastic, ingestion, marine litter, marine debris, waste management, Nova Scotia, Ecological Risk Assessment

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CHAPTER 1: INTRODUCTION

1.1 POLLUTION AND MARINE DEBRIS

Pollution is no stranger to marine and terrestrial ecosystems. Over several decades, contaminants of various types have increasingly persisted to the extent of becoming ubiquitous in the environment (Ye et al., 2013; GESAMP, 2015a). The term contaminant refers the introduction or presence of a substance into the environment that results in pollution which causes harmful or toxic effects to organisms whether terrestrial, freshwater, or marine (GESAMP, 2009). Forms of contaminants can be classified according to their physiochemical properties (i.e. atmospheric or wastewater inorganic and organic compounds), physical state (solid, solutes, gases), and persistence which involves the capability of the pollutant either chemical or material to degrade in the environment (Frid and Caswell, 2017). Marine pollution has been a growing concern for decades, specifically, regarding the amount of waste entering and persisting in the ocean (Schneider et al., 2018). Marine debris originates from land-based waste that has been introduced into the environment through inadequate disposal or dumping, which has been practiced globally for centuries (Topping et al., 1997; Sheavly and Register, 2007; Dipper, 2016). It can also originate from sea-based activities through cargo loss and abandoned, lost, and otherwise discarded fishing gear. The ocean has accumulated an assortment of waste including; glass, timber, ceramics, textiles, paper, metals, and plastic which has gained notoriety over the last decades (Schneider et al., 2018).

An estimate of 4.8-12.7 million tonnes of plastic is introduced to the marine environment each year and may make 60-93% of marine debris (Derraik, 2002; Jambeck et al., 2015; Ambrose et al., 2019). The concern with plastics entering the ocean is that plastic is made of synthetic or semi-synthetic organic polymers that can take years to degrade. Its composition renders it to be lightweight, durable, and corrosive resistant (Thompson et al., 2009). Plastics can travel for an extended amount of time and over long distances in the environment before degrading into smaller fractions known as micro- and nano-plastics which are subsets of microplastics (Schneider et al., 2018). Moreover, their reduced size renders them easily ingestible by marine organisms and as a consequence can enter the food chain (Teuten et al., 2009). The production of plastics has greatly increased since the early 20th century resulting in an overwhelming abundance on land and in sea (Nelms et al., 2016). Plastic pollution is found on the seafloor, in sediments, in biota, along coastlines, in sea ice, within the water column, and at the sea surface (Walker et al., 2006; Mathalon and Hill, 2014; Lusher et al., 2015; Law, 2017; Karbalaei et al., 2019; Goodman et al., 2020). As a result, there has been a dramatic change in the composition of marine ecosystems and much of the wildlife have suffered adverse consequences (Sheavly and Register, 2007).

1.2 Ecological Risk Assessment

Solid waste pollution found in the ocean poses sub-lethal to lethal threats to marine turtles (Nelms et al., 2016). Marine turtles are migratory species that inhabit terrestrial and marine environments. Throughout their life cycle, they occupy varying marine zones such as coastal/supratidal, intertidal, and oceanic habitats (Wallace et al., 2013). All of these zones have been contaminated by plastic as a result of its persistence in the environment (Jambeck et al., 2015). Therefore, it comes with no surprise that interactions between marine turtles and marine debris are likely to occur. However, the probability of contact and the risk associated with this occurrence remain relatively unknown.

Marine turtles are at risk of encountering plastic pollution through various pathways such as ingestion, entanglement, and habitat degradation (GESAMP, 2009; Nelms et al., 2016). All seven marine turtle species have been reported having plastic debris in their bodies with the first record identified in the loggerhead turtle (*Caretta caretta*) (Ceccarelli, 2009; Nelms et al., 2016). Juvenile marine turtles may be at an increased risk of plastic ingestion as they spend a greater amount of time foraging in coastal environments where plastic debris is abundantly found (Schuyler et al., 2013). Post-hatchlings have also been reported with plastic debris in their digestive system, though not as often as juveniles (Ryan et al., 2016). The accumulation of plastic in the digestive system can lead to intestinal blockage resulting in a reduction of food intake and other health concerns that remain relatively unknown (McCauley and Bjorndal, 1999). The ingestion of plastics may also have altering effects on foraging behaviour. Additionally, biofouled plastics can emanate airborne odorants which can be detected by marine turtles. These odorants may attract marine turtles leading them to respond in a similar way as they would if it was food (Pfaller et al., 2020).

The leatherback turtle (*Dermochelys coriacea*) is one of the seven species that may be greatly impacted by plastic debris. It is currently listed as vulnerable under the IUCN Red List with subpopulations including the Northwest Atlantic Ocean leather listed as endangered (Wallace et al., 2013; The Northwest Atlantic Leatherback Working Group, 2019). This subpopulation migrates from tropical regions to temperate ones for the sole purpose to forage on zooplankton and gelatinous zooplankton (James et al., 2007). In Canadian waters, leatherbacks are susceptible to entanglement with fishing gear, such as longlines, and plastic ingestion (direct or indirect) as these are critical feeding habitats. As the leatherbacks feed on jellyfish, they can mistakenly ingest floating plastic due to the resemblance to their prey (Mrosovky et al., 2009). During nesting seasons, these turtles occupy southern beaches in the United-States and in the Wider Caribbean Region where they are exposed to multiple contaminants, including plastic debris (Rabon et al., 2003; Ivar do Sul and Costa, 2007).

Plastic pollution has been known to exist in the environment for decades, dating back to the 1970s, which was recognised by GESAMP early on as a major land-based pollutant (personal communications, P. Wells, November 8, 2020). Yet, the global production of plastic continues to increase along with its persistence in the marine environment (Law, 2017). Plastics entering the marine environment from land-based sources contribute to at least 80% of the debris found in the ocean. A substantial portion of this originating from densely populated areas where the use of plastic bags, littering, and inefficient solid waste disposal occur (Derraik, 2002; Borelle et al., 2020; Law et al., 2020). In many countries, solid waste management is inadequately keeping up with the amount of waste being produced, leading to an overflow of debris in the environment. In 2010, an estimated 0.16 to 0.42 million tons of plastic generated from coastal populations entered the Caribbean Sea. A figure that is predicted to gradually increase to 0.29 to 0.79 million metric tons by 2025 (Jambeck et al., 2015; Patil et al., 2016).

Management of marine debris, especially in the form of plastic, is a transboundary problem that requires global efforts. Worldwide, nations have already begun to implement regulations and policies for the production of plastics with hopes of moving towards more sustainable measures. However, the issue of debris entering, persisting in the environment, and causing detrimental effects on marine life, such as leatherback turtles, remains a significant one. As they are faced with multiple threats throughout their migratory path, there is a need to assess the risks and probability of encounter with marine debris in order to implement appropriate management and conservation measures.

1.3 Project Purpose and Objectives

The purpose of this study was to evaluate the effects and the ecological risks of plastic pollution on the migratory leatherback sea turtle, specifically in the context of the Northwest Atlantic Ocean. Additionally, current management efforts employed in three different regions adjacent to the Northwest Atlantic will be assessed to achieve the following objectives:

1) Evaluate the abundance of marine plastics on the shorelines of Nova Scotia, Prince Edward Island and Newfoundland and Labrador from 2010 to 2019.
2) Provide an ecological risk assessment of marine plastics for leatherback sea turtles that migrate within the Northwest Atlantic.
3) Identify current waste management strategies implemented in three Canadian maritime provinces, the United States, and the Wider Caribbean Region.
4) Identify successful measures that have been implemented to reduce the interaction of marine plastics and sea turtles.
5) Provide recommendations on where to focus efforts for reducing the impacts of plastics on leatherback turtles in Atlantic Waters.
6) Identify outstanding research needs on this topic.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Globally, leatherback turtles are listed as vulnerable under the IUCN Red List as a result of many anthropogenic pressures (Wallace et al., 2013). Over the centuries, leatherback populations have declined due to multiple threats deriving from commercial and residential development which threaten their nesting habitats, pollution (terrestrial and oceanic), egg harvesting, and climate change (Wallace and Saba, 2009). Leatherback turtles are globally distributed in oceanic and coastal waters, and sandy coastal terrain, which increases the potential of encountering a threat. A big conservation concern for leatherbacks is their interactions with fisheries. The industry is a great contributor of adult leatherback mortality through bycatch and entanglement (Wallace and Saba, 2009). The increase of plastic abundance in the ocean is contributing to leatherback population decline through different pathways of exposure including ingestion, entanglement, and habitat degradation (Nelms et al., 2016).

2.2 PLASTICS

Over the last decades, the production of plastic has increased heavily in response to rising demand (UNEP, 2016). The global production of plastic grew from 1.5 million to 368 million metric tons between 1950 and 2019 (Garside, 2020). From 1950 to 2015, the global production of resins and fibers has increased from two million to 380 million metric tons with half of the amount produced in the last 19 years (Geyer et al., 2017). Plastic is widely used in packaging, textiles, containers, construction material, fishing gear, automotive, and electronics (Andrady, 2011; UNEP, 2016). These plastics, which are ubiquitous in the ocean, are made up of different synthetic polymers, sizes, and originate from varying sources (UNEP, 2016; Steensgaard et al., 2017). The term plastic is simplified from its original term of thermoplastic which can be repeatedly deformed when heated (UNEP, 2016). Once exposed to UVB radiation, the polymers become brittle leading them to break down into smaller fractions. This characteristic contributes greatly to its ability to proliferate into the environment (Moore, 2008). Moreover, their hydrophobic properties combined with the surface area can allow for the accumulation of toxins and contaminants such as heavy metals and pathogens which can have sub-lethal to lethal impacts on wildlife (Koelmans, 2015). Plastics have varying life cycles and originate from different sources, either land or ocean-based, and have differing leakage points depending on what they are used for.

2.2.1 Types of Plastics

Plastics are commonly classified based on their size which include macroplastic, microplastic, and nanoplastic. Macroplastics are generally >5 mm in size, whereas microplastics are <5 mm or equal, and nano-plastics are considered as a subset ranging from 1-100nm (Thompson et al., 2004; Galloway et al., 2017; Rist and Hartmann, 2018). Microplastics are subdivided into two categories including primary or secondary. Regardless of the size, ample evidence suggests that these plastics can be harmful to wildlife through choking and starvation in addition to being carriers of pathogen and potential invasive species (Barnes, 2002; Vegter et al., 2014; Santos et al., 2015). The ability of plastic to remain at the sea surface is largely dependent on its buoyancy, which is measured through its density and specific gravity. If the specific gravity is greater than one, it will usually sink to the bottom (Li et al., 2016). Hence, all three types can be found throughout the ocean's water column.

2.2.1.1 Macroplastics

Globally, macroplastic pollution has been a persistent issue along shorelines and within oceanic waters. Macroplastics consist of large plastic items which are used in copious amounts and thrown away daily. Over the decades, macroplastics have been accumulating on remote island shores, as well as the sea surface, continental shelf beds, and deeper waters (Ryan and Moloney, 1993; Galgani et al., 2000). A big concern today is the abundance of single-use plastics which include a variety of items such as bags, cutlery, straws, food containers, and food wrappings (Schnurr et al., 2018). These large plastic items can have severe impacts on many organisms and the environment depending on their size and persistence (Werner et al., 2016). Evidence suggests that macro-sized debris, including plastics, can smother several species of coral and alter soft-bottom benthic assemblages (Katsanevakis et al., 2007; Moore et al., 2009; Rochman et al., 2016). While there is little evidence on macro-sized debris impacting assemblages, the increase in deaths of individual organisms may potentially lead to this outcome (Rochman et al., 2016).

Macroplastic pollution adversely impacts marine organisms through entanglement, ingestion, and habitat degradation (Nelms et al., 2016). Mortality caused by entanglement in items such as ropes, cable ties, nets, plastic bags, and package rings has been observed in at least 243 marine species. Most impacted by entanglement are marine invertebrates, seabirds, fish, and marine mammals (Gall and Thompson, 2015). Additionally, many of these species are exposed to the adverse effects of plastic through ingestion whether it is intentional or unintentional. The intentional ingestion of plastic occurs when a marine organism mistakes the plastic for prey. The unintentional ingestion of plastic is when the predator consumes prey that has already ingested plastic (Werner et al., 2016). Habitat integrity can drastically be impacted by macro-sized plastics. An abundance of plastics at the water surface and shorelines can act as ecosystem stressors and may alter the ecosystem biodiversity and function (Werner et al., 2016).

2.2.1.2 Microplastics

Microplastics have been subject to much study and have become the center of concern regarding plastic pollution. These plastics identify as either primary or secondary microplastics. Primary microplastics are manufactured to be a specific microscopic size, whereas secondary microplastics are derived from fragmentation of larger plastic size (Ryan et al., 2009; Cole et al., 2011). Primary microplastics are generally found in facial cleansers and cosmetics and are used as drug vectors in medicine and as abrasive blasting products (Zitko and Hanlon, 1991; Gregory, 1996; Patel et al., 2009). While up to 99% of these microplastics get retained in modern waste treatment, the abundance of microplastics released into the environment is still significant (Rochman et al., 2016). Secondary microplastics are formed by physical, biological, and chemical processes that alter their structural integrity and account for the majority of nanoplastics (Browne, 2007; Rist and Hartmann, 2018).

Similar to macroplastics, microplastics are commonly found along shorelines, within the water column, on the seabed, and until recently within organisms (Jamieson et al., 2019). Due to their microscopic size, these plastics are more easily and unintentionally ingested by marine organisms across several taxa. Commonly ingested microplastics are in the form of fragments and fibres (Burns and Boxall, 2018). Feeding behaviour is said to be a driving factor to the uptake of microplastics. Specialized feeders will often ingest microplastics unintentionally as they are feeding on their prey, whereas nonselective filter feeders may be more prone to uptake these particles (Scherer et al., 2018). While ingestion is receiving much attention, egestion is also an important aspect to consider. Given their small size, microplastics, such as microbeads and microfibres, may be as easily egested. However, the time for complete egestion to occur is dependent on the amount ingested and the organism's excretion efficiency (Grigorakis et al., 2017). In one study, microplastic fibres were found to take longer than microbeads to egest by an amphipod crustacean (Au et al., 2015). This may be due to their physical form.

Regardless of an organism being capable to fully egest the microplastics, evidence suggests that these particles can have adverse effects on marine wildlife. Once ingested, micro-size plastics can be harmful at the cellular level, lead to inflammation, alter gene expression, and can irritate and tear tissues (GESAMP, 2016; Rochman et al., 2016). Notably, the ecotoxic effects may cause changes in behaviour such as reduction in prey consumption which can lead to secondary adverse impacts (Foley et al., 2018).

2.2.2 Sources of Plastics

Globally, marine plastics of all size originate from varied sources, including land-based and ocean-based activities. Plastics originating from land enter the marine environment through numerous points of entry such as rivers, wastewater, and coastal habitats (UNEP, 2016). Sea-based debris coming from shipping and cruise vessels, fisheries and aquaculture has either been abandoned, lost, or intentionally discarded (GESAMP, 2016; UNEP, 2016).

2.2.2.1 Land-based

Land-based plastic is said to contribute to at least 80% of debris found in the environment (GESAMP, 2015). The amount of land-based plastic entering the ocean is largely dependent on how densely populated or industrialized a region is (Derraik, 2002). Different source sectors produce and convert plastics into products for various sectoral consumers. Many plastic products are used in agriculture, construction, terrestrial transportation, tourism industry, sport, textile industry, packaging, cosmetics, and personal care products. Most of these items are introduced into the environment through different entry points including rivers, coastlines, the atmosphere, and the open ocean. This is also true for the waste entering municipal solid waste management systems (GESAMP, 2016).

The plastic used in packaging products and housing materials is said to account for more than two thirds of production (Andrady and Neal, 2009). Moreover, plastic used for toys, automotive parts, furniture, textiles, and construction and electrical equipment accounts for the remainder of production (Andrady and Neal, 2009; UNEP, 2016). In 2016, it was estimated that 3,268 kilotons of plastic waste from industrial sectors was discarded in Canada alone. Of this, 47% consisted of single-use plastics (i.e. plastic bags, food packaging, and straws) and 19% consisted of other plastics products such as toys, chemicals, and household furniture. Other items such as textiles, automotive parts, electronical equipment, and agricultural products represented a smaller percentage of discarded plastics due to their extended use (Deloitte, 2019).

2.2.2.2 Sea-based

Sea-based plastic makes up 20% of the contributing factor for marine debris (Derraik, 2002). Sectoral sources and consumers include fisheries, aquaculture, in addition to shipping and offshore industries. The most common form of marine debris from the fishing industry consists of fishing gear (GESAMP, 2016). Often, fishing gear is lost, abandoned, or discarded at sea due to various causes, including conflicts between gear, poor weather conditions, and the deliberate discard of broken or malfunctioning equipment (Ayaz et al., 2010; GESAMP, 2016). Types of fishing gear that contribute to marine plastic debris include longlines, nets, traps, rope, and other items aboard the vessels such as trash, rubber gloves, and bait boxes and attached strings (Sheavly, 2005). Equipment used for aquaculture is also made of plastic and can contribute to the abundance of marine debris. This industry uses cages that are suspended from buoyant structures that are made of plastic, as well as lines that hold these structures into place. The causes associated with this gear loss are similar to those of fisheries (i.e. storms, conflict, malfunction, weathering of gear) (GESAMP, 2016).

The shipping and offshore industries contribute a sizeable amount to marine debris. Large vessels carry supplies for a large crew that reside at sea for months generate a significant amount of waste that may be disposed of at sea (Sheavly, 2005). A source of microplastic that leaks into the ocean from these vessels are found in the abrasive cleaning products that are used daily (Song et al., 2015). Moreover, incidents of mishandled cargo and accidental spills contribute largely to the microplastic abundance found in harbour sediments (GESAMP, 2016). Similar waste originates from oil and gas platforms and scientific vessels which may in addition lose equipment. Items such as hard hats, gloves, storage bins, single-use plastics, meteorological balloons, and passive drifters also originate from sea-based activities (Allsopp et al., 2006; GESAMP, 2016).

It is important to consider the amount of plastic entering the marine environment from cruise ships. Cruise ship tourism is a fast-growing industry with over 300 cruise ships operating, globally. A single vessel can carry between 2,000 to 3,000 passengers and can generate 1,000 tonnes of waste per day which include toxic waste, garbage (i.e. single-use plastic), and wastewater (Oceana, 2004). Cargo waste, including plastics, can also be deposited into the marine environment accidentally by improper handling or unfavourable weather conditions (GESAMP, 2016).

