Using a Geospatial Approach to Evaluate the Impacts of Shipping Activity on Marine Mammals and Fish in Arctic Canada

Thesis
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Abstract

A loss in sea ice cover, primarily attributed to climate change, is increasing the accessibility and navigability of the Arctic Ocean. This increased accessibility of the Canadian Arctic, and in particular the Northwest Passage, presents important global and national shipping and development opportunities. However, increased shipping in the region also present challenges related to the environmental sustainability, sovereignty and safety, and cultural sustainability. The Low Impact Shipping Corridors (the Corridors) is currently the foundational framework for governing ship traffic within the Canadian Arctic. However, the Corridors were largely established based on historic traffic patterns and thus they do not fully consider important areas for marine mammals and fish in the region. This research addresses this important research gap by spatially identifying important areas for marine mammals and fish in the Kitikmeot region of Nunavut using both Traditional Knowledge and western science, evaluating ship tracks from 1990-2015, and geospatially identifying and evaluating areas of potential disturbance for marine mammals and fish related to vessel noise from different ship types transiting the Corridors within the study region. The results of this study indicate that all vessel types have the potential to cause behavioural disturbance to marine mammals and fish when navigating through these important wildlife areas, and that louder vessels (i.e. Tanker ships) travelling outside of these important wildlife areas have a greater potential to cause behavioural disturbance to marine mammals and fish than quieter vessels (i.e. Pleasure Crafts). The results also indicate that vessels navigating through certain regions of the Kitikmeot have a higher potential to cause behavioural disturbances in these species, including through the Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet.

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Acronyms

ACIA	Arctic Climate Impact Assessment
AMSA	Arctic Marine Shipping Assessment
AMSP	Arctic Marine Strategic Plan
Corridors	Low Impact Shipping Corridors
EBSAs	Ecologically and Biologically Significant Areas
GIS	Geographic Information Systems
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
MPAs	Marine Protected Areas
NCRI	Nunavut Coastal Resource Inventory
NLUP	Nunavut Land Use Plan
NORDREG	Northern Canada Vessel Traffic Service Zone

OAG	Office of the Auditor General of Canada
Polar Code	International Code for Ships Operating in Polar Waters
PAME	Protection of the Arctic Marine Environment

Chapter 1: Introduction

1.1 Introduction

A loss in sea ice cover, primarily attributed to climate change, is increasing the accessibility and navigability of the Arctic Ocean (Dawson, et al., 2016; Dawson, Johnston, & Stewart, 2014; Johnston, Dawson, De Souza, & Stewart, 2016; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Stephenson, Smith, & Agnew, 2011). In the Canadian Arctic, summer sea ice has declined at a rate between 2.9% ± 1.2% decade^{-1} in the Canadian Arctic Archipelago and 11.3% ± 2.6% decade^{-1} in Hudson Bay during the period of 1968 and 2008 (Derksen, et al., 2012; Tivy, et al., 2011). These biophysical changes in sea ice are influencing a number of direct socio-economic responses; for example, the opening of shipping routes and the lengthening of the navigation season for marine transportation, natural resource extraction, and tourism (Aporta, Taylor, & Laidler, 2011; Dawson, et al., 2016; Dawson, Johnston, & Stewart, 2014; Furgal & Prowse, 2008; Kelley & Ljubicic, 2012; Lasserre & Pelletier, 2011; Stewart, Dawson, & Johnston, 2015; Têtu, Pelletier, & Lasserre, 2015). Recent studies have used climate models to suggest navigation will likely become easier and faster in the Canadian Arctic by the mid-21st century (Barnhart, Miller, Overeem, & Kay, 2015; Melia, Haines, & Hawkins, 2016; Smith & Stephenson, 2013; Stephenson, Smith, & Agnew, 2011). This increased accessibility of the Canadian Arctic, and in particular the Northwest Passage, presents important global and national shipping and development opportunities. However, increased shipping in the region also present challenges related to the environmental sustainability, sovereignty and safety, and cultural sustainability (Table 1). For instance, China released a white paper on China's Arctic Policy in January 2018 that highlights a Polar Silk Road initiative, which would connect Asia, Europe, the Middle East and Africa through the Arctic Ocean (Ministry of Foreign Affairs of the People's Republic of China, 2018). Such an initiative presents both opportunities and challenges for Canada as declining sea ice opens shipping corridors in the Canadian Arctic. Research is needed to better understand the potential impacts of increased shipping in the region and also to inform evidence-based decision-making for shipping management and oceans governance.

Table 1. Potential impacts of increased shipping and related studies.

Impact	Studies
Environmental Impacts • Noise pollution • Icebreaking operations • Ship strikes • Accidental and regular discharge • Light disturbance • Invasive species	Arctic Council 2009, Dawson, Copland and Johnston, et al. 2016, Ghosh and Rubly 2015, Halliday, et al. 2017, Hodgson, Russel and Megganety 2013, Hovelsrud, et al. 2011, Huntington, Daniel, et al. 2015, PEW Charitable Trusts 2016, Reeves, et al. 2012, Veirs, Veirs and Wood 2016
Cultural Impacts • Disrupting wildlife – altering ability to hunt and fish • Disrupting travel routes • Increased tourism • Degradation of historic or culturally significant sites	Aporta, Taylor and Laidler 2011, Carter, Dawson and Joyce, et al. 2017a, Carter, Dawson and Joyce, et al. 2017b, Carter, Dawson and Knopp, et al. 2018, Laidler, et al. 2011, Dawson, Johnston and Stewart 2014, Kelley and Ljubicic 2012, Meier, et al. 2014
Safety and Security • Vessel incidents (fire, groundings, collision) • Safety of crew • Security threats	Fisheries and Oceans Canada 2018a, Fisheries and Oceans Canada 2018b; the Polar Code (see International Maritime Organization 2016); Federal acts in Table 3

The Low Impact Shipping Corridors Initiative (formerly known as the Northern Marine Transportation Corridors Initiative; herein referred to as ‘the Corridors’), co-led by the Canadian Coast Guard, the Canadian Hydrographic Service, and Transport Canada, is currently the foundational framework for governing ship traffic within the Canadian Arctic (Canadian Coast Guard, 2014). The aim of the Corridors is to increase ship safety by providing predictable levels of service to mariners transiting through them (Canadian Coast Guard, 2014). However, the Corridors were largely established based on historic traffic patterns and thus they do not fully consider important areas for marine mammals and fish in the region. The lack of full consideration of these important areas in the identification of the Corridors was identified as a significant gap within the seminal Arctic Marine Shipping Assessment (AMSA) Report (Arctic Council, 2009). This important research gap must be addressed to enable a safe environment for Arctic shipping and to ensure important areas for marine mammals and fish are fully considered in federal level shipping investments, regulations and policies. Spatial understanding of the correlation between historic shipping trends, the placement of the Corridors, and the impacts that ships could have on important and congruent areas of marine mammals and fish habitat is needed to ensure the Corridors Initiative is an effective tool for marine transportation governance.

The focus of the study will be on the Kitikmeot region of Nunavut considering the region has experienced a relatively rapid increase in shipping activity since 2005 (Dawson, Johnston, & Stewart, 2014; PEW Charitable Trusts, 2016; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014) and because it is home to the Northwest Passage – an infamous trade route connecting the Pacific and Atlantic oceans. Behavioural disturbance in marine mammals and fish caused by vessel noise is assessed and reveals areas most likely to be impacted by increased shipping activity in the Kitikmeot region. Decision-makers can use this information to suggest alternative locations or regulatory measures for the Corridors to reduce the potential impact of shipping on marine mammals and fish. For instance, the Canadian Coast Guard could reroute Corridors that have a high degree of congruence with areas important to marine mammals and fish in the Kitikmeot region, or could implement mitigation measures to reduce the impacts ship traffic could have on these species, such as reducing vessel speeds.

1.2 Objectives

The primary objectives of this research are to: 1. Spatially identify important areas for marine mammals and fish in the Kitikmeot region of Nunavut using both existing and published Traditional Knowledge and western science; 2. Identify the shipping season length and vessel types transiting the Kitikmeot region based on historic Northern Canada Vessel Traffic Service Zone (NORDREG) ship tracks from 1990-2015, and average vessel broadband source levels (i.e. vessel noise) based on other studies, and; 3. Geospatially identify and evaluate areas of potential disturbance for marine mammals and fish related to vessel noise from different ship types transiting the Corridors within the study region. Three interrelated research questions are addressed:

1. Where are the known important habitat and use areas for marine mammals and fish within the Kitikmeot region and when (i.e. time of year) are these areas considered important?
2. Which vessel types transited through the Kitikmeot region from 1990-2015, when did they transit, and what are the average vessel broadband source levels for each vessel types?
3. Is vessel noise likely to cause behavioural disturbance in marine mammals and fish when transiting the Corridors, during what time of year, and which vessel types will cause greater or lesser behavioural disturbance?