2.3 Plastic Abundance and Distribution in the Marine Environment

As stated, plastic has become omnipresent in the marine environment. However, quantifying its abundance is not a simple task. Macroplastics are easily observed at the water surface and along the coasts. Still, their abundance on the seabed remains unclear, which can also be said for microplastics. A global estimate of five to 50 trillion tonnes of microplastic on the sea surface has been determined. However, this estimate is based on data obtained only from the North Pacific Ocean and the North Atlantic Ocean (van Sebille et al., 2015). Moreover, microplastics have been observed in remote areas including the Arctic, in sea ice, and in the Southern Ocean (Barnes et al., 2010; Obbard et al., 2014). Floating microplastics are often observed in subtropical gyres in the North and South Atlantic, the Indian Ocean, the North and South Pacific Ocean, and in the Mediterranean where the marginal areas are densely populated (Cózar et al., 2014). Additionally, plastics aggregate in converging ocean currents, creating garbage patches throughout the ocean. Norén and Naustvoll (2010) measured a maximum concentration of 100 000 particles m^3 residing in these patches. Ocean fronts are dynamic zones that play a significant role in marine ecosystems. The surface convergences contribute to high primary production and are hot spots for marine life aggregation. These high biodiversity areas serve as spawning, nursing, and feeding habitats for many fish, marine mammals, and marine turtles (Belkin et al., 2009).

2.4 Marine Turtles and Plastics

Plastics have been reported to cause harmful impacts on marine wildlife (Ceccarelli, 2009). Marine turtles are charismatic species that have been used as a poster child in the media to draw public attention to the impacts of single-use plastics such as straws and plastic beverage rings. Sadly, all marine turtle species are impacted by the presence of plastic in their habitats consisting of both terrestrial and marine. There are only seven marine turtle species that remain and that have all been impacted by plastic debris (Nelms et al., 2016).

2.4.1 Leatherback Ecology

The leatherback turtle (*Dermochelys coriacea*) is widely distributed in the marine environment and is better known for its extensive migration. The Atlantic Leatherback subpopulation is listed as endangered under the Species At Risk Act and the IUCN Red List (The Northwest Atlantic Leatherback Working Group, 2019; DFO, 2020d). Out of the seven marine turtle species, it is the only one that migrates to cold northern waters in higher latitudes to forage. The leatherback sets itself apart as being the largest turtle found in the ocean and the fact that it is the only marine turtle to generate heat internally, and not from the environment, which contributes to its tolerance to cold water (Spotila and Standora, 1985). Throughout its life cycle, this species occupies terrestrial and marine habitats which yield the necessary components to facilitate growth and reproductive success (Eckert et al., 2012).

2.4.1.1 Distribution

Leatherback turtles occupy a wide geographic range including tropical, subtropical, and subpolar regions (Eckert et al., 2012). The leatherback's geographic distribution includes the pan-Atlantic (western and eastern central, northeast, northwest, southeast, and southwest), Indian Ocean (eastern and western), the Mediterranean and Black Sea, and the Pacific (eastern, western central, northeast, northwest, southeast, southwest) (Wallace et al., 2013). For simplification, the leatherback population is divided into subpopulations such as the Pacific leatherback (western and eastern) and the Atlantic leatherback. These subpopulations each have distinct migratory patterns (NMFS and UFWS, 2020).

For the purpose of this project, the distribution of the Atlantic leatherback subpopulation will be the central focus of this section (Figure 1). The Atlantic leatherback is well known for its extensive migration into northern cold waters. Individuals demonstrate a large variation between migratory paths following nesting season (Fossette et al., 2010). Some leatherbacks disperse widely to forage into higher latitudes, going as far as Cape Breton Island, Nova Scotia, the Grand Banks, and Newfoundland (James et al., 2006). Turtles nesting below in regions below the equator, such as French Guinea and Suriname, can migrate northwest, northeast or eastward, while others nesting in Panama travel shorter distances to the Gulf of Mexico (Fossette et al., 2010). Migrations from nesting beaches to the northern hemisphere reoccur seasonally as many individuals exhibit spatial fidelity during their foraging years (James et al., 2005). Similarly, turtles migrating to the eastern Atlantic from the Caribbean exhibit the same migratory behaviour. Individuals will migrate to regions within the Atlantic that are familiar to them, rather than dispersing into uncharted regions (Fossette et al., 2010).

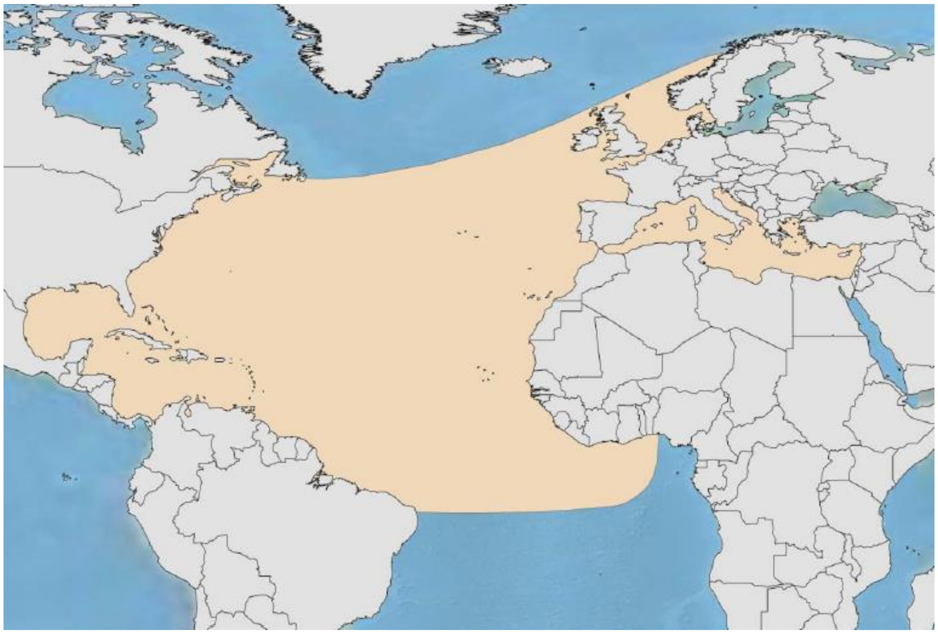

Figure 1**.** Map representing the distribution of the Atlantic Leatherback subpopulation directly copied from Wallace et al. (2013).

2.4.1.2 Nesting Beaches

During mating season, female marine turtles emerge from the ocean onto sandy beaches along the coast of many countries to lay their eggs in deep nests. Nesting season is typically nocturnal as lunar, solar, and tidal patterns act as strong environmental cues (Law et al., 2010a). Generally, female turtles carefully chose their nest sites to minimise the exposure of undesirable conditions to avoid causing physiological and energetic stress (Pike, 2008). Interestingly, female leatherbacks tend to lay their clutch on dynamic beaches where conditions are unpredictable and are varying between individual nests (Schulz, 1975). They may have developed this random nesting strategy to increase the probability of survival and reproductive success (Kamel and Mrosovsky, 2004). Northwest Atlantic leatherbacks tend to nest along the coast of the United-States (Florida), the Wider Caribbean Regions (Trinidad, St. Croix, Grenada), Costa Rica, and South America (French Guiana, Brazil) (Ferraroli et al., 2004; Stewart et al., 2016).

2.4.1.3 Life Stages

The leatherback turtle has a complex life cycle that can be classified into three stages for simplicity. The first being pre- (eggs) and post-hatchling, followed by juvenile and sub-adult, and lastly the adult stage. During their developmental stages (hatchling, juvenile and sub-adult), they make use of different habitats including sandy beaches, coastal waters, and pelagic waters (Eckert et al., 2012). Pre- and post-hatchlings occupy nesting beaches in subtropical and tropical regions. Leatherback eggs remain buried in the sand, approximately 80 cm deep, until developed and ready to hatch in a synchronous fashion to aid with survival success (Swiggs et al., 2018). There are combined ecological factors that contribute to the survival of these hatchlings. Nest success is influenced by temperature, moisture, and site selection with respect to vegetation and water (Wood and Bjorndal, 2000; Hilterman and Groverse, 2007).

Temperature is an important factor during the incubation period of the pre-hatchlings as it influences the sex ratio, which is known as temperature-dependent sex determination (Mrosovsky and Yntema, 1980; Ceriani and Wyneken, 2008; Woolgar et al., 2013). Temperature triggers the development of either female or male gonads - at warmer temperatures female hatchlings are produced and cooler at temperatures males are produced (Ceriani and Wyneken, 2008; Woolgar et al., 2013). At lower depths, temperature tends to fluctuate less as it is less susceptible to climatic variability (Ackerman and Lott, 2004). However, the deeper the nest the longer it will take the hatchling to emerge while being exposed to harsher environmental conditions (Mrosovsky, 1968; Patino-Martinez et al., 2012). From the moment turtles begin to hatch, they face multiple life-threatening obstacles. As leatherbacks tend to choose their nests at random, these threats can be varying between clutches. There is also variability between hatchlings from the same clutch. For instance, the first emerging hatchlings may be at greater risk of predation than the last hatchlings, while the last emerging hatchlings may have greater chances of mortality from energy expenditure (Triessnig et al., 2012). Consequently, the chances of survival for hatchlings are very low and the survival rate is often cited as 1:1000 (Frazer, 1986).

Pelagic drifting, also referred to as the “lost years”, is the period when hatchlings and juvenile turtles are transported by currents from their natal beaches to oceanic zones of high productivity (Scott et al., 2014). The term “lost years” is used to represent the period between the first time the hatchling contacts the ocean to its first sighting (by humans) as a juvenile in neritic foraging waters (Carr, 1987). The oceanic currents transport these turtles to areas where oceanic convergences occur such as upwelling areas (Bolten, 2003). These areas are of high productivity and are considered hot spots for foraging (Schuyler et al, 2013). Unfortunately, there is a lack of data regarding the "lost years" which warrants further investigation as this may be when leatherbacks are most vulnerable (Nelms et al., 2016).

2.4.1.4 Feeding Habits

The North Atlantic leatherback turtle demonstrates flexible foraging movements that are largely dependent on the availability of its prey (Hays et al., 2006). Leatherback turtles primarily feed on gelatinous zooplankton that reside in shelf, slope, and oceanic habitats (Shillinger et al., 2008). Individuals migrating from temperate water to cold water do so to feed on jellyfish. Throughout foraging seasons, leatherbacks are seen in abundance in Canadian waters. Sightings have been reported along the Scotian Shelf and in the Southern Gulf of St. Lawrence during summer and fall months (James et al., 2006). Consequently, leatherback foraging sites overlap heavily fished areas resulting in reductions of prey and forces them to forage at higher latitudes where their prey may be more abundant.

2.4.2 Pathways of Effect and Effects

As migratory species in coastal waters, the leatherback turtle is likely to have a high probability of encountering plastic debris. As previously stated, plastic is omnipresent in both terrestrial and marine environments that overlap critical sea turtle habitats. Throughout the decades, research has helped identify possible pathways of effects of plastics for many marine organisms including the leatherback turtle. Possible pathways of effects include ingestion and entanglement, in addition to the environmental impacts on nesting beaches and emerging hatchlings (Table 1). Despite these advancements, there is still a need for supplemental research to completely understand the pathways and effects of plastic exposure for marine turtles (Nelms et al., 2016).

Table 1. Possible pathways of exposure and the possible effects of plastics for leatherback turtles.

Pathways of Effects	Effects
Ingestion	• Intestinal blockage • Reduced gut absorption • Reduced energy storage • Impaired health and reproduction
Entanglement	• Injury (abrasions, limb loss) • Reduced ability to avoid predators • Reduced ability to forage • Long term suffering - slow deterioration
On Nesting Beaches	• Abortion of nesting attempts • Trapping emerging hatchlings • Increasing vulnerability to predation • Increased energy expenditure • Egg desiccation • Alteration in sex ratio • Plasticizer exposure altering physiological processes

Note. Type of effects from Mrosvosky et al. (2009), Oehlmann et al. (2009), Plot and Georges (2010), Carson et al. (2011), Triessnig et al. (2012), Hoarau et al. (2014), Poeta et al. (2014), and Nelms et al. (2016).

2.4.2.1 Ingestion

The ingestion of plastic can lead to severe adverse effects in marine organisms, especially marine turtles (Table 1). Both macro- and micro-plastics can be ingested either directly or indirectly by turtles. Reports of direct ingestion from feeding on their prey and by mistaken identification of the nourishment has been documented over the years (Mrosovsky et al., 2009; Schuyler et al., 2014). Items ingested, such as plastic bags, balloons, sheet plastics, and bottle caps have been reported across taxa (Mrosovsky, 1981; Gregory, 2009; Hoarau et al., 2014). Leatherbacks have been observed to consume on average 10 jellyfish per hour and based on energy calculations, they require 65 to 260 kg of jellyfish per day (Duron, 1978; Lutcavage and Lutz, 1986). As marine turtles are visual feeders, leatherbacks can easily mistake plastic bags for gelatinous zooplankton which can lead to serious impacts such as gut blockage or can impair reproduction and overall health (Mrosovsky et al., 2009). Moreover, indirect ingestion can occur through jellyfish consumption as jellyfish have also been reported to have plastic in their gastrovascular cavity (Macali et al., 2018). It is important to consider that the risk of exposure and adverse impacts can vary throughout the life cycle. For instance, hatchlings and juvenile turtles are smaller and may experience sub-lethal to lethal effects from ingesting a smaller amount of plastic in comparison to adult leatherbacks (Nelms et al., 2016).

2.4.2.2 Entanglement

Entanglement is a common hazard caused by various fishing gear that has either been abandoned, lost, or otherwise discarded (derelict fishing gear). Derelict fishing gear can lead to the incidental capture of marine taxa including turtles (Wallace et al., 2013). Marine turtle bycatch has been studied extensively and is a worldwide issue. Studies report that entanglement is one of the main causes associated with population declines of marine turtles (Lucchetti et al., 2017). For some species, such as the leatherback, entanglement has been reported globally. Different types of commercial fishing gear are distributed throughout the marine environment, each having been reported to interact with marine turtles (Hamelin et al., 2017). Bycatch from set nets can cause apnoea (stop breathing) which ultimately results in death by drowning (Lucchetti et al., 2017). Other types fishing gear, such as passive nets, have been reported to lead to comatose states as a result of exhaustion from trying to swim free (Echwikhi et al., 2010). Plastic debris and derelict fishing gear can also cause serious injury, such as forelimb amputation, which can have secondary negative impacts (Barreiros and Raykov, 2014) (Table 1).

2.4.2.3 On Nesting Beaches

Nesting beaches are critical habitats for marine turtles and are subject to multiple pressures, including destruction through coastal development, in addition to sea-level rise, and erosion (Fuentes et al., 2010). Moreover, these areas are natural collectors of plastic waste generated from the tourism industry, local traffic, or plastics originating from the ocean (Triessnig et al., 2012; Poeta et al., 2014). The presence of plastics on the shorelines create obstacles which can deter females from laying their eggs as they require a lot of energy to crawl onto the beaches to subsequently lay their clutches (Chacón-Chaverri and Eckert, 2007). Additionally, there may be the chance of encountering derelict fishing gear which can lead to entanglement leaving females stranded (Ramos et al., 2012). This is also true for emerging hatchlings. Microplastics within the sand column can make it difficult for hatchlings to emerge from their egg chamber (Nelms et al., 2016). Not only do microplastics act as an obstacle in the sediment, there is also evidence that they can alter the permeability and temperature of the nests. As stated earlier, this is significant as temperature plays a leading role in hatchling sex determination and can consequently alter the sex-ratio. Moreover, an increase in nest permeability resulting from microplastics can cause reduced humidity resulting in desiccation of the eggs (Carson et al., 2011) (Table 1). These cumulative effects can have grave consequences for global population numbers of leatherback turtles.

2.4.3 Summary

To summarize, based on the review by Nelms et al. (2016), evidence suggests that plastic ingestion by marine turtles, in comparison to entanglement, is the most common pathway of exposure across taxa. Exposure to macro- and micro-plastics can occur throughout the leatherback's life cycle as they spend most of their time foraging in pelagic waters. These effects can also be more severe for hatchlings given their small size and accumulation of plastic in the gut which cannot be detected by humans when alive. With entanglement, the chances of humans interfering to remove the nets and treating wounds or lacerated flippers is more likely to occur. Moreover, the ingestion of plastic can cause systemic health issues leading to impaired reproduction and feeding habits, whereas with entanglement the effects are more likely to be superficial (i.e. wounds) which can heal on their own. To date, few studies have investigated whether marine plastics can induce mortality in hatchlings on the nesting beaches. This is an area of study that needs more attention as these are critical habitats where leatherbacks are extremely vulnerable. To conclude, there is a need for further research to fill knowledge gaps on the effects of plastics on leatherback turtles. Specifically, assessing how these plastics interact with marine turtles throughout their entire life cycle is needed.

CHAPTER 3: ECOLOGICAL RISK ASSESSMENT OF PLASTICS TO LEATHERBACKS

3.1 INTRODUCTION

In response to the increasing amount of litter in the environment and concerns about its effects on wildlife, various initiatives have been implemented to clean up and monitor the abundance and characteristic of this litter. As Canada has the longest coastline in the world measuring 243,042 km and it is the responsibility of Canadians to clean it up to avoid wider contamination in the environment (Statistics Canada, 2016). NGOs such as the Ocean Wise and WWF Canada have teamed up together to lead the Great Canadian Shoreline Cleanup. This is an initiative that encourages the public to engage in picking up debris found in the environment, specifically, along the coast and in watersheds. Organizations such as Greenpeace Canada designed initiatives such as the Plastic Polluters Brand Audit of shorelines and green spaces, essentially an initiative to identify which major corporation's products contribute to the accumulation of plastic waste. Plastics collected off Canadian shorelines originate from either land- or ocean-based activities and have likely been transported by ocean currents from different entry points. The plastic generated from coastal zones can subsequently enter the wider, offshore marine environment.

During their travel, plastics can pose sub-lethal to lethal threats on marine life through entanglement and ingestion (Nelms et al., 2016). Marine turtles are in the top six species being severely affected by marine debris (Gall and Thompson, 2015). An analysis assessing the overall risk of plastic ingestion by all marine turtle species predicted global hotspots of these occurrences. Schuyler et al. (2016) modelled the probability of debris ingestion using estimated exposure rates of debris from global predictions of debris distribution and the consequence of exposure (ingestion), in addition to incorporating different ecological factors for each species. Schuyler et al. (2016) predicted that leatherbacks are at an overall moderate risk of debris ingestion in the Northwest Atlantic Ocean (Figure 2). However, this study does not evaluate other potential threats (i.e. on nesting beaches, entanglement) associated with plastic debris and further research is needed at both the species and population levels (Schuyler et al., 2016). This section will provide an ecological risk assessment of plastic for leatherback turtles that migrate within the Northwest Atlantic by evaluating the abundance of plastics collected from shorelines of Nova Scotia, Prince Edward Island, Newfoundland and Labrador, and Sable Island.

Figure 2. Map of global hotspots of the risk of leatherbacks ingesting marine debris in the ocean. Dark shading represents a higher risk, whereas the lighter shading represents a lower risk directly copied from Schuyler et al. (2016).

3.2 Methodology

This section discusses the quantity, type, and origins of plastic debris on the saltwater shorelines of Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. Data on plastics collected from 2010 to 2019 kindly provided by the Great Canadian Shoreline Cleanup were assessed and analyzed, in addition to reviewing and discussing the plastic data collected from Sable Island by Plastic Polluters Brand Audit.

3.2.1 Great Canadian Shoreline Cleanup

In 1994, the Great Canadian Shoreline Cleanup began in British Columbia by a group of volunteers at the Vancouver Aquarium who decided to clean up the beach in Stanley Park. From then on, the initiative grew across the province and country to rapidly becoming a national conservation initiative. In 2010, a partnership with WWF-Canada developed, followed by the partnership with Ocean Wise in 2017. As one of the largest action conservation programs in Canada, the Great Canadian Shoreline Cleanup continues to grow and inspire Canadians to keep the shorelines and waterways clean from debris. Since its establishment, volunteers have collected more than 2 million kg of litter from 44,262 km of Canadian freshwater and marine shores (GCSC, 2020a). Volunteers can host their own community cleanup events across Canada. Following the cleanup event, participants are responsible for sending their recorded data to the Great Canadian Shoreline Cleanup and for arranging waste disposal with their municipality (GCSC, 2020c). Depending on the waste facilities available, the waste may get disposed of in landfills, may be recycled, or incinerated.

The Great Canadian Shoreline Cleanup initiative provided this study with comprehensive data on marine debris collected from 2009 to 2019. However, the data are solely gathered through citizen scientists which can result in discrepancies in location and timing throughout the years. The accuracy and consistency of data collection might differ across Canada as it is difficult to monitor a wide volunteer program. Moreover, amounts might be lower than what is actually present as a result of insufficient participation to fully clean up the shorelines.

3.2.2 Plastic Polluters Brand Audit

The Plastic Polluters Brand Audit was conducted in 2018 as part of the first World Cleanup Day on Sable Island. The goal of this initiative was to help identify the corporations whose products are contributing to the plastic accumulation on inland waters and the ocean (Lucas, 2018).

3.3 Results

From 2010 to 2019, approximately 16,000 volunteers participated in the Great Canadian Shoreline Cleanup initiative in Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. Data collected from various sites include total weight of debris collected, length of the areas cleaned, and the number of items collected per category. From this data, plastic items such as tiny plastic and foam particles, bottle caps (plastic and metals), straws and stirrers, utensils, cups, fishing buoys, pots or traps, plastic containers, miscellaneous wrapping and personal hygiene products were separately identified from 2017 onwards. In comparison, from 2009 to 2016 these items were combined into broader categories. This is important to note and to not confuse with the notion of these items suddenly appearing on the shorelines as of 2017. For the purpose of this project, quantity of plastic debris and type of plastic debris collected from saltwater sites for Nova Scotia, Prince Edward Island, and Newfoundland island (hereinafter referred to as Newfoundland) have been compiled into graphs. Debris was collected on shorelines of

Newfoundland and Labrador; however, all saltwater collection sites are on the province's island. On September 16th, 2018, 15 km of Sable Island's south shoreline were surveyed for the purpose of a marine debris brand audit to identify which corporations are associated with the litter (Lucas, 2018).

3.3.1 Quantity of Plastic Debris

Quantities of plastic debris collected on the shorelines of Nova Scotia, Prince Edward Island, Newfoundland, and Sable Island are represented in the Figures below. Total plastic items collected per year are separated into individual columns.

3.3.1.1 Nova Scotia

Figure 3 shows the number of plastic items collected from various shoreline locations in Nova Scotia from 2010 to 2019. During this period, a total of 132,541 plastic items were collected from 317 sites. The highest quantity of plastics is in 2017 with 18,691 items collected from 35 sites (534 items/site). The type of plastic item with the highest number for 2017 is rope, with 4,211 items retrieved. Plastic items collected from 2010 to 2012 are the lowest, which corresponds with the average number of sampling sites (30) being lower than the average number of sampling sites (32) for the period of 2013 to 2019. In 2010, 8,380 items were collected from 30 sites (279 items/site), 9,075 items were collected from 29 sites (312 items/site) in 2011 and 9,270 items were collected from 33 sites (294 items/site) in 2012. In 2014, 15,292 items were collected from 32 sites (478 items/site), 13,523 items were collected from 23 sites (588 items/site) in 2015, 10,249 items were collected from 24 sites (427 items/site) in 2016, 16,379 items were collected from 32 sites (512 items/site) in 2018, and 12,317 items were collected from 37 sites (360 items/site) in 2019 (Figures 3 and 4). The average (i.e. mean) number of plastic items collected for 2010 to 2012 is 9,058 and the median for the number of items collected for 2013 to 2019 is 15,292. The change between 2010-2012 and 2013-2019 may be due to more efficient collection methods and increased number of participants (Figure 3).

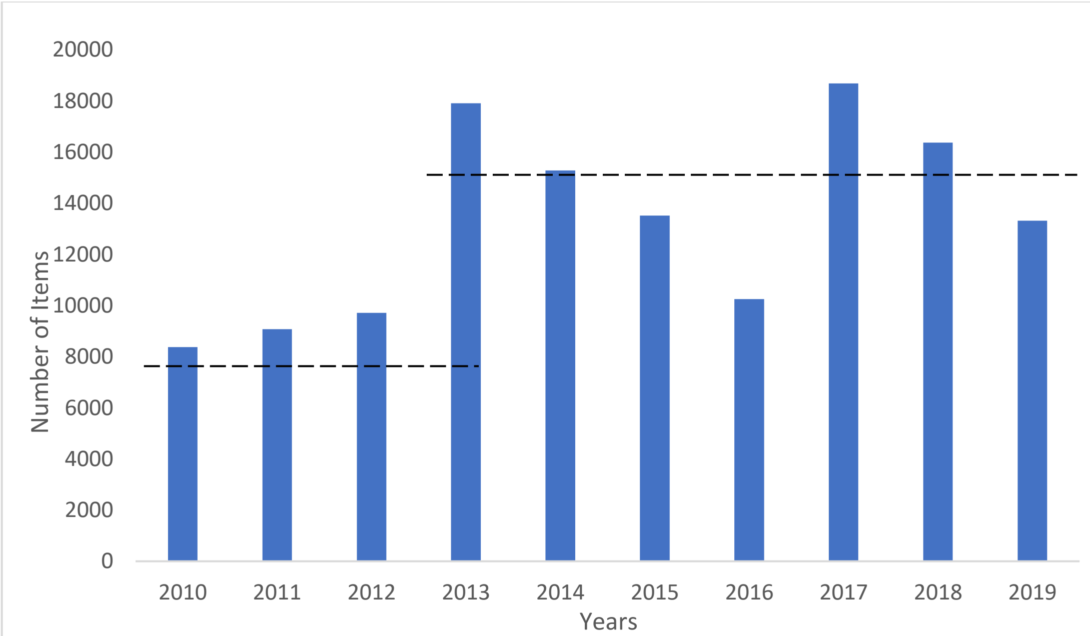

Figure 3. Bar graph depicting the total number of plastic items collected per year from 2010-2019 on the shorelines of Nova Scotia by the Great Canadian Shoreline Cleanup. The dash lines represent the average ($\overline{x}$) (9,058) of items for 2010-2012 and the median (15,292) of items for 2013-2019.

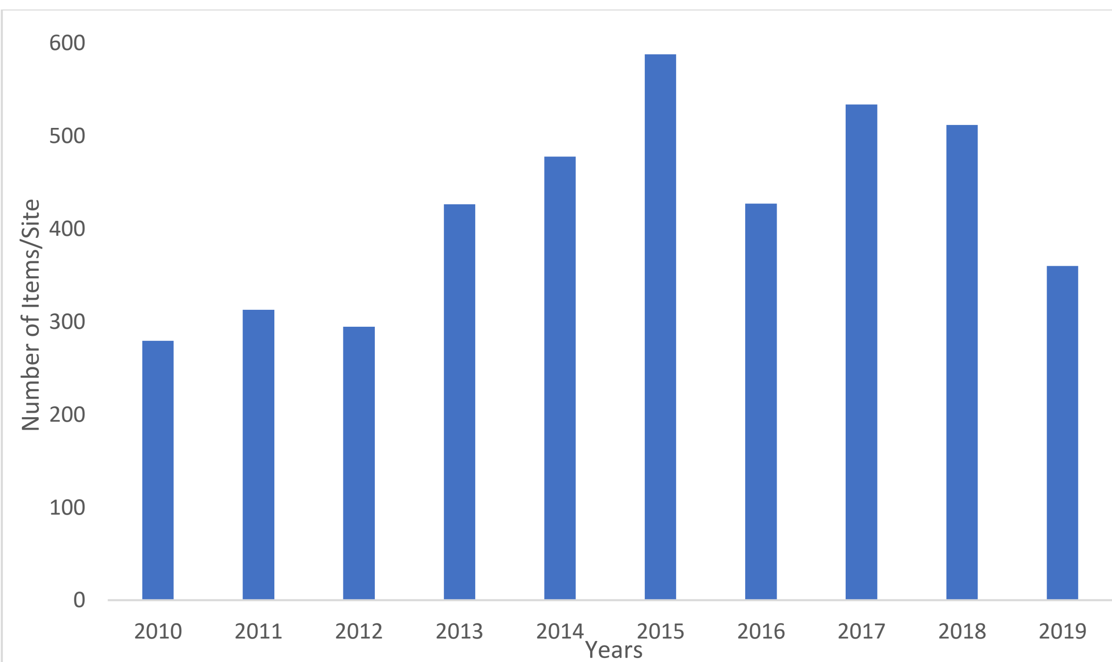

Figure 4. Bar graph depicting the average number of plastic items collected per site for each year from 2010-2019 on the shorelines of Nova Scotia by the Great Canadian Shoreline Cleanup.

3.3.1.2 Prince Edward Island

Figure 5 depicts the number of plastic items collected from various shoreline locations in Prince Edward Island from 2010 to 2019. During this period, a total of 23,502 plastic items were collected from 118 sites. The highest quantity of plastics is in 2015, with 3,981 items collected from 28 sampling sites (highest number of sample sites) (142 items/site). The type of plastic item with the highest number for 2015 is plastic pieces, with 935 items collected from one site. The second highest value is in 2017, with 2,965 items collected from four sites. The type of plastic item with the highest number for 2017 is tiny plastics, with 1,218 items retrieved. The median for the number of items collected between 2010 to 2019 is 2,302. The median was chosen over the average to account for the outliers. The average number of items per site for each year consists of 298 items/site for 2010, 172 items/site for 2011 and 2012, 207 items/site for 2013, 173 items/site for 2014, 201 items/site for 2016, 741 items/site for 2017, 98 items/site for 2018 and 259 items/site for 2019 (Figure 6).

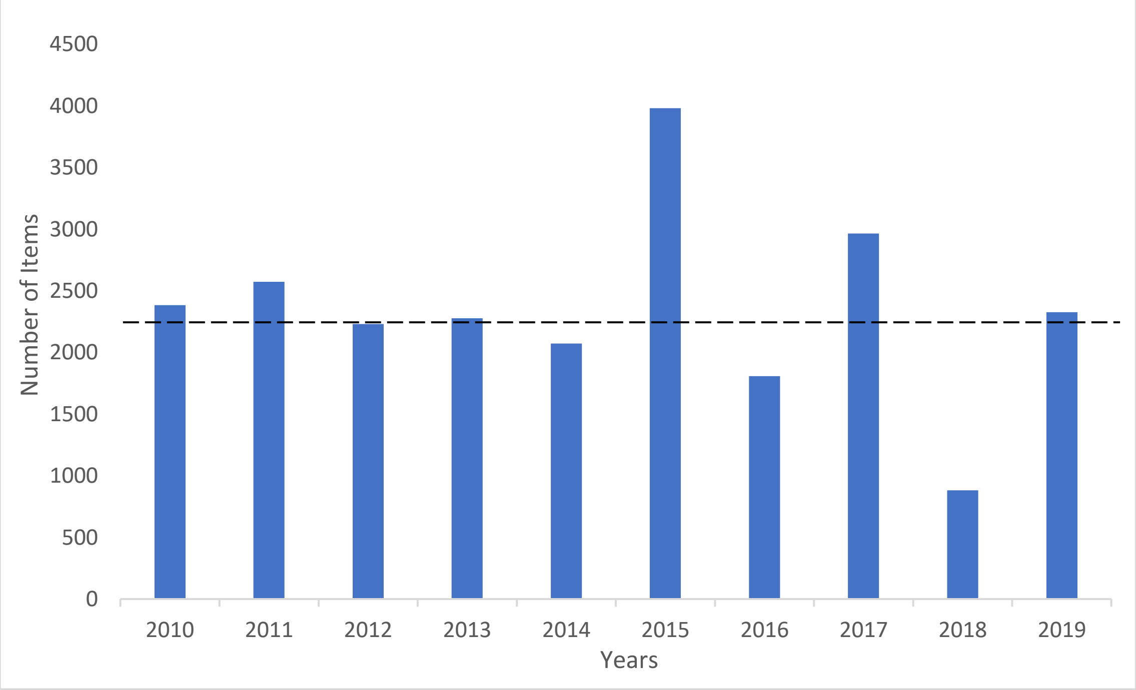

Figure 5. Bar graph depicting the total number of plastic items collected per year from 2010-2019 on the shorelines of Prince Edward Island by the Great Canadian Shoreline Cleanup. The dash line represents the median (2,302) of items for 2010-2019.

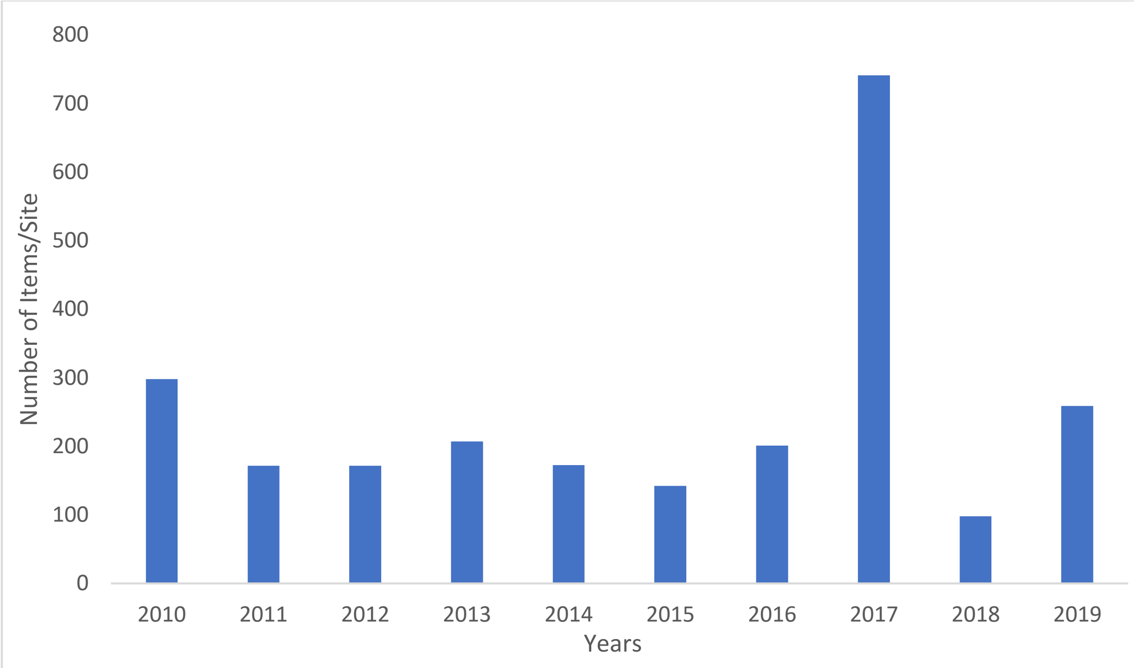

Figure 6. Bar graph depicting the average number of plastic items collected per site for each year from 2010-2019 on the shorelines of Prince Edward Island by the Great Canadian Shoreline Cleanup.

3.3.1.3 Newfoundland

Figure 7 depicts the number of plastic items collected from various shoreline locations in Newfoundland from 2010 to 2019. During this period, a total of 77,824 plastic items were collected from 151 sites. The highest quantity of plastics is in 2018, with 26,903 items collected. This corresponds with the number of sampling sites being the second highest (21). The type of plastic item with the highest number for 2018 is cigarettes/cigarette filters, with 6,917 items retrieved. A total of 2,538 cigarette/cigarette filters were collected from one site for that year**.** In 2019, only 3,965 plastic items were collected, which is the lowest number of items collected and from the highest number of sampling sites (22). The median for the number of items collected between 2010 to 2019 is 5,088. The median was chosen over the average to account for the outlier seen in 2018. The average number of items per site for each year consists of 345 items/site for 2010, 449 items/site for 2011, 294 items/site for 2012, 530 items/site for 2013, 469 items/site for 2014, 442 items/site for 2015, 599 items/site for 2016, 348 items/site for 2017, 1281 items/site for 2018 and 180 items/site for 2019 (Figure 8).

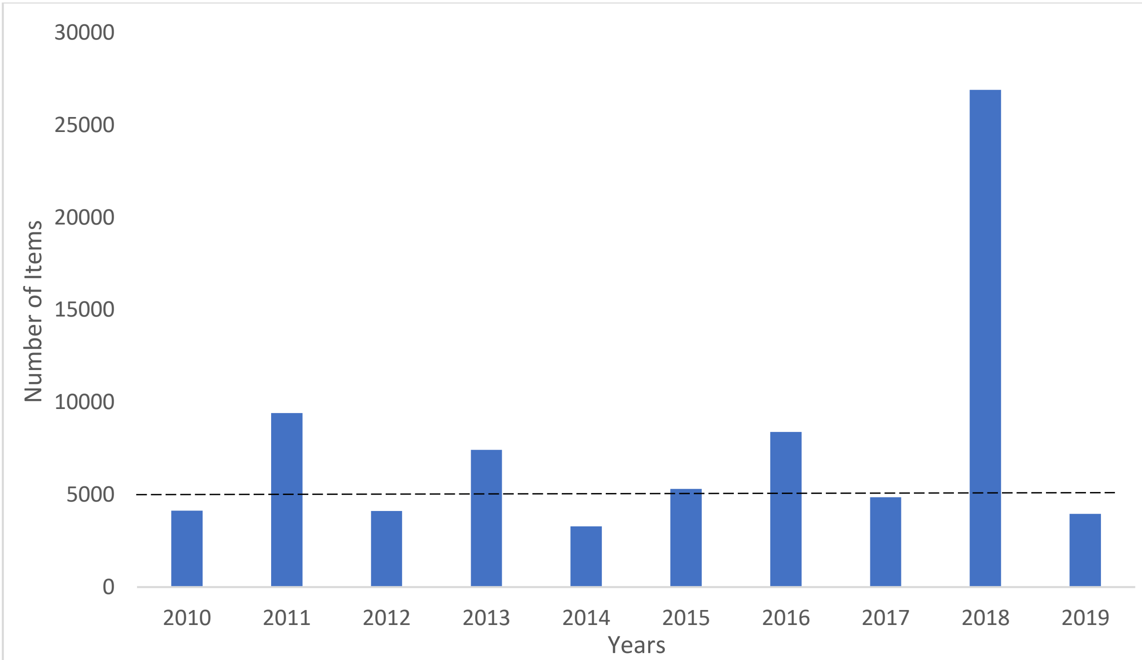

Figure 7. Bar graph depicting the total number of plastic items collected per year from 2010-2019 on the shorelines of Newfoundland by the Great Canadian Shoreline Cleanup. The dash line represents the median (5,088) of items for 2010-2019.

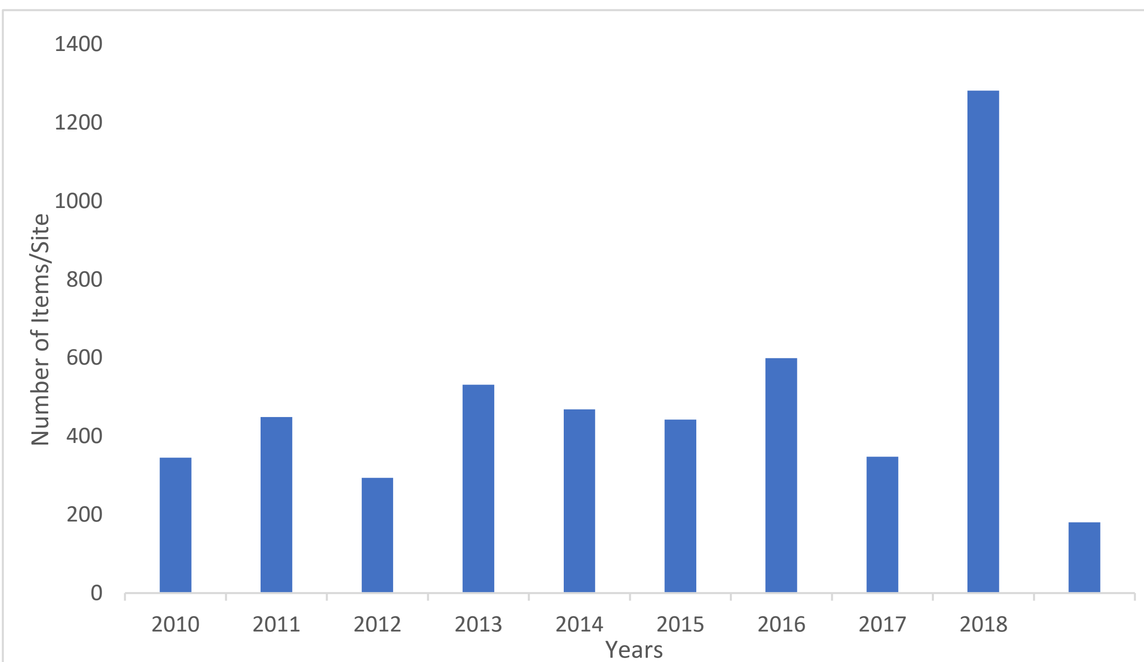

Figure 8. Bar graph depicting the average number of plastic items collected per site for each year from 2010-2019 on the shorelines of Newfoundland by the Great Canadian Shoreline Cleanup.

3.3.1.4 Sable Island

Due to the nature of the brand audit project, only labelled plastic items were collected. A total of 111 labelled items were collected during this survey on September 16th, 2018. Labelled items were collected which represented an estimated 10% of the plastic found of the shorelines (Lucas, 2018).

3.3.2 Types of Plastic Debris

Since 2010, volunteers have categorized each plastic item collected. From this data, plastic items such as tiny plastic and foam particles, bottle caps (plastic and metal), straws and stirrers, utensils, cups, fishing buoys, pots or traps, plastic containers, miscellaneous wrapping, and personal hygiene products were separately identified from 2017 onwards. Hence, for 2009 to 2016 these items were classed in broader plastic categories or were simply not present.

3.3.2.1 Nova Scotia

Figure 9 represents the total number of plastic items per category collected from the shorelines of Nova Scotia from 2010 to 2019. Types of items listed on the figure exceed 1,000; categories having less than 1,000 items were omitted from the graph for visual purposes. Some of these items include plastic containers and utensils, recycling bags, fishing line and random items, such as syringes, tires, condoms, and others. Types of items are further categorized based on origin. Land-based activities are classified as: shoreline and recreational activities, smoking-related, hygiene and medical, other plastic items and automotive, construction and household items. Ocean-based activities are classified as commercial and recreational fishing activities. Types of items having the highest value include cigarettes/cigarette filters (37,787), rope (14,436), and tiny plastic or Styrofoam pieces (10,010).

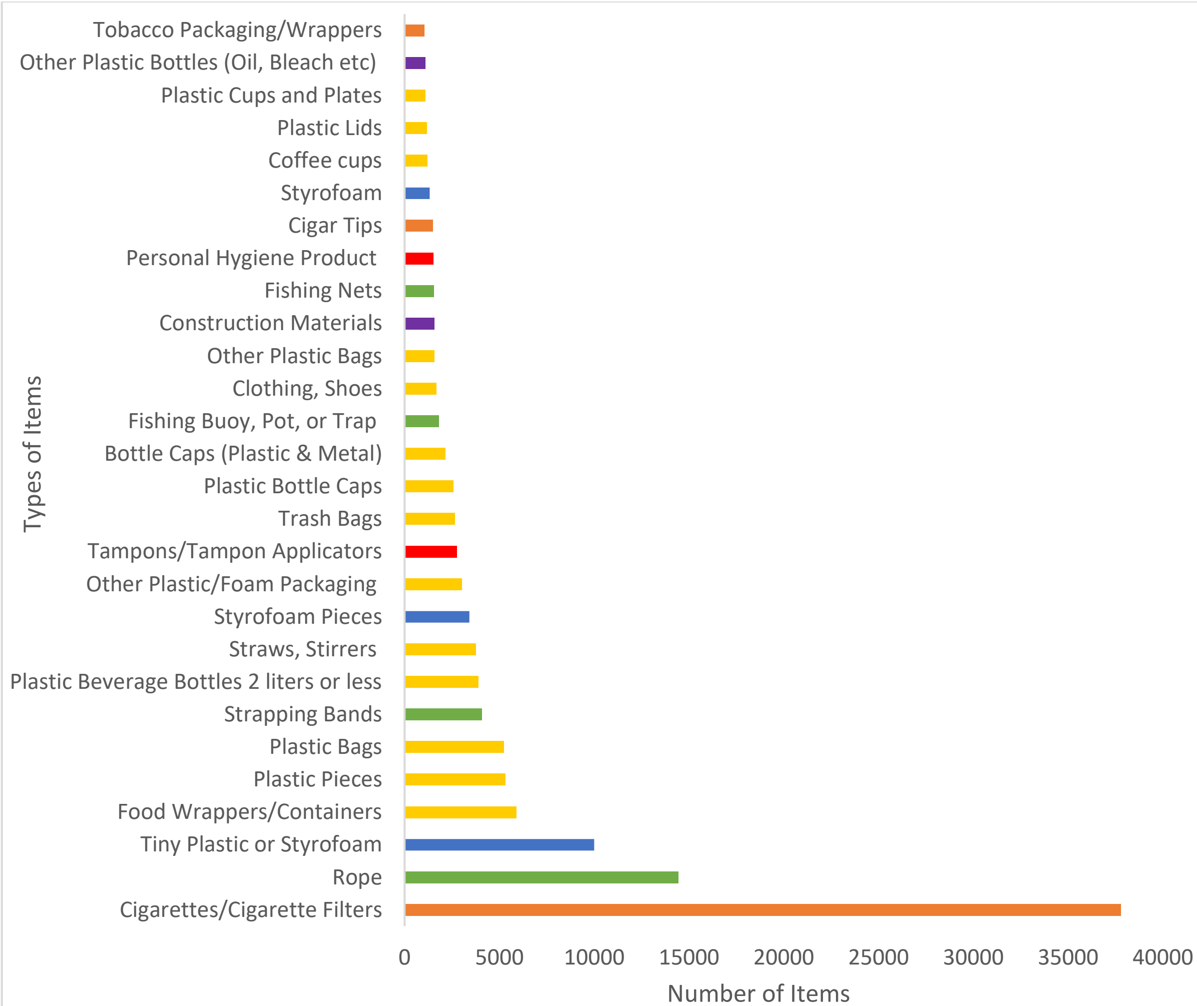

Figure 9. Bar graph representing the total number of plastic items collected from 2010 to 2019 on the shorelines of Nova Scotia by the Great Canadian Shoreline Cleanup. Items such as tiny plastic and foam particles, bottle caps (plastic and metals), straws and stirrers, utensils, cups, fishing buoys, pots or traps, plastic containers, miscellaneous wrapping and personal hygiene products were separately identified from 2017 onwards. Plastic items originating from land and ocean-based activity are represented by individual coloured bars; shoreline and recreational activities (yellow), smoking-related (orange), hygiene and medical (red), other plastic items (blue), automotive, construction and household items (purple) and commercial and recreational fishing activities (green).

3.3.2.2 Prince Edward Island

Figure 10 depicts the total number for each category of plastic items collected from the shorelines of Prince Edward Island from 2010 to 2019. Types of items listed on the figure exceed 1,000; categories having less than 1,000 items were omitted from the graph for consistency. Some of these items include fishing line, toys, cigar tips, plastic and foam containers/wrapping/utensils, recycling bags, coffee cups and plates and random items such as syringes, tires, condoms, and others. Types of items are further categorized based on origin. Land-based activities are classified as: shoreline and recreational activities, smoking-related, hygiene and medical, other plastic items, and automotive, construction and household items. Ocean-based activities are classified as commercial and recreational fishing activities. Items having the highest value include rope (3,057), tiny plastic or Styrofoam (2,360), and fishing buoy, pot, or trap (2,084).

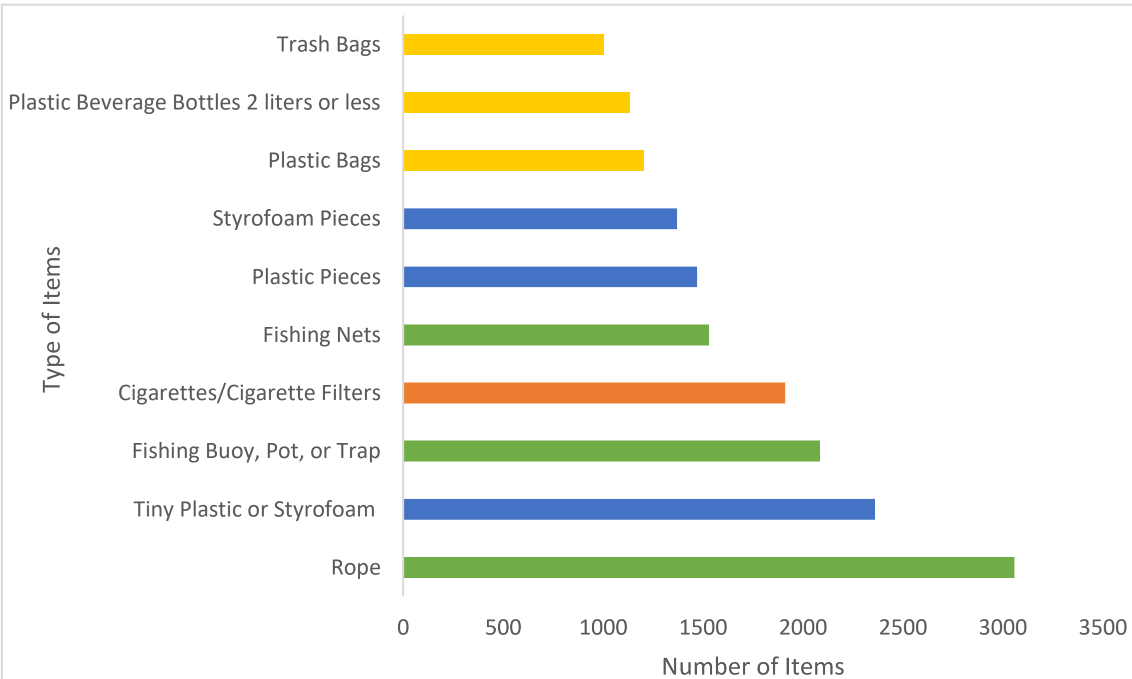

Figure 10. Bar graph representing the total number of plastic items collected from 2010 to 2019 on the shorelines of Prince Edward Island by the Great Canadian Shoreline Cleanup. Items such as tiny plastic and foam particles, bottle caps (plastic and metals), straws and stirrers, utensils, cups, fishing buoys, pots or traps, plastic containers, miscellaneous wrapping and personal hygiene products were separately identified from 2017 onwards. Plastic items originating from land and ocean-based activity are represented by individual coloured bars; shoreline and recreational activities (yellow), smoking-related (orange), other plastic items (blue) and commercial and recreational fishing activities (green).

3.3.2.3 Newfoundland

Figure 11 depicts the total number for each category of plastic items collected from the shorelines of Newfoundland from 2010 to 2019. Types of items listed on the figure exceed 1,000; categories having less than 1,000 items were omitted from the graph for visual purposes. Some of these items include fishing nets, toys, cigar tips, plastic takeout containers, recycling bags and random items, such as syringes, tires, condoms, and others. Types of items are further categorized based on origin. Land-based activities are classified as: shoreline and recreational activities, smoking-related, hygiene and medical, other plastic items, and automotive, construction and household items. Ocean-based activities are classified as commercial and recreational fishing activities. Items having the highest value include cigarettes/cigarette filters (19,886), plastic and metal bottle caps (7,887), and plastic bags (4,984).

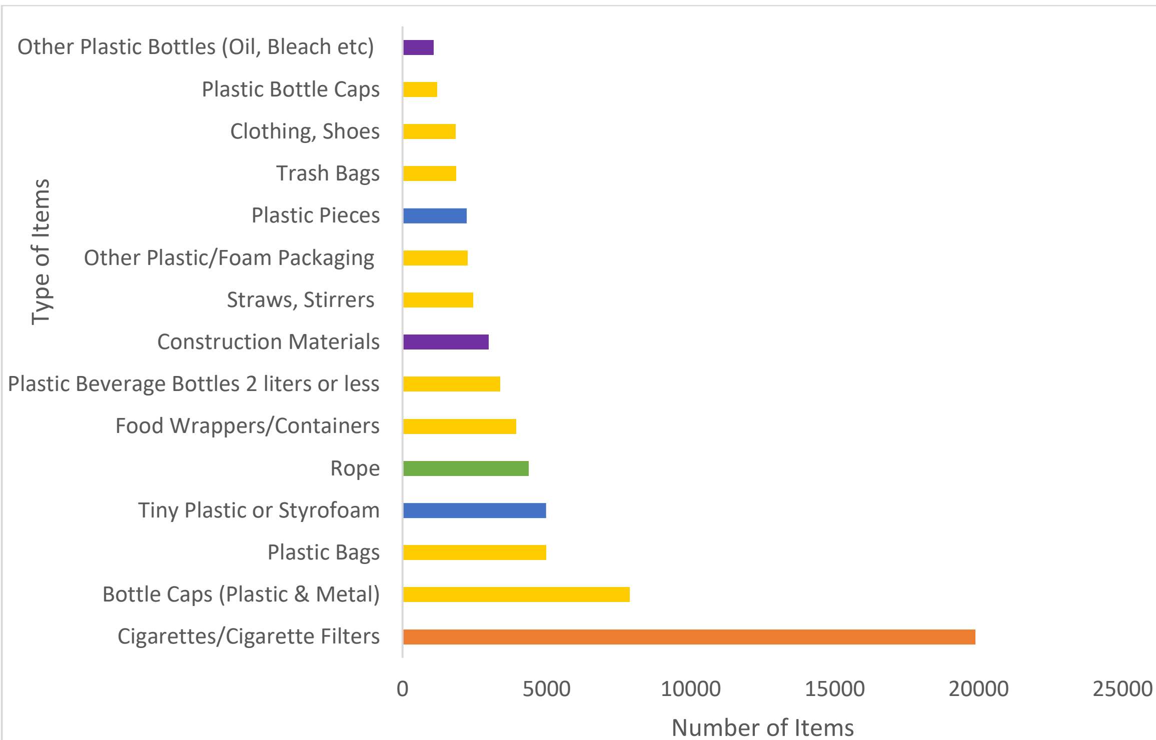

Figure 11. Bar graph representing the total number of plastic items collected from 2010 to 2019 on the shorelines of Newfoundland by the Great Canadian Shoreline Cleanup. Items such as tiny plastic and foam particles, bottle caps (plastic and metals), straws and stirrers, utensils, cups, fishing buoys, pots or traps, plastic containers, miscellaneous wrapping and personal hygiene products were separately identified from 2017 onwards. Plastic items originating from land and ocean-based activity are represented by individual coloured bars; shoreline and recreational activities (yellow), smoking-related (orange), other plastic items (blue), automotive, construction and household items (purple) and commercial and recreational fishing activities (green).

3.3.2.4 Sable Island

Labelled plastic products found during the 2018 brand audit include food packaging consisting of food and beverage bottles, tubs, jugs, cartons, and bags engine oil containers, household products, personal hygiene products, machine grease, fishing bait, industrial cleansers, whiskey, and silicone (Figure 12). Water and juice jugs represent 60% of food packaging items found (Lucas, 2018).

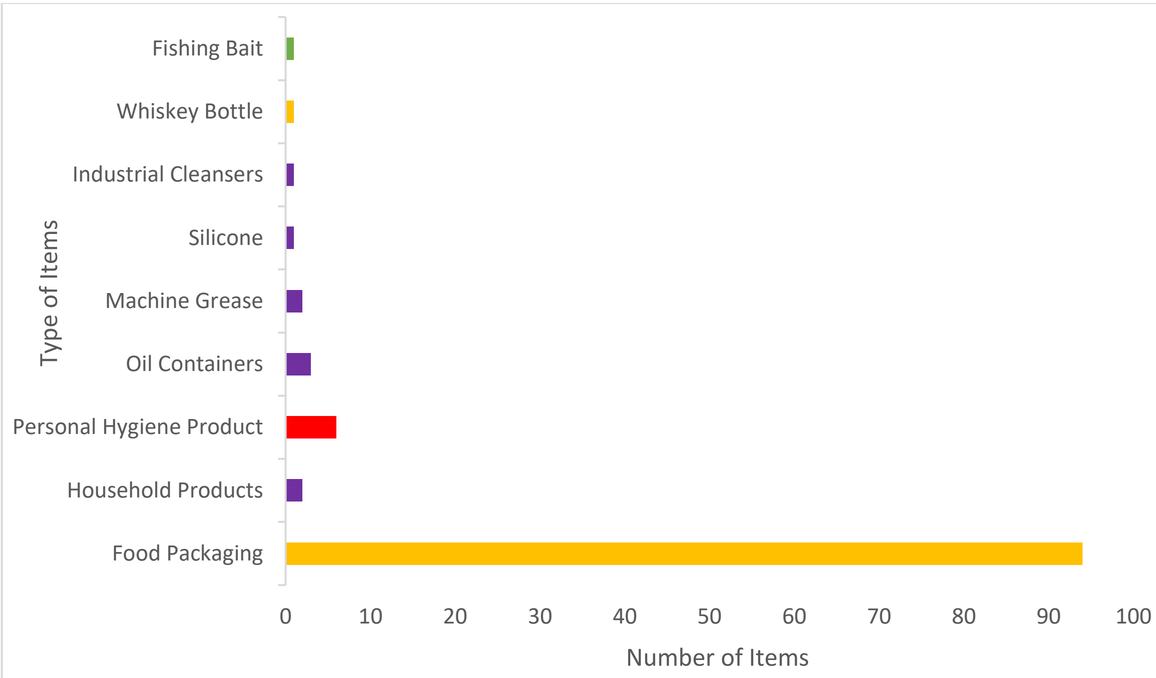

Figure 12. Bar graph representing the total number of plastic items collected on September 16th, 2018 on the shorelines of Sable Island, Canada, by the Plastic Brand Auditors. Plastic items originating from land and ocean-based activity are represented by individual coloured bars; shoreline and recreational activities (yellow), automotive, construction and household (purple), hygiene (red) and recreational fishing (green).

3.3.3 Origins of Plastic

Data obtained from 2010 to 2019 by the Great Canadian Shoreline Cleanup show that litter originates from both land- and ocean-based activities. Land-based activities are categorized as: shoreline and recreational activities, and hygiene and medical, smoking-related, and automotive, construction and household. Ocean-based activities are categorized as commercial and recreational fishing.

Results obtained from Sable Island's Marine Litter Audit originate from land- and ocean-based activities. Land-based activities are categorized as: shoreline and recreational activities, hygiene, and automotive, construction and household. Ocean-based activities are categorized as recreational fishing. The labelled items are mostly food packaging produced by varying corporations from different countries. Marine debris is heavily regulated on this island; hence these items were very likely transported to the shorelines from the ocean by wave action (Lucas, 2018).

3.3.3.1 Nova Scotia

The most abundant plastic items from shoreline and recreational activities consist of single-use food packaging (i.e. bottle caps, bottles, and plastic bags) (Table 2). For the hygiene and medical category, tampon applicators and syringes are the most abundant. The most abundant item for smoking related activities include cigarette filters. Additionally, the most abundant items from commercial and recreation fishing activities consist of rope, buoys, floats, and fishing nets. Table 2 shows the total number of plastics originating from land-based and ocean-based activities and the total number of plastics collected from Nova Scotian marine shorelines. From the total number of items collected, 79.7% originate from land-based activities and 20.3% originate from ocean-based activities (Table 6).

Table 2. Number of plastic items collected from the shorelines of Nova Scotia from 2010 to 2019.

Land-Based Activities	Number of Items	Total
Shoreline & Recreational Activities	41,350	89,641
Hygiene & Medical	4,681	
Automotive, Construction & Household	2,955	
Smoking-Related	40,655	
Ocean-Based Activities	Number of Items	Total
Commercial & Recreational Fishing	22,834	22,834
Overall Total		112,475

Note. Other items such as tiny plastic or foam pieces, and plastic pieces were omitted from the table as they are too small to determine their origin.

3.3.3.2 Prince Edward Island

The most abundant plastic items from shoreline and recreational activities consist of single-use food packaging (i.e. bottle caps, bottles, and plastic bags) (Table 3). Hygiene and medical items include tampon applicators and syringes, and cigarette plastic wrapping are the most abundant in smoking-related activities. Additionally, the most abundant items from commercial and recreation fishing activities consist of buoys, floats, and fishing nets. Table 3 shows the total number of plastics originating from land-based and ocean-based activities and the total amount of plastics collected from Prince Edward Island shorelines. From the total number of items collected, 58% originate from land-based activities and 42% originate from ocean-based activities (Table 6).

Table 3. Number of plastic items collected from the shorelines of Prince Edward Island from 2010 to 2019.

Land-Based Activities	Number of Items	Total
Shoreline & Recreational Activities	7,486	10,487
Hygiene & Medical	214	
Automotive, Construction & Household	538	
Smoking-Related	2,249	
Ocean-Based Activities	Number of Items	Total
Commercial & Recreational Fishing	7,577	7,577
Overall Total		18,064

Note. Other items such as tiny plastic or foam pieces, and plastic pieces were omitted from the table as they are too small to determine their origin.

3.3.3.3 Newfoundland

The most abundant plastic items from shoreline and recreational activities consist of single-use food packaging (i.e. bottle caps, bottles, and plastic bags) (Table 4). Hygiene and medical items include tampon applicators and syringes, and cigarette plastic wrapping are the most abundant in smoking-related activities. Additionally, the most abundant items from commercial and recreation fishing activities consist of fishing nets and fishing lines. Table 4 shows the total amount of plastic originating from land-based and ocean-based activities and the total amount of plastics collected from Newfoundland shorelines. From the total number of items collected, 89.7% originate from land-based activities and 10.3% originate from ocean-based activities (Table 6).

Table 4. Number of plastic items collected from the shorelines of Newfoundland from 2010 to 2019.

Land-Based Activities	Number of Items	Total
Shoreline & Recreational Activities	35,312	62,051
Hygiene & Medical	980	
Automotive, Construction & Household	4,234	
Smoking-Related	21,525	
Ocean-Based Activities	Number of Items	Total
Commercial & Recreational Fishing	7,137	7,137
Overall Total		69,188

Note. Other items such as tiny plastic or foam pieces, and plastic pieces were omitted from the table as they are too small to determine their origin.

3.3.3.4 Sable Island

The most abundant plastic items obtained from the Marine Litter Audit are from shoreline and recreational activities, consisting of food packaging; water and juice jugs accounting for the majority (Table 5). The second most abundant category is automotive, construction and household products accounting for 9 items and hygiene products are the third most abundant with 6 items out of 111 items collected. One container of fishing bait was retrieved, which falls under the recreational fishing category. Out of the 111 items retrieved, 81 of which were either manufactured of packaged in Canada, 17 in the USA, and 13 from other countries, including Brazil, Cuba, Haiti, Japan, Malaysia, South Africa, France, and Russia (Lucas, 2018).

Table 5. Number of plastic items collected from the shorelines of Sable Island on September 16th, 2018.

Land-Based Activities	Number of Items	Total
Shoreline & Recreational Activities	95	110
Hygiene	6	
Automotive, Construction & Household	9	
Ocean-Based Activities	Number of Items	Total
Recreational Fishing	1	1
Overall Total		111

3.4 Discussion

It is clear from the results obtained from both the Great Canadian Shoreline Cleanup and the Sable Island Marine Litter Audit that there is an abundance of plastic along Canada's east coasts and in its coastal waters. There are variations in quantity, types, and origins of plastic debris across Maritime Regions. These variations can be attributed to geographic location, number of volunteers participating in clean ups, length and width of sampling sites, and marine waste regulations. Nevertheless, plastic debris remains an issue as plastics can have sub-lethal to lethal impacts on migratory species such as the leatherback turtle that is present in waters adjacent to these regions. Published evidence suggests that leatherbacks have been affected by plastic pollution through ingestion and entanglement. A study by Mrosovsky et al. (2009) suggest that 34% of 408 leatherback turtles were found with plastic in their gastrointestinal tract with cases reported since 1968. This information was obtained through personal communication and a literature review of studies that sampled leatherbacks, globally (Mrosovsky et al., 2009). With the increase in amount of plastic entering the ocean over the decades, it would come as no surprise that the frequency of plastic ingestion by leatherbacks has increased in conjunction.

3.4.1 Quantity of Plastic Debris

While one would suspect that the amount of plastic found on shorelines would increase in response to the increase in plastic production, the results obtained may suggest otherwise. Findings for Nova Scotia show that there is an increase in plastics collected from the shorelines in 2013 going forward (Figure 3). However, for Prince Edward Island and Newfoundland, findings show that the amount of plastic collected from shorelines has remained constant from 2010 to 2019 (Figures 5 and 7). Notably, these results are not reflective of the amount of plastic remaining at sea. Nonetheless, they are a good indication of how much plastic is in adjacent coastal waters as this number is likely far greater than what accumulates on shorelines. Additionally, plastics collected from the shoreline cleanups do not include the amount of microplastics found within the sediment. A report by Mathalon and Hill (2014) determined that between 20 to 80 microplastic fibers are within 10 grams of sediment along Nova Scotia's Eastern Shore. As most plastics are extremely durable, they can persist in the environment for decades, breaking down slowly (Thompson et al., 2004). Ocean currents play a vital role in transporting plastic in the marine environment. Out of the three Atlantic provinces sampled, Nova Scotia has a higher number of plastic items collected from the shorelines from 2010 to 2019 (Table 6). While on average, more sites have been sampled in Nova Scotia (32 sites) compared to Prince Edward Island (12 sites) and Newfoundland (15 sites), the Scotian Shelf is exposed to more ocean currents which may be responsible for transporting plastics in and out of the coast. Plastics can be transported to and from the shorelines of Nova Scotia through the Gulf Stream, the Northeast Current, and the Laurentian Channel. The Laurentian Channel may also transport plastics to Prince Edward Island and Newfoundland and Labrador, which is also exposed to the Labrador Current (Figure 13). Furthermore, the population of Nova Scotia is greater than in Prince Edward Island and in Newfoundland and Labrador (Statistics Canada, 2020). Since most of the plastic debris comes from land, the difference in population is reflective in the numbers.

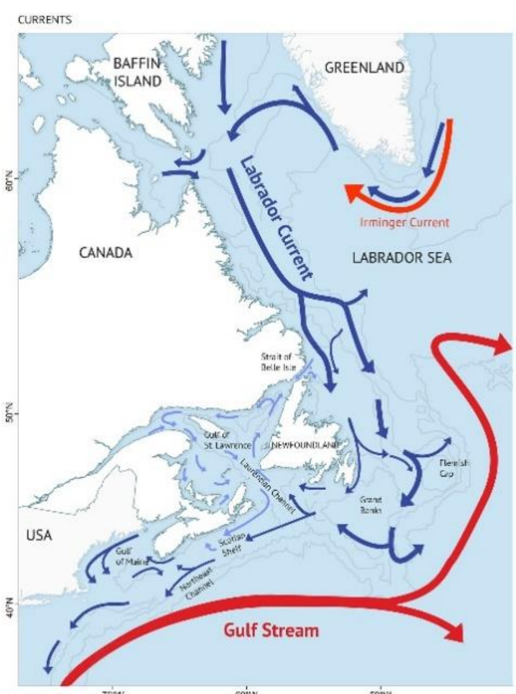

Figure 13. Currents in the Northwest Atlantic Ocean adjacent to Canada directly copied from DFO (2018).

Table 6. Summary of data on plastic collected from 2010 to 2019 by the Great Canadian Shoreline Cleanup.

Province	Length of Coastline (km)	Total Number of Collection Sites	Source of Litter: Land-based	Source of Litter: Ocean-based	Number of Plastic Items
NS	13,300	480	89,641	22,834	112,475
			79.7%	20.3%	
PEI	1,800	118	10,487	7,577	18,064
			58%	42%	
NL	17,542	280	62,051	7,137	69,188
			89.7%	10.3%	
Range of Percent			58-89.7%	10.3-42%	
Mean Percent			75.8%	24.2%	

3.4.2 Types of Plastic Debris

A recent report from the Ocean Conservancy (2020) revealed that food wrappers are now the most commonly abundant plastic debris accumulating on shorelines worldwide, topping cigarette butts. However, the accumulation of cigarettes/cigarette filters remains the top contributor for Canada's coastlines. For both Nova Scotia and Newfoundland and Labrador, cigarette/cigarette filters are the number one type of debris collected from shorelines, with values more than triple their respective runner up. As for Prince Edward Island, cigarettes/cigarette filters are the fourth highest debris found on shorelines. The last occurrence of cigarette filters being the most abundant for this province was in 2013. Cigarette waste has been the dominant form of debris for years and has been a global issue (Slaughter et al., 2011). Tiny plastic and Styrofoam are listed as the second most found items on Canadian shorelines (GCSC, 2020b), which is reflective for Nova Scotia, Prince Edward Island, and Newfoundland as this category is in the top three most abundant. A study indicated that certain types of plastics found in the Western North Atlantic Ocean are less dense than seawater, giving them buoyancy. These plastic materials are of high- and low-density polyethylene, and polypropylene (Law et al., 2010b). Polyethylene is the most used plastic making up plastic bags, containers such as bottles, packaging, milk carton coating, toys, automotive plastics, and more.

Polypropylene is another readily used plastic, which is found in food packaging, medical devices, household products, for industrial application, and consumer goods (PlasticsEurope, 2020). Many of these plastics are commonly found on the shorelines of Nova Scotia, Prince Edward Island, and Newfoundland. Hence, they can be easily transported into adjacent coastal waters, which can lead to negative impacts on marine organisms and ecosystems.

3.4.3 Origins of Plastic Found Along Atlantic Canada Coast

In Nova Scotia, plastics originating from land-based activities account for 79.7% of the debris collected (Table 6). Results obtained for Newfoundland and Prince Edward Island vary. For Newfoundland, plastics from land-based activities account for 89.7% and for Prince Edward Island these plastics account for 58%. When compiling all three results, an average of 75.8% of plastics originate from land-based activities (Table 6). These findings agree with other data showing that 80% of marine debris originates from land-based activities (GESAMP, 2015). The difference between provinces can likely be attributed to factors such as waste regulations and policies, dominant livelihood, proximity to urban areas, and awareness and engagement. The greatest contributors of land-based activities are recreational and shoreline activities, which consist of a variety of plastics such plastic bags, bottle caps and food packaging, and from smoking related activities (cigarettes/cigarette filters). These plastics are most likely single-use plastics that originate from urban areas and even beach outings. Given their lightweight, they can easily be transported to shorelines by wind and wave action. This shows the importance of managing solid waste on land to protect marine ecosystems and wildlife.

3.5 Ecological Risk Assessment of Plastics and Leatherbacks

To determine whether leatherback turtles are at risk of encounter with marine plastics, fundamental questions need to be addressed. The first is investigating whether leatherbacks could encounter marine plastic. In other words, does plastic exist in the same locations that leatherback turtles frequent? Moreover, if these interactions do occur, how do they affect leatherback turtles? (Hardesty and Wilcox, 2017). This section highlights the exposure to plastics in the Northwest Atlantic Ocean where leatherback turtles are known to be present, the pathways of effects (i.e. how they interact with plastics) and known effects that can possibly occur from these interactions (Figure 14).

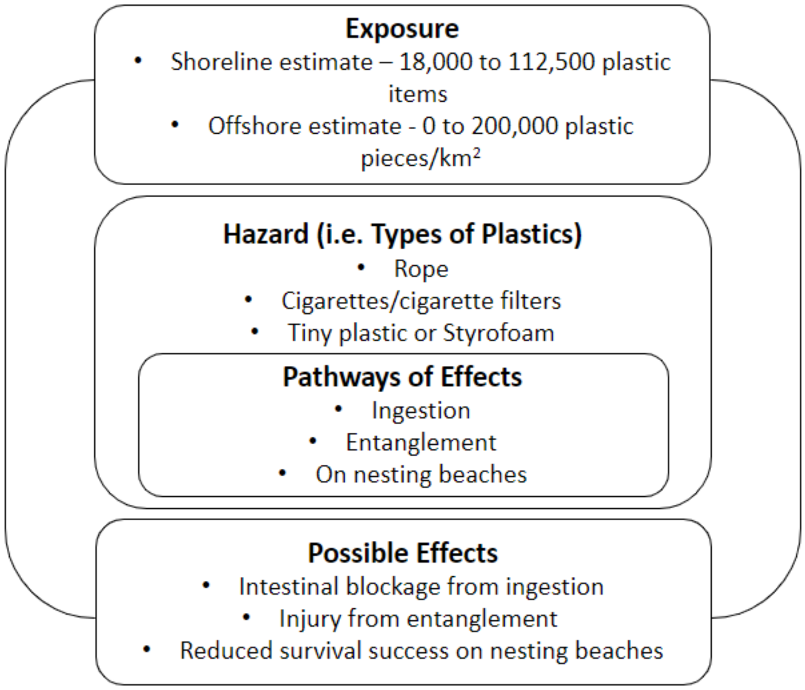

Figure 14. Risk Assessment Framework modified from the GESAMP (2020) Risk Assessment Framework to show the interactions of marine turtles and plastics.

3.5.1 Exposure

For there to be a risk of plastic exposure to the North Atlantic Leatherback turtle, there must be an overlap in distribution for both, which has been assessed in this study through a literature review and data evaluation. Leatherback turtles are known to migrate to forage in Canadian cold waters from summer to fall. Numerous leatherback sightings in waters surrounding Nova Scotia and in the southern Gulf of St. Lawrence and some sightings near Newfoundland have been reported from 1998 to 2005 (James et al., 2006). Figure 15A is a map of the reported sightings from various sources including satellite telemetry studies, fisheries observers, and from aerial surveys (James et al., 2006). Leatherbacks appear to be present in both inshore and offshore waters, which are also tainted with plastic pollution (Wilcox et al., 2020). Figure 15B demonstrates the distribution of plastic debris collected from 1986 to 2015 and their concentration levels are depicted by colour.

Plastic pieces per square km around Nova Scotia and near Newfoundland appear to fall between 0 and 200,000, which may have negative impacts on leatherback turtles (Wilcox et al., 2020). Keeping in mind, these results are from five years ago and plastic pollution has increased since. Therefore, one can infer that if leatherbacks were at risk of plastic exposure then, they are likely to still be at risk now. Importantly, the highest concentration of plastic is within the subtropical gyre, where leatherbacks traverse during migration. Passing through oceanic gyres increases the likelihood of debris contact and ingestion (Schuyler et al., 2016).

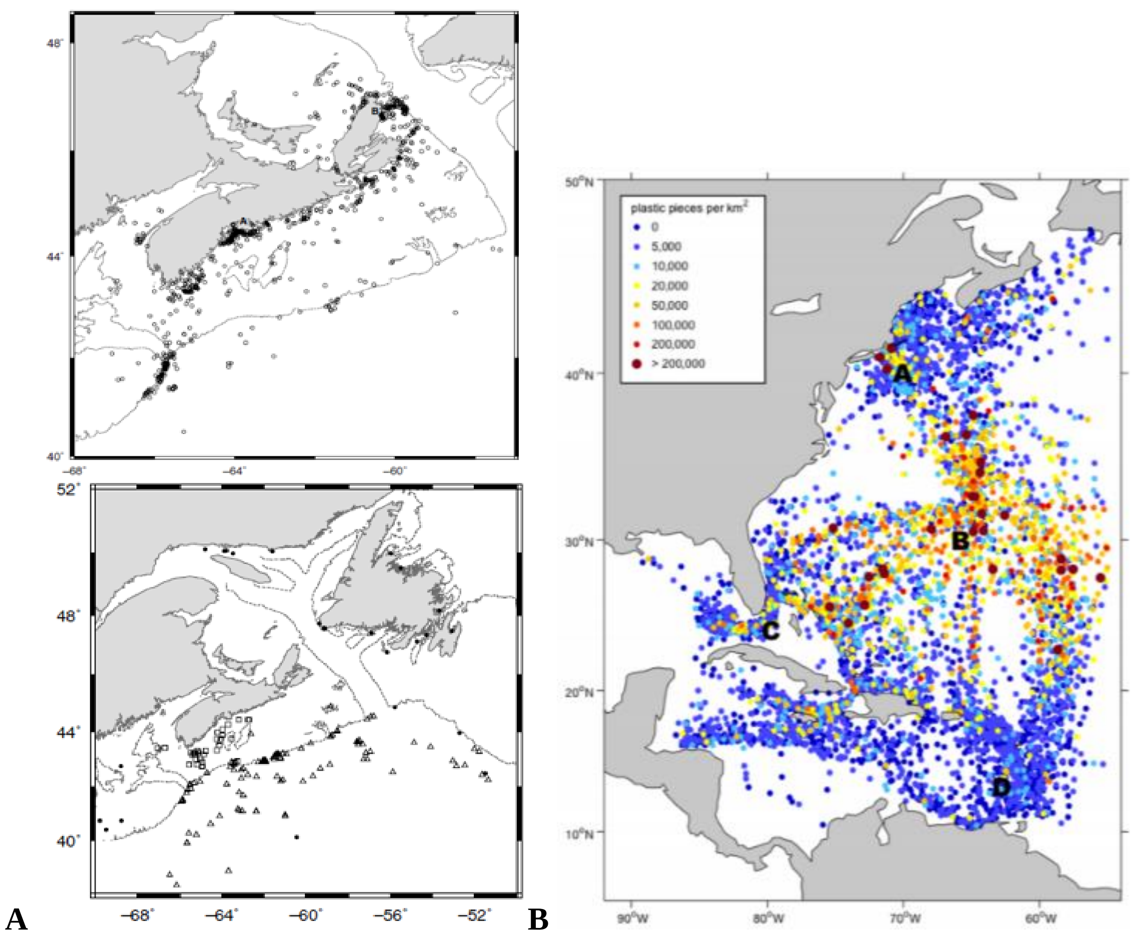

Figure 15A. Map of leatherback sightings from 1998 to 2005 in the waters adjacent to Nova Scotia directly copied from James et al. (2006). Figure 15B. Map of the distribution of plastic debris sampled between 1986 to 2015 in the Western North Atlantic Ocean directly copied from Wilcox et al. (2020).

Mrosovsky et al. (2009) report plastic bags, fishing line, balloons, candy and cigarette wrappings, twine fragments, and plastic spoons being identified as items ingested by leatherback turtles. As cigarettes and their filters are found most abundantly on the shorelines of the three Canadian maritime provinces sampled, there may be a risk of ingestion to leatherbacks if these items are washed to sea. While no case of cigarette ingestion has been reported for leatherback turtles, ingestion of cigarette filters has been reported in other marine turtles including the loggerhead (*Caretta caretta*), the green turtle (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), and the hawksbill (*Eretmochelys imbricate*) (Stanley et al., 1988; Macedo et al., 2011). There is likely low to moderate risk associated with cigarette waste to marine organisms (Patra and Cole, 2002). Despite there being no reports with cigarette filter ingestion by leatherbacks, this should not be ruled out as many studies are from over a decade ago.

Plastic bags were reported as the most common debris sampled in the leatherback gastrointestinal tract in the Mrosovsky et al. (2009) study. These items are easily mistaken as gelatinous plankton, such as jellyfish, and can easily be intentionally ingested by leatherbacks (Mrosovsky et al., 2009). Plastic bags are in the top five most abundant items found on the shorelines of Nova Scotia and Newfoundland and are in the top eight most abundant debris for Prince Edward Island (Figures 9, 10, and 11). A total of 16,949 plastic bags were collected from the shorelines of these three provinces. Plastic bags are lightweight and can be easily transported (i.e. blown) from shorelines into the ocean. Once in the marine environment, they can remain there for decades, degrading into smaller secondary plastic pieces over time (Wilcox et al., 2020). Leatherbacks may also be exposed to other abundant plastic items (top 10) collected from the shorelines, including rope, bottle caps, food wrappers, and fishing nets.

Tiny plastic and Styrofoam pieces are becoming more abundant along Canadian shorelines. They are ranked second most abundant among 595,227 items collected by the latest Great Canadian Shoreline Cleanup initiative in 2019 (GCSC, 2020b). Of that, roughly 4,000 tiny pieces were collected from the shorelines of Nova Scotia, Newfoundland, and Prince Edward Island. Plastic fragments have become an increasing issue as they are now ubiquitous in the water column (Mathalon and Hill, 2014). Notably, microplastics are more difficult to collect, requiring sophisticated plankton nets and subsequent microscopic analysis. They are less obvious along the shorelines, rendering it a challenging task to determine their accurate abundance. Mathalon and Hill (2014) provided an estimate of 20 to 80 microplastic fibers found within 10g of sediment from Nova Scotia's Eastern Shore intertidal zones. Additionally, they reported microplastics in polychaete worm fecal casts and in live blue mussels. These species are not the only ones found with microplastics in them. Various zooplankton, including jellyfish, have been exposed to microplastics and have suffered negative impacts (Botterell et al., 2019). As leatherbacks predominantly feed on gelatinous zooplankton, the food source itself, if contaminated, can increase the chances of internal plastic exposure (Mrosovsky et al., 2009).

3.5.2 Pathways of Effects

Two pathways of plastic exposure of the Atlantic leatherback turtle subpopulation are threatened by plastics in the waters adjacent to the three Canadian maritime provinces sampled - ingestion and entanglement. Several types of plastic debris on the shorelines of Nova Scotia, Newfoundland, Prince Edward Island, and Sable Island consist of easily ingestible items. These items include cigarette filters, tiny plastic pieces, plastic bags, food wrappings, and secondary plastics from degraded food packaging, containers, and household and hygiene products. Plastic ingestion can occur in two ways; direct and indirect (Nelms et al., 2016). As leatherbacks feed on gelatinous prey within the water column, there may be a risk of direct ingestion of plastic in the form of bags and microplastics (Mrosovsky et al., 2009). Microplastics can also be ingested indirectly when they are feeding as tiny plastics are not readily visible in the water column and by consuming contaminated jellyfish (Macali et al., 2018; Jamieson et al., 2019). Over the decades, plastic ingestion has been consistent with findings suggesting that at least one third of adult leatherbacks have ingested plastic (Mrosovsky et al., 2009). Coupling the fact that Canadian waters are critical feeding habitats for leatherbacks and evidence of plastic bags, tiny plastics, and other plastics being found in their gut, it is evident that the potential of ingesting plastic in these waters is high for leatherbacks.

Entanglement is another pathway of plastic exposure that can impact leatherback turtles in the Northwest Atlantic Ocean. Leatherbacks can get entangled in derelict fishing gear which includes nets, longlines, and rope. Entanglement in fixed-fishing gear is also likely to occur as leatherbacks tend to overlap commercial fishing hotspots (Hamelin et al., 2017). Rope and fishing nets make up most ocean-based activity debris collected from the shorelines of Nova Scotia, Newfoundland, and Prince Edward Island. Reports of incidental capture come from coastal Nova Scotia and Newfoundland with most entanglements occurring during the summer months. Research suggests that leatherbacks are most likely to get entangled in pot gear (lobster and crab) and trap nets, which are made of polypropylene lines (Hamelin et al., 2017). From satellite surveys in the Northwestern Atlantic, Innis et al, (2010) found seven out of 19 leatherback turtles entangled in fishing gear. As with plastic ingestion, the potential for entanglement in derelict gear in these waters is also high for leatherback turtles.

3.5.3 Effects

There are many known effects of plastic debris on marine organisms. Countless studies have investigated the interactions of plastics and organisms, showing the potential for sub-lethal and lethal impacts. All seven marine turtle species have succumbed to the effects of plastics, with the loggerhead and green turtle appearing in the literature most frequently (Nelms et al., 2016). Few studies reporting the effects of plastic on leatherback turtles are available. However, this does not imply the lack in occurrence. From available studies, intestinal blockage has presumably resulted in mortality, although reported infrequently (Mrosovsky et al., 2009). In one study, the accumulation of plastics blocked the cloaca of a nesting leatherback which prevented her from depositing her eggs (Plot and Georges, 2010). The ingestion of buoyant plastic materials not only leads to intestinal blockage but may also alter the swimming and buoyancy behaviour of leatherbacks (Fossette et al., 2010; Nelms et al., 2016). Deep-diving swimming behaviour is often exhibited by leatherbacks, and so buoyancy control is crucial to avoid decompression sickness (Fossette et al., 2010). Moreover, with repeated ingestion of plastic bags, if they survive, the energy requirements for leatherbacks to migrate long distances may be impaired, resulting in delayed migrations which may have secondary effects (i.e. reproductive) (Mrosovsky et al., 2009). Microplastic ingestion can cause a wide range of physiological impacts including endocrine disruption through chemical leaching, impaired digestion, and reproductive abnormalities (Oehlmann et al., 2009; Wright et al., 2013). Prolonged residency of these plastics may lead to chronic effects as these particles can penetrate cell membranes, tissues, and organs (Wright et al., 2013). To date; however, these effects have not been demonstrated for leatherback turtles suggesting the need for additional research.

Entanglement is one of the leading causes of marine turtle mortality (Wilcox et al., 2013). In the Northwest Atlantic Ocean, leatherbacks are gravely affected by longlines, nets, and rope. Leatherbacks tend to have their front flippers and neck entangled as they swim directly into the gear. Subsequently, they tend to panic and get themselves even more entangled (Hamelin et al., 2017). Some negative effects include severe injuries such as limb loss or abrasions which can have secondary impacts including reduced ability of predator avoidance (Barreiros and Raykov, 2014). Leatherbacks have been found with fishing lines tightly wrapped around their flippers, rendering them unable to free themselves resulting in suffocation or drowning (Hamelin et al., 2017). Entanglement also causes physiological changes such as impaired kidney function likely resulting from reduced food ingestion and eliciting a generalized stress response and inflammatory response (Innis et al., 2010). Some leatherbacks can resume normal behaviour following the one incident of entanglement; however, Innis et al. (2010) suggest that adverse impacts on health and survival can be more significant from multiple entanglement events.

3.5.4 Estimates of Risk

Based on this study's findings, leatherbacks may be at risk of plastic ingestion and entanglement in the Northwest Atlantic Ocean. To provide a definitive conclusion on the risk of plastics to leatherback turtles in this region, further evidence is needed on the exposure and the effects of exposure. However, results show that plastics are a definitive hazard to leatherback turtles in the Northwest Atlantic Ocean as there is high potential for sub-lethal to lethal effects to occur from entanglement and plastic ingestion, which have been reported in Lucas (1992), Mrosovsky et al. (2009), and Innis et al. (2010). Results suggest that leatherbacks would likely be more at risk of exposure to tiny plastic and

Styrofoam pieces than plastic bags in the waters adjacent to Nova Scotia and Prince Edward Island (Figures 9 and 10). Whereas in Newfoundland, leatherbacks would likely be more at risk of exposure to plastic bags than tiny plastic and Styrofoam pieces (Figure 11). Furthermore, leatherbacks would likely be more at risk of exposure to rope in the waters adjacent to Prince Edward Island and in Nova Scotia as this item is in the top two most abundant items collected from those shorelines (Figure 9 and 10). From an earlier study by Lucas (1992), two deceased leatherback turtles washed up on the shore of Sable Island and were necropsied. The gut contents included rope, balloons, and plastic bags. It is unclear whether these items were ingested in adjacent waters; however, it is clear that plastics are a hazard to leatherbacks and that more data is needed to determine the level of risk associated with these items for the Northwest Atlantic region.

CHAPTER 4: MANAGEMENT EFFORTS

4.1 INTRODUCTION

As plastic production continues to grow and negatively impact marine ecosystems and organisms, management efforts need to evolve concurrently to ensure effective protection. In this chapter, descriptions of the various management efforts such as solid waste management and non-governmental organization conservation programs aiming to reduce the impacts of plastic on marine turtles, policies, conventions, and legislation being implemented in nations (Canada, United-States, and the Wider Caribbean Region) in the Northwest Atlantic Ocean region will be discussed.

4.2 SOLID WASTE MANAGEMENT

Solid waste management is a global challenge as economies continue to grow. Poor solid waste management can have detrimental impacts on the environment and organisms through exposure to contaminants causing impaired health (Kaza et al., 2018). There are different types of solid waste management on land and at sea that vary depending on geographic location and resource accessibility. Waste management is predominantly handled at the municipal level and can be very costly (Abdel-Shafy and Mansour, 2018). Municipal solid waste management is defined as the waste collected and disposed of at municipal disposal sites. This waste comes from residential, industrial, institutional, and commercial industries (Hoornweg et al., 2015). For the purpose of this study, focus will be on regions neighbouring the Northwest Atlantic Ocean with an emphasis on Canada.

4.2.1 Waste Management on Land

Land-based activities account for 80% of the amount of the waste, including plastics, in the marine environment (GESAMP, 2015). Depending on the standard of management, waste systems are good indicators of how much litter can enter the marine environment. Poorly managed waste systems, commonly seen in developing countries resulting from inadequate resources, are major contributors to marine debris (Jambeck et al., 2015). However, that is not to say that developed countries do not contribute to marine debris as well. There remains a substantial amount of mismanaged waste as populations and the production of plastic continue to grow. Over the decades, waste management has evolved in attempts to keep up with these trends. Historically, land dumping and the process of burning or burying waste appeared sufficient prior to the rise in plastics (Rogers, 1976; Young, 2010; Jambeck et al., 2015). Regulation of waste has evolved through policies, facility development, and novel technology and as a result several solid waste management processes are implemented globally (Figure 16). For the purpose of this study the focus will be on recycling, incineration, and landfill.

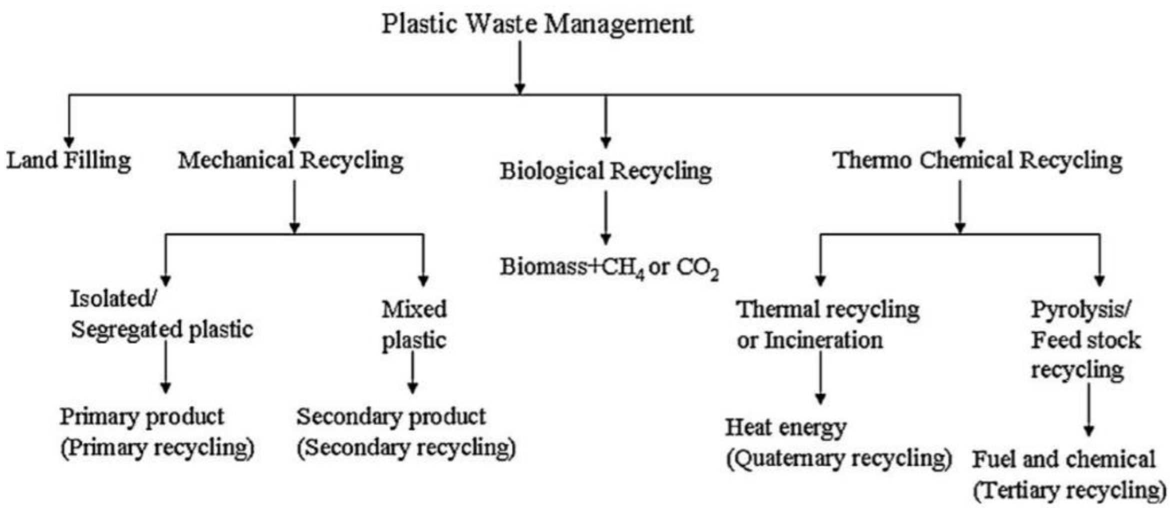

Figure 16. Global plastic waste management practices directly copied from Panda et al. (2010).

4.2.1.1 Recycling

Recycling was introduced many centuries ago when used pulp paper was re-pulped and sold in regions of Japan (Cleveland and Morris, 2014). Since then, recycling has adapted and evolved in response to novel solid waste materials generated over the centuries. One of the most common behaviours dealing with house-hold waste is the notion of the 3R's defined as reduce, reuse, and recycle (Barr, 2007). While many consumers partake in reducing and reusing waste by-product, the most commonly practiced out of the three is recycling (Barr et al., 2001). In this context, recycling refers to the act of separating household waste products into their respective categories, including glass, paper, and plastic (Hopper and Nielsen, 1991). In a greater context, the aim is to close the plastic loop through recycling to transition towards a circular economy (European Commission, 2018).

In Canada, the plastic economy is far from circular. An estimated 9% of plastic waste is recycled, of that 8% is mechanically recycled, and the remaining percent is divided into chemical recycling from diverted waste and disposed waste (Deloitte, 2019). There are 10-11 facilities across Canada that are equipped for mechanical recycling and which produce resin or flakes of resin as a secondary plastic product. Unfortunately, these products come with a higher operating cost and lower profitability for municipalities. To move towards a circular economy, Canada would have to implement chemical recycling which converts plastic waste into shorter molecules for the use of new plastic or fuel (Deloitte, 2019). Chemical recycling of plastics can be beneficial by conserving natural resources through reducing the amount of fossil fuels generated to produce plastic and by protecting the environment by reducing pollution (Ragaert et al., 2017). By 2030, Canada aims to have a zero plastic waste economy. To achieve this, most of the plastic waste will be removed from landfills and will no longer be disposed there; therefore, recycling (chemical and mechanical) will become the dominant waste management strategy (Deloitte, 2019). By the end of 2021, the Federal Government plans to ban harmful single-use plastics thereby reducing the load of plastics being recycled or landfilled (Kelly, 2020). Furthermore, there is a shift to implement Extended Producer Responsibility (EPR) strategies which allows greater control of waste streams at local levels (Diggle and Walker, 2020).

In 2018, 292.4 million tons of municipal solid waste was generated in the U.S. with plastics accounting for 35.68 million tons. While solid waste management is a high priority for state and local governments, only 69 million tons of the generated waste was recycled. This figure is roughly 20% of the total waste, and of that only 4.38% consisted of plastics (3.02 million tons) (EPA, 2020). The U.S. aims to decrease disposal rates by targeting source reduction, prevention, reuse, and recycle, as well as reduce the environmental impacts of waste materials across their life cycle. These objectives are part of the strategic plan for the 2017-2020 Sustainable Materials Management (SMM)

Program implemented by the U.S. Environmental Protection Agency. Anticipated outcomes for 2020 include increasing the yield rates of recyclables collected and processed, and to make them readily available for secondary production use, as well as increasing the participation in recycling (EPA, 2015).

4.2.1.2 Incineration

In Canada, 4% of plastic waste is incinerated with energy recovery. Plastic is a useful source of fuel when incinerated as it is made from petroleum. However, when incinerated these plastics release harmful chemicals such as heavy metals, furans, dioxins, and volatile organic compounds (Deloitte, 2019). Furans and dioxins are extremely harmful due to their persistence in the environment, capacity to accumulate in tissues, and high toxicity. The goal is to have these toxins eliminated under the Canadian Environment Protection Act, the Federal Toxic Substances Management Policy, and the CCME Policy for the Management of Toxic Substances (CCME, 2014). As a result, numerous out-dated Canadian incineration facilities have been closed including those in Nova Scotia (CCME, 2010). To reduce the municipal solid waste produced, the Canadian government emphasizes the best practices such as reduce and reuse (Deloitte, 2019).

In the United-States, remaining solid waste that is not recycled, landfilled, or composted is sent to modern incinerator plants for combustion (Mathews et al., 2019). These modern plants are Waste-To-Energy facilities which convert approximately 12.8% of solid waste in the U.S. to energy (Michaels, 2010; Mathews et al., 2019). A concern with this method is the ash that is generated which is usually disposed of in landfills thereby contributing to environmental pollution. Alternatively, the ash can be repurposed as concrete, as done so in Bermuda (personal communications, P. Wells, November 8, 2020), and in road construction which is implemented in several countries (Mathews et al., 2019).

4.2.1.3 Landfill

Landfills are the most common solution for municipal waste disposal. Often the waste is buried underground or remains above depending on the geological composition of the land (Giroux, 2014). Landfills are considered an unsustainable form of plastic waste management as site capacities are decreasing in response to increasing solid waste (Brems et al., 2012). Concerns with landfill are the release of greenhouse gases, such a methane, and the lengthy biodegradation process of common packaging polymer (Garforth et al., 2004). Moreover, space used for disposal is limited and becoming expensive (Panda et al., 2010). In Canada, an estimate of 86% of plastic waste ends up in landfill and 1% leaks into the environment. Until recently, Canada and the U.S. would export the recycled plastic to China which was banned in 2017. This inevitably added pressure on these developed countries to manage their own plastic waste (Walker, 2018). With time, landfills will no longer be able to sustain the amount of plastic waste generated. Hence, the time seems appropriate to manage the issue of plastic at the source, rather than temporarily dealing with it.

Managing waste in developing countries is different than in developed countries. Due to fewer resources and economic instability, developing countries usually practice low cost waste management practices such as landfill disposal, household burning, and illegal dumping into the ocean. In many cases for small island states, there is insufficient amount of space to simply rely on landfill for waste management (Howell and Fielding, 2019). Often, there is a lack in regulations and policies relating to solid waste practices as concern for the environment is surpassed by other pressing issues (Diaz, 2017). In Latin America and the Caribbean, the daily waste generated exceeds 541,000 tonnes, with 90% being disposed in landfills, garbage dumps, and other disposal sites. This number is expected to increase in the Wider Caribbean Region and will likely surpass the waste capacity of landfills and other dumping sites (UNEP, 2018). Moreover, landfills are often poorly sited, not sanitary, and mismanaged (UNEP, 1998). Hence, solid waste management must be addressed through policy, financially sustainable partnerships, and novel systems and strategies (UNEP, 2018).

4.2.2 Waste Management at Sea

Plastic originating from ocean-based activities accounts for 20% of the marine plastics (GESAMP, 2015). Sources of plastic waste at sea are generated from fishing vessels and ships, both cruise and merchant (van Truong and beiPing, 2019). These vessels generate several types of plastic waste including fishing gear, single-use plastic (food packaging and bottles), parts of ship construction, floats, rope, bags, and many more (Čulin and Bielić, 2016). Historically, solid waste was disposed of in the ocean which resulted in the ubiquity of plastic there (Hagen, 1990). Waste management on ships (merchant, cruise, and fishing) falls under the International Convention for the Prevention of Pollution from Ships (MARPOL Annex V) adopted by the International Marine Organization (IMO) in 1973, which has since been amended a number of times and is referred to as MARPOL 73/78 (Čulin and Bielić, 2016). Despite the establishment of policies and conventions that aim to regulate solid waste from ships, marine debris remains an issue as illegal ocean dumping continues to occur which is difficult to monitor and manage (Matossian et al., 2020).

4.2.2.1 Ships (Merchant and Cruise)

Merchant vessels contributed to a significant amount of plastic pollution at sea as ocean dumping was traditionally practiced. In 1982, it was estimated that over 600,000 plastic containers were deposited daily into the ocean via merchant ships (Horsman, 1982). The MARPOL 73/78 Convention was increasingly applied as awareness and concern surrounding pollution in the ocean grew. This Convention was initially implemented following the increased numbers of incidents of oil spillage from tankers and has since been amended with protocols targeting specific types of pollution. Under the MARPOL 73/78, Annex V, there are regulations for the Prevention of Pollution by Garbage from Ships that prohibit the discharge of all garbage at sea (ECCC, 2020c). Following the protocol, ships require a garbage management plan and a garbage record book containing entries of garbage discharge events that may be necessary for safety. These entries must be handed to the reception facilities ashore to monitor the pollution and to facilitate enforcement thereby preventing pollution at sea (Čulin and Bielić, 2016). However, ships under 400 GT, such as fishing vessels, are not required to keep garbage record books (Chen and Lui, 2013). Despite having international laws to control plastic pollution at sea, enforcement is a challenging task. Hence, there is a need for other waste management measures such as raising awareness on plastic pollution and providing environmental education training for crew members to promote positive behaviour (Chen and Lui, 2013; Čulin and Bielić, 2016).

Concerns of solid waste management aboard cruise ships have grown in consequence of the fast-growing industry (Sanches et al., 2020). Ships generate a mass amount of solid waste such as plastic, incinerator ash, and electronic waste which is later disposed at port facilities. Consequently, the increase in solid waste adds extra pressure on the waste facilities and the environment (Slišković et al., 2018). Like merchant ships, the solid waste generated usually gets disposed of at port facilities. Cruise ships should not rely solely on disposal facilities to regulate the waste and should instead incorporate plastic reduction programs on board (Pallis et al., 2017). In efforts to reduce all non-essential single-use plastic aboard cruise ships, Carnival Corporation implemented an environmental program known as Operation Oceans Alive. The goal for 2021 is to reduce various single-use plastics including straws, cups, bags, lids, stir sticks, and select food packing items. This commitment is further supported with the implementation of a Single-Use Item Policy (Heldewier and Enge, 2019).

4.2.2.2 Fishing Vessels

The biggest contributor of plastic waste generated from fishing vessels is derelict fishing gear (Richardson et al., 2018). Fishing gear may be discarded, abandoned, or lost at sea. The causes of this vary among fisheries and depend on the type of gear used, available resources for proper gear disposal, weather, and site popularity (NOAA, 2015). Illegal, Unreported and Unregulated (IUU) fishing is also a big contributor to gear lost at sea (Richardson et al., 2018). Consequently, this issue has proven to be a challenging task to manage aboard these vessels. Fishing gear loss, discard, or abandonment can be managed through preventative and mitigation measures. Preventative measures include strengthening port regulations, reducing fishing effort, spatial management, and gear marking (Macfadyen et al., 2009). Gear marking has recently been implemented for fish harvesters in eastern Canada (DFO, 2020b). Canadian fishers are required to keep records of lost gear and to report incidents to the Department of Fisheries and Oceans (Goodman et al., 2019). To mitigate the issue, biodegradable nets and pots can be used as an alternative, in addition to enforcing gear loss reporting, re-evaluating end-of-life gear disposal centers, and implementing recovery programs (Macfadyen et al., 2009). The Global Ghost Gear Initiative (GGGI) collaborates with fishing industry, various NGOs, academia, and government to tackle the issue of ghost gear by collecting evidence, defining best practices to inform policy makers, and implementing these practices (GGGI, n.d.). Moreover, Canada has developed a program to encourage Canadians to act in reducing plastic in the environment through the Ghost Gear Fund. This initiative supports various projects focused on fishing gear retrieval, use of innovative technologies, and responsible disposal measures (DFO, 2020c).

4.3 Conservation and Monitoring Programs

4.3.1. Marine Turtle Conservation

Globally, several marine turtle conservation programs exist to protect the seven species and their habitats from various human activity. Conservation efforts include rehabilitation centres (hospitals), monitoring and ocean tracking, educational programs, and research. This study focuses on well known conservation programs in the Northwest Atlantic and the Wider Caribbean Region. In Canada, the Canadian Sea Turtle Network collaborates with worldwide scientists, fishermen, government, and coastal communities to protect endangered marine turtles. The research focuses primarily on leatherback turtles in the Atlantic Ocean as they migrate to higher latitudes (Canadian Sea Turtle Network, 2020). Research findings have contributed towards the development of the recovery action plan for the Atlantic Leatherback Turtle published by DFO (2020a).

The Greater Atlantic Region Sea Turtle Program led by NOAA Fisheries and the United-States Fish and Wildlife Service focuses on managing and conserving five of the seven marine turtle species found in Mid-Atlantic waters. The program aims to rebuild marine turtle populations from Maine to Virginia through the Endangered Species Act, Section six program, which facilitates cooperation between States to allocate funding for monitoring programs, management, research, and outreach projects (NOAA, 2017; NOAA, 2020a). The Greater Atlantic Region Sea Turtle Program coordinates with the Greater Atlantic Marine Mammal Stranding Networks to respond to marine turtles in distress, stranded, and entangled so they can be brought to rehabilitation facilities (NOAA, 2019). Moreover, select commercial and recreational fisheries operating in State or Federal Atlantic waters are required to record marine turtle observations for data collection on the interactions of fisheries and turtles, existing preventative measures of marine turtle take (i.e. harass, harm, kill, and capture), and if additional measures need to be implemented (NOAA, 2020b).

The Sea Turtle Conservancy (STC) is the oldest non-governmental organization that is dedicated to national and international marine turtle conservation. This NGO is based out of Florida and focuses its research and conservation initiatives throughout Central America and the Wider Caribbean Region. They have several monitoring projects related to marine turtle survival and work closely with conservationists to influence policy decisions regarding marine turtles. Moreover, they work towards establishing refuges for habitats and coastal environments inhabited by marine turtles and host research and education programs. To engage the public, the STC provides an online tracking education program that shows the migratory movements of tagged marine turtles. This also allows researchers to collect data and monitor the movements of these turtles to better understand the threats faced and how to protect them (STC, 2020).

4.3.2 Solid Waste Clean-ups

National Cleanup Day is a global initiative that aims to keep the environment free from debris by engaging community members in clean-ups. The goal is to change daily behaviours by incorporating small actions such as picking up litter when encountered (National Cleanup Day, 2020a). Several cleanup initiatives are held throughout the year, including World Cleanup Day, Clean trails, Cleanup Ambassadors, the International Coastal Cleanup, and the Great Global Cleanup event for Earth Day (National Cleanup Day, 2020b). In the latest International Coastal Cleanup report by the Ocean Conservancy (2020), the top three items collected, globally, from shorelines, coastal waters, and on the seafloor include food wrappers (4,771,602), cigarette butts (4,211,962), and plastic beverage bottles (1,885,833). In Canada, plastic bottles caps are the third most abundant, followed by straws and plastic bags. In the United-States, cigarette butts are the most abundant, followed by food wrappers, and plastic beverage bottles. Along the east coast of the U.S., where many leatherbacks are present, cigarette butts appear to be the most abundant, followed by either plastic bottle caps or food wrappers. In Florida, plastic bottle caps are the second most abundant, at 110,241 items collected. In Trinidad, plastic beverage bottles are the most abundant, followed by plastic bottle caps (Ocean Conservancy, 2020).

Keep America Beautiful is an organization in the United-States that strives to maintain clean spaces by engaging the community in participating and supporting cleanup initiatives. Their main goals are to end littering and improve recycling through various programs including the annual Great American Cleanup, America Recycles Day, Employee Engagement, and the Cigarette Litter Prevention Program (Keep America Beautiful, 2020). In their latest publication, the most abundant litter collected is cigarette butts and food packaging and miscellaneous plastics make up 46.7% of total litter collected from the roadways in the United-States. Moreover, from 1969 to 2009, visible litter on the roadways decreased by 91%; however, the number of plastic items in streams almost doubled (Schultz and Stein, 2009; Keep American Beautiful, 2010). These initiatives demonstrate the efficacy and importance of citizens contributing to science.

4.3.3 Citizen Science

Citizen science refers to the participation of members from the public in scientific research and monitoring by gathering, categorizing, transcribing, or analyzing scientific data in collaboration with scientists (Cigliano and Ballard, 2017). As seen with the solid waste cleanup initiatives, citizen science plays an important role in marine debris and marine turtle research and conservation. Globally, many programs promote citizen science. To avoid repetition, this section focuses on projects that demonstrate ways citizens contribute to marine turtle science.

In the United-States, the North Carolina Sea Turtle Project takes on volunteers to help monitor endangered marine turtle species along the coast, collect nesting data, and educate the public. While some institution scientists' have concerns with members of the public contributing to science, citizens play a vital role in marine turtle conservation by filling knowledge gaps through data collection from beach surveys and by simply being more familiar with that environment. Citizen science also provides a unique perspective on marine turtle ecology through individual experiences and an alternative view to the human-environment interaction (Cornwell and Campbell, 2012).

SpeSeas is an NGO dedicated to protecting the ocean surrounding Trinidad and Tobago and the Caribbean through sustainable use advocacy. In collaboration with Save Our Sea turtles (SOS) and ProTector Inc., they have developed a mobile application for marine turtle citizen science. This initiative, which is becoming common in other sectors (i.e. derelict fishing gear), allows for citizens to collect data on marine turtle populations. Reported sightings are uploaded onto a mapping software with information on species identification, water depth, time, and additional information on the encounter (i.e. disentanglement). Pictures of each marine turtle are also uploaded which allows for scientific specialists or taxonomists to confirm species and gender. Reporters can choose to leave their contact information which can be beneficial if a scientist has additional questions on the encounter (SpeSeas, n.d.).

4.4 Legislation, Conventions, and Protocols

The following section briefly describes legislation, conventions, and policies relevant to marine plastic waste and marine turtle conservation in Canada, the United-Sates, and the Wider Caribbean Region, as well as discuss some limitations.

4.4.1 International

Protecting the ocean through sustainable use and conservation is the responsibility of all nations. Agreements have been made to regulate ocean activity and avoid conflict. Such agreements include international conventions which are legally binding contracts for participating States. The following describes important conventions pertaining to marine debris and marine turtle protection that have yet to discussed.

The United Nations Convention on the Law of the Sea (UNCLOS), implemented in 1982 and signed in 1994, outlines a legal framework for regulating activities that take place in the ocean, in addition to coastline sovereignty, jurisdiction, and countries' responsibilities relating to environmental protection. Article 194, Section1, Part XII outlines the necessary measures to prevent, reduce, and control marine pollution in the environment. The marine pollution section considers the release of harmful and persistent waste originating from land-based sources and dumping. This agreement has been ratified by Canada and the Wider Caribbean Region (Parris, 2016; ECCC, 2020a). Despite being one of the first nations to have participated at the conference, the United-States has yet to ratify UNCLOS. However, the country recognises and implements UNCLOS as an international law (U.S. Department of State, 2019).

In addition to the MARPOL 73/78 described above, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) prohibits the disposal of waste in the ocean. This Convention was one of the first international agreements to protect the environment from human activity. In response to changing times, the Convention was replaced by the London Protocol in 1996. Under this protocol, all ocean dumping is prohibited unless listed under the "reverse list". This protocol is adopted by Canada, the United-States, and the Wider Caribbean Region (EPA, 2006; Carbin et al., 2014; ECCC, 2020b).

The Convention on International Trade in Endangered Species (CITES) is another multilateral treaty which was put in force into 1975 to protect populations of endangered species by regulating international trade. CITES protects over 38,700 species from over-exploitation, listed under Appendices (I, II, III) based on their level of threat. The leatherback turtle is listed under Appendix I, indicating that it is threatened with extinction and the trade of this species is permitted only under strict circumstances. As with other conventions, signed Parties must adopt their own legislation at the national level as the Convention does not take the place of national laws. CITES provides a framework to be voluntarily respected and implemented by the Parties (CITES, 2019).

4.4.2 National and Regional

In addition to international conventions and agreements, individual nations have developed and implemented legislation that aim to protect the marine environment and vulnerable to threatened species within their jurisdiction. Legislation has the force of law and there can be serious consequences if not followed. This section focuses on legislation relevant to marine pollution and marine turtles in Canada, United-States, and the Wider Caribbean Region.

4.4.2.1 Canadian Legislation

The Oceans Act was established in 1996 to respect the oceans along Canada's coast which include the Arctic, Atlantic, and Pacific. The legislation provides a framework for managing Canada's marine resources sustainably while promoting a precautionary approach to marine ecosystem conservation. This legislation includes the designation of Marine Protected Areas that aim to conserve and protect endangered species, unique habitats, and areas of high biodiversity or productivity. The aim of the Act is to reconstruct ocean management through the Ocean Strategy that seeks to strengthen partnerships with stakeholders and ensure an integrated approach (Government of Canada, 2019c).

The Species At Risk Act, 2002, provides a framework for protecting wildlife species at risk in Canada. Under the Act, there are guidelines and regulations for listing a species as endangered which is assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Once identified as endangered under the Act, a recovery strategy needs to be prepared, followed by an action plan which should include monitoring and reporting. Moreover, listed species are to be reassessed every 10 years by COSEWIC (Government of Canada, 2019d).

The Canadian Environmental Protection Act, revised in 1999, aims to prevent pollution and protect the environment for sustainable development. Under the Act, there is a section on preventing land-based source pollution from entering the marine environment. This section is short and does not include prohibitions or regulations to control this issue. Objectives, guidelines, and codes of practice are to be consulted with other organization and agencies. Marine pollution as defined under this Act is described as:

> The introduction by humans, directly or indirectly, of substances or energy into the sea that results, or is likely to result, in (a) hazards to human health; (b) harm to living resources or marine ecosystems; (c) damage to amenities; or (d) interference with other legitimate uses of the sea (Government of Canada, 2019a).

This Act does not specifically mention prevention of marine pollution that can harm the species listed as endangered. However, it will include plastic manufactured items under the toxic substance list by the end of 2021 which will facilitate the ban on certain single-use plastic items (Kelly, 2020).

The Fisheries Act (rev.1985) provides a framework for managing and controlling fisheries, in addition to conserve and protect the fish and their habitats and to prevent pollution. Under the Fish and Fish Habitat Protection and Pollution Protection, individuals are not allowed to obstruct the free passage of fish, unless work or activity that is deemed non harmful to fish can be authorized by the Minister. Additionally, certain substances, including deleterious substances, are prohibited from being thrown overboard by any person. Deleterious substances (pertaining to this study) are defined as any substance that, if added to any aquatic environment, would alter the quality of water, or render deleterious to fish and their habitat. The Act also highlights several fishing regulations including respect of fishing gear and equipment, conservation and protection of fish habitat, and prevention of any deleterious substance from entering the water. Under the fishing gear and equipment regulation, individuals must mark and identify fishing gear accordingly and comply with the designation of persons as observer aboard a vessel. Moreover, under the Maritime Provinces Fishery Regulations (SOR/93-55), no person shall leave fishing gear unattended for more than 72 hours consecutively. The Fisheries Act also provides the Marine Mammal Regulations to protect cetaceans (whales and porpoises), walrus, and seals (Government of Canada, 2019b).

4.4.2.2 United-States Legislation

Marine turtles are protected under several laws in the United-States including the Federal Endangered Species Act of 1973, Florida's Marine Turtle Protection Act (379.2431, Florida Statutes), and The Marine Turtle Conservation Act, 2004. The Federal Endangered Species Act of 1973 provides a framework designed to protect and restore species that are listed as endangered or threatened by implementing recovery plans. The Florida's Marine Turtle Protection Act protects five of the seven marine turtle species that nest along the coast of Florida. The legislature ensures that the Fish and Wildlife Conservation Commission has authority to implement recovery plans for the marine turtles in the United-States. Several regulations under the Act protect marine turtles, their hatchlings, nests, and eggs. Activities that may affect marine turtles or their nests need to be approved by the Department of Environmental Protection. However, the authority of the Department of Environmental Protection is limited to the Atlantic coast of Florida (The Florida Legislature, 2016).

The Marine Turtle Conservation Act, 2004, is a multinational species conservation act that provides a framework to assist with the protection of marine turtles and their nesting habitats in foreign countries (U.S. Congress, 2004). The aim of this Act is to provide leadership and support by developing capacity building training programs for beach monitoring, implementing standardized beach surveys, and assisting with long-term scientific studies that assess potential climate change impacts. Since implemented, this Act has already benefitted marine turtles through the Wildlife Without Borders programs (Possardt and O'Toole, 2010). While the Act protects marine turtles in foreign habitats and their nesting habitats, the Act fails to protect other critical marine turtle habitats such as foraging sites.

The Marine Protection, Research and Sanctuaries Act (MPRSA), 1972, also referred to as the Ocean Dumping Act, implemented the requirements provided under the London Convention. This Act provides regulations that restrict ocean dumping of all materials that can adversely impact the environment, human health, ecological systems, and economic potentialities. Under the Act, materials is defined as:

> Matter of any kind or description, including, but not limited to, dredged material, solid waste, incinerator residue, garbage, sewage, sewage sludge, munitions, radiological, chemical, and biological warfare agents, radioactive materials, chemicals, biological and laboratory waste, wreck or discarded equipment, rock, sand, excavation debris, and industrial, municipal, agricultural, and other waste (EPA, 2014).

This Act is effective in ocean waters beyond the United-States jurisdiction as it prohibits material to be transported from the United-States for the purpose of ocean dumping. Moreover, management plans are to be developed for previously used ocean dumping areas to reduce environmental impacts (EPA, 2014).

4.4.2.3 Wider Caribbean Region Convention and Protocols

The Cartagena Convention, 1986, provides a framework for the protection and development of the marine environment of the Wider Caribbean Region. This is a legally binding agreement between 26 Parties for the protection of the Caribbean Sea, the Gulf of Mexico, and areas of the Atlantic Ocean. Three protocols under this Act regulate oil spills, Specially Protected Areas and Wildlife (SPAW), and land-based sources of marine pollution (LBS). SPAW protects coastal and marine biodiversity by promoting sustainable use of the marine environment. Under this protocol, there are guidelines and different management plans that focus on Marine Protected Areas and wildlife, threatened and endangered marine species, and marine and coastal ecosystems. The LBS protocol assists with meeting goals addressed in the UNCLOS Convention. This protocol requires developing management plans that address agricultural non-point source pollution (UNEP, 2019).

4.5. Summary

In summary, several management efforts to reduce plastic pollution and increase marine turtle protection are being implemented in Canada, the United-States, and the Wider Caribbean Region. Solid waste management strategies have already started to adapt in response to the increase of plastic pollution. However, it has clearly been a slow process as plastic waste continues to accumulate in the marine environment. To close the plastic loop by recycling requires adapted laws on plastic pollution, drastic enforcement measures, cooperation and collaboration between industries, governments, civil society organizations, and community, as well as efficient decision making to deliver strategic management approaches quicker. As plastic pollution is a transboundary challenge, neighbouring nations should work together and support each other towards closing the plastic loop. In developed countries, the concepts of reduce, reuse, and recycle are not difficult behaviours to implement as they often depend on the individual’s level of consciousness. These behaviours can be taught at an early age through education and outreach programs, which will be discussed in the following chapter. While solid waste management on land is receiving a lot of attention from the government, as it is the major source for plastic pollution, waste management at sea should not be neglected. Specifically, regarding monitoring and enforcement of the regulations for marine pollution.

Marine turtles appear to be well monitored and cared for by many conversation groups and by incorporating citizen science. They also appear to be well protected under various national and regional legislation, protocols, international conventions, and conservation programs implemented in Canada, the United-States, and the Wider Caribbean Region. Multiple legislation that specifically target marine turtles are implemented in the United-States as their coasts serve as nesting habitats throughout several months in a year. Under the Canadian Fisheries Act, there are Regulations for other migrating species, such as whales and porpoises. Perhaps leatherback turtles would benefit from having their own Regulation implemented. Moreover, Canadian legislation on environmental protection and pollution prevention does not account for the severity of plastic abundance in the environment. The United-States recently implemented the Break Free From Plastic Pollution Act of 2020 to amend their Solid Waste Disposal Act. This Act targets certain single-use plastic packaging and products to reduce the production and use and to improve producer responsibility. Sections under this Act include guidance for recycling to be standardized across the States, as well as provides an action plan for plastic tobacco filters (U.S. Congress, 2020). Given the number of cigarettes/cigarette filters and single-use plastics collected from the shorelines of Nova Scotia, Prince Edward Island, and Newfoundland, Canada would certainly benefit from developing and implementing an act specific to its plastic waste. While plastic manufactured items are to be added under the Canadian Environmental Protection Act, 1999, by 2021, the enormity and complexity of plastics may warrant its own Act.

CHAPTER 5 – DISCUSSION

5.1. MANAGING RISK OF PLASTICS IN CANADA'S NORTHWEST ATLANTIC OCEAN

Results from the Great Canadian Shoreline Cleanup (2010-2019) indicate that 75.8% of plastic entering the marine environment, surrounding Nova Scotia, Prince Edward Island, and Newfoundland originate from land-based activities (Table 6). This is in part due to intentional or unintentional discarding of items into the environment and largely due to inefficient municipal solid waste management systems, and too few outreach and educational programs. Plastic waste can be prevented from entering the ocean by developing and implementing municipal more effective waste management, which is the responsibility each regional authority, and by developing and providing educational programs for youth and adults.

5.1.1 Provincial Solid Waste Management Strategies

Newfoundland has the highest percent of plastics (89.1%) originating from land-based activities (Table 6). However, the total plastic waste generated from this province accounts for six percent of their total waste (Government of Newfoundland and Labrador, 2019). The provincial solid waste management strategy was implemented in 2005 and highlights goals for reducing the amount of waste generated by the province. The aim is to divert (reduce, reuse, recycle and recovery) solid waste from landfills by 50%, and phase out landfills and incineration, as well as reduce the number of waste disposal sites by 80%. This strategy is an interdepartmental initiative requiring regional governments to work together in achieving these goals. The latest strategic review outlines the accomplishments and status for the goals. Newfoundland has reduced materials going to landfills by 25%, has reduced waste disposal sites to 170 (72%), closed 154 operational unlined landfills, and eliminated open burning and incineration at 149 landfill sites. They have also made modern water management waste systems accessible to 83% of the population (Government of Newfoundland and Labrador, 2019). These accomplishments are significant. However, based on the results obtained from the Great Canadian Shoreline Cleanup, the amount of plastic waste on shorelines has not decreased. Reasons to explain this include items originating from neighbouring regions washing up onto shores from the ocean, and the intentional or unintentional disposal of waste by individuals. In the case of the latter, emphasis should be on developing outreach and educational programs on proper waste disposal such as reduce, reuse, recycle and recover in communities across Newfoundland and Labrador. Moreover, incorporating cleanup initiatives, such as National Cleanup Day, on a quarterly basis can reduce the amount of waste on shorelines and can promote environmentally friendly waste behaviors among communities (National Cleanup Day, 2020a).

Nova Scotia coastlines have the second highest percent of plastics (79.7%) originating from land-based activities (Table 6). The government of Nova Scotia commits to maintaining a goal of 50% in diverting waste from landfills by reducing at the source and recycling, and to have no more than 300kg/person/year of disposal waste. These targets fall under the Canadian Environmental Protection Act. The Nova Scotia Environment aims to develop new programs, increase participation for waste prevention, increase producer responsibility of products and materials, and increase the waste diversion. Across the province, there are several facilities including solid wastes disposal sites (landfills) (9), recycling facilities (8), waste transfer facilities (20), and more than 75 locations for Enviro-Depot which accept a variety of recyclable materials and manufacture new products from these materials (Nova Scotia Environment, 2017). The overall goal is to become the cleanest and most sustainable environment in the world by 2020. The progress report 2011 highlights Nova Scotia's achievements since implementation of the 1995 Solid Waste Resource Management Strategy and future targets. From 1990 to 2010, the province has achieved the 50% diversion goal, reduced the disposal waste by almost half, from 743kg/person/year to 401kg/person/year, has recycled over 50,000 tonnes of materials, and recycled 2.6 billion beverage containers since 1996 (Nova Scotia Environment, 2011). Despite these accomplishments, the amount of waste on the Nova Scotia shorelines remain quite high. Having met their goal for waste diversion, focus for waste management should be on phasing out landfills, and encouraging much less use of plastics and more recycling.

The number of plastic waste (58%) originating from land-based activities on Prince Edward Island's shorelines accounts for little over half of the total amount of plastic waste collected. The solid waste is managed by the Island Waste Management Corporation (IWMC) which is a provincial Crown Corporation. There are six Waste Watch Drop-off centres on the island that accept a variety of household wastes, in addition to two waste facilities that accept waste only from commercial haulers. The Waste Watch Program was implemented in early 1990s to divert waste from landfills by properly disposing solid materials through mandatory sorting into categories (recyclable, compostable and waste). In 2017, Prince Edward Island managed to divert 58,949 tonnes of materials. Moreover, several programs implemented by the government include Beverage Container Refund Programs, Electronic Recycling Programs and educational programs that promote good waste management practices (reuse, reduce, and recycle,). The IWMC also supports community initiatives such as roadside cleanup events, and competitions that encourage the public to clean up litter (IWMC, 2018). In efforts to reduce plastic, the Prince Edward Island government has implemented the Plastic Bag Reduction Act, 2019, which prohibits business from distributing plastic bags, and encourages the use of reusable bags (Government of Prince Edward Island, 2019).

In the Northwest Atlantic Ocean, leatherback turtles may also be at risk of entanglement in derelict fishing gear. In all three provinces, fishing lines and rope are retrieved from shorelines. To combat this issue, Fisheries and Ocean Canada has developed the Sustainable Fisheries Solutions and Retrieval Support Contribution Program (Ghost Gear Fund). This initiative supports projects that aim to retrieve lost gear, modify end-of-life fishing gear facilities, encourage innovative recycling measures, and the development of technologies that retrieve derelict fishing gear. Over a two-year period, a total of 26 projects are to be supported with the goal of protecting the marine environment and its organisms (DFO, 2020c). Moreover, under the Species At Risk Act, DFO has finalized the action plan for leatherback turtle conservation, which has projects listed as high priority that aim to reduce the risk of leatherback entanglement (DFO, 2020a).

5.1.2 Education and Outreach Programs

The Governments of Newfoundland and Labrador, Nova Scotia, and Prince Edward Island have implemented the Project WET Canada, which was created by the Canadian Water Resources Association and offered to educators across the country. This project is an educational program regarding water for educators of Kindergarten to Grade 12 students and offers home and distance learning resources (CWRA, n.d.). In Newfoundland and Labrador, the program is designed for outdoor and indoor setting and is a supplement for existing curricula. The project offers workshops for youth and family groups, such as the Fishing for Success workshop that provides guided activities including hiking, campfire and movies nights, fishing and dipping in ponds, and other educational activities (Environment, Climate Change and Municipalities, n.d.). Rethink Waste Newfoundland and Labrador provides resources on waste reduction to teachers to inspire students to help keep waste out of landfills by reducing, reusing, and recycling their waste (Rethink Waste NL, 2020). Moreover, the Multi-Materials Stewardship Board (MMSB) offers the incentive of matching recycling refunds for Kindergarten to Grade 12 schools, which encourages students to adopt sustainable waste management behaviours at school and at home (Green Depot, 2020).

Project WET Canada offers a new curriculum on Climate, Water and Resilience to Nova Scotia. The science curriculum is offered to Kindergarten through Grade 10 and incorporates several topics including human-environment relationship, impacts of climate change, ecosystem adaptation, etc. However, it is unclear whether solid waste management (reduce, reuse, and recycle) is offered in Nova Scotia's curriculum. Despite this, broader topics such as identifying human impacts on environment and how to address theses issues are incorporated (CWRA, 2020). Divert NS aims to raise awareness through educational efforts to change waste disposal behaviours across the province. Divert NS offers tools and resources (activity sheets) and lesson plans for school curricula, industry, and community and hosts regional workshops for waste educators and enforcement officers (Divert NS, 2020). Several engagement, education and outreach programs are implemented by NGOs across Nova Scotia that offer programs and resources to educators (Green Schools NS, 2015; Clean NS, 2020). Clean Nova Scotia offers virtual educational programs on topics such as litter, clean energy, air and water, and climate change (Clean NS, 2020).

Project WET Canada also offers a new curriculum on Climate, Water and Resilience for students in Kindergarten to Grade 12 from Prince Edward Island. The curriculum incudes demonstrating ways to reduce, reuse, and recycle materials to students as early as Grade 1 (CWRA, 2020). Additionally, the IWMC offers educational guides for instructors, such as lunch lesson plans, interactive sorting games, colouring pages, and other children activities in addition to arranging tours of the IWMC facilities (IWMC, 2020).

5.2 Summary

In summary, several solid waste management strategies are practised in the three Atlantic provinces that are considered in this study. However, their success remains an open question due to the large quantities of plastics being found along the Atlantic shorelines. Hence, there is still work that needs to be done on both the management strategies and outreach and education at a local level. Teaching programs on solid waste management and engagement should be mandatory in schools across Canada to promote long-lasting waste disposal behaviours in people that will naturally persist throughout their lifetimes.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Plastic pollution continues to enter the marine environment from Newfoundland and Labrador, Nova Scotia, and Prince Edward Island, despite there being regional solid waste management strategies, national legislation, engagement, education, and outreach programs. In these three Atlantic Provinces, land-based sources are the biggest contributors to marine plastic pollution and require more managerial effort to prevent the release of plastics. From 2010 to 2019, data on plastic items collected off these shorelines reveal that Newfoundland has the highest of the three provinces for land-based plastic pollution (89.1% of 69,628 items), followed Nova Scotia (79.7% of 112,475 items) and Prince Edward Island (58% of 18,064 items). Moreover, results show that plastic items collected off Nova Scotian shorelines have increased since 2013, whereas in Newfoundland and Prince Edward Island, plastic items collected from 2010-2019 have remained constant.

Several plastic items originating from land-based sources in these three Atlantic Provinces are a hazard for leatherback turtles foraging in Canadian cold waters. Plastic bags are in the top eight most collected items from the shorelines of Nova Scotia, Newfoundland, and Prince Edward Island, which can pose threat to leatherback through direct ingestion. Furthermore, tiny plastics and Styrofoam are in the top four most abundant items collected. These items may pose a threat to leatherbacks through the unintentional ingestion of contaminated gelatinous prey. There is evidence of leatherbacks experiencing negative impacts (intestinal blockage) from plastics ingestion (bags, fishing line, balloons, cigarette wrapping, and utensils) and entanglement in fishing gear (nets and rope), which was abundantly collected off shorelines of all three provinces (Mrosovsky et al., 2009; Hamelin et al., 2017). Notably, the abundance of cigarettes/filters accumulating on of Nova Scotia, Newfoundland, and Prince Edward Island remains a big issue as cigarette waste may pose low to moderate risk to aquatic organisms (Patra and Cole, 2002). To date, there have been no reports on cigarette/filter ingestion by leatherbacks. Hence, this occurrence should be further investigated as it is not uncommon for other marine turtle species to ingest cigarettes/filters (Stanley et al., 1988; Macedo et al., 2011).

This study shows that plastics may pose a risk to leatherback turtles in the Northwest Atlantic Ocean, specifically in the coastal waters of Nova Scotia, Prince Edward Island, and Newfoundland. The plastic waste originating from land-based activities accounts for 75.8% of the total plastic collected from the shorelines from 2010 to 2019. Hence, efforts should focus on improving solid waste management systems on land, as well as improving outreach, engagement, and education programs. Moreover, the coastal cleanup initiatives should continue as they contribute significantly to research and conservation by quantifying and removing plastic debris. Leatherback turtles are protected under several pieces of legislation that aim to restore endangered species populations through effective management and continuous monitoring. There are, however, limitations to these international and national laws and regulations that need to be improved to effectively protect leatherback turtles from the threats of human activity. The following highlights knowledge gaps, as well as recommendations to reduce the threats of plastic on the Northwest Atlantic Leatherback Turtle.

6.2 Research Gaps

Several research gaps relevant to marine plastics and leatherback conservation were identified from the literature review. Knowledge gaps relating to cigarettes/filters require additional research as these items are the most abundant type of marine litter found on shorelines of the three Atlantic Provinces. This information would contribute to managing the amount of cigarette filters along the shorelines, through regulations and public education. Furthermore, this study suggests that leatherbacks may be at a high risk of plastic encounters in the Northwest Atlantic along Canada’s coast. However, the proportion of the leatherback population in the Northwest Atlantic waters actually exposed and affected by plastic pollution has yet to be determined. The following research gaps should be addressed by:

1. Quantifying the risk of plastic ingestion by leatherback turtles in regions along their migratory path, specifically in the Northwest Atlantic Ocean, by

conducting field studies at sea on the occurrence of plastics in surface water and water column.

2. Identifying whether cigarette filters are ingested by leatherback turtles, and if so, what effects they may cause.
3. Investigating whether not marine plastics can cause mortality in hatchlings on the nesting beaches.

6.3 Recommendations

To address the risk of plastics on leatherback turtles in the Canadian Atlantic Provinces, the following recommendations should be considered in order of priority:

1. Conduct field studies to collect evidence on the exposure and effects of exposure of plastics to leatherback turtles at all life stages, including hatchlings, juvenile, and adult.
2. All leatherbacks captured in tagging studies should be thoroughly examined in addition to those found stranded or deceased.
3. Develop public education and outreach programs on leatherback turtles in Canadian waters and raise awareness by implementing these programs across Canada.
4. Emphasis should be put on Extended Producer Responsibility to manage the plastic used in single-use products, in addition to implementing a legislation specific to plastics in Canada.
5. Increase enforcement for anti-litter laws in communities to deter the discard of plastics and for action accountability.
6. Increase enforcement at sea and onshore to deter illegal discarding of fishing gear.
7. Incorporate national cleanup events by partnering with various initiatives (i.e. National Cleanup Day, etc.). If already hosting such events, increase the frequency of events (i.e. instead of annually, can do quarterly)
8. Create an open platform relevant to leatherbacks and plastics to facilitate communication and allows for data and knowledge transfer, in addition to incorporating data collected through citizen science.

9. Collaborate with the United-States and Wider Caribbean Regions to address knowledge gaps regarding waste impacts on leatherbacks and share information on successful leatherback conservation programs.
10. Continue to develop partnerships with solid waste management industries and implement diversion waste initiatives to phase-out landfills.

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[i] This project includes a comprehensive bibliography which was omitted from this copy due to its length