1.3 Geographic Area of Interest

The geographic area of interest for this research is the Kitikmeot region of Nunavut, Canada with a focus on the marine environment (Figure 1). The Kitikmeot region is the most western area of Nunavut with a total land area of 443,277 km^2 (Statistics Canada, 2017). The region consists of the southern and eastern portion of Victoria Island, King William Island, the southern portion of Prince of Wales Island, and adjacent mainland (Explore Nunavut, 2006). The marine area consists of Coronation Gulf, Queen Maud Gulf, M'Clintock Channel, and the western part of the Gulf of Boothia (Kitikmeot Inuit Association, 2008). It also includes the southern route of the Northwest Passage and is home to numerous important marine wildlife areas. The Government of Canada has highlighted many water bodies within this region as important ecological areas, including Lambert Channel, which contains a recurrent polynya important for sea ducks and Arctic Char (Fisheries and Oceans Canada, 2011).

There are seven settlements within the Kitikmeot region including Ikaluktutiak (Cambridge Bay), Ursuqtuq (Gjoa Haven), Kugaaruk (Pelly Bay), Kugluktuk (Coppermine), Taloyoak (Spence Bay), Umingmaktok (Bay Chimo), and Kingaok (Bathurst Inlet) (Explore Nunavut, 2006; Inuit Circumpolar Council, 2008; Kitikmeot Inuit Association, 2008) The population of the Kitikmeot region is 6,543 and is predominantly Inuit (Statistics Canada, 2017). The Kitikmeot Inuit Association (KIA) is responsible for representing and benefiting the Kitikmeot Inuit by protecting and promoting social, cultural, political, environmental, and economic well-being (Kitikmeot Inuit Association, 2018).

The Kitikmeot region of Nunavut was chosen as a case study for this thesis research considering the time and financial challenges that exist in examining the full extent of the Corridors, which extend across the entire Canadian Arctic and include primary, secondary, and tertiary routes. Shipping has increased substantially within the Kitikmeot region over the past decade and growth in the southern route of the Northwest Passage is expected to continue due to sea ice reduction and demand related to tourism, trade, transport, and resource development (Dawson, et al., 2016; Howell, et al., 2013; Prowse, et al., 2009; Smith & Stephenson, 2013). In addition, shipping activity in this region has the potential to impact marine wildlife. This region is one of the most remote areas of shipping in the world thus enhancing the risk of any major incident such as groundings, hull strikes, engine failure, or others. In 2010, two groundings were recorded along with several minor fuel spills and other minor incidents (PEW Charitable Trusts, 2016). However, should a major incident occur, such as a major fuel spill or a ship sinking, the consequences would be significant considering limited search and rescue, salvage, and other infrastructure in the remote region (PEW Charitable Trusts, 2016). Because of these concerns and others, local communities in the Kitikmeot region have highlighted that addressing shipping concerns is a top research and policy priority (Stewart, Dawson, & Johnston, 2015). The Kitikmeot region includes the southern route of the Northwest Passage and is home to numerous important marine wildlife areas.

1.4 Outline of Thesis

This thesis is article based and organized by chapters – the first being this Introduction chapter. The second chapter titled Study Context gives an overview of information and studies related to the thesis topic, including an overview of shipping trends in the Canadian Arctic, known environmental impacts of shipping, current shipping regulations and management, and important areas for marine wildlife in the Canadian Arctic. The third chapter is a research article titled "Assessing the disturbance potential of marine mammals and fish from vessel noise in the Kitikmeot region of Nunavut, Canada". The focused of this article is on assessing the disturbance potential of marine mammals and fish from vessel noise in the Kitikmeot region of Nunavut and provides the basis for the development of a peer-reviewed journal article. The fourth and final chapter is a concluding section that outlines key findings and contributions of the thesis, study limitations, and future research needs. Because of the structure of the thesis (article-based) there is some necessary repetition among some chapters to ensure the thesis article can both standalone and also be part of the larger thesis document. However, repetition has been kept to a minimum.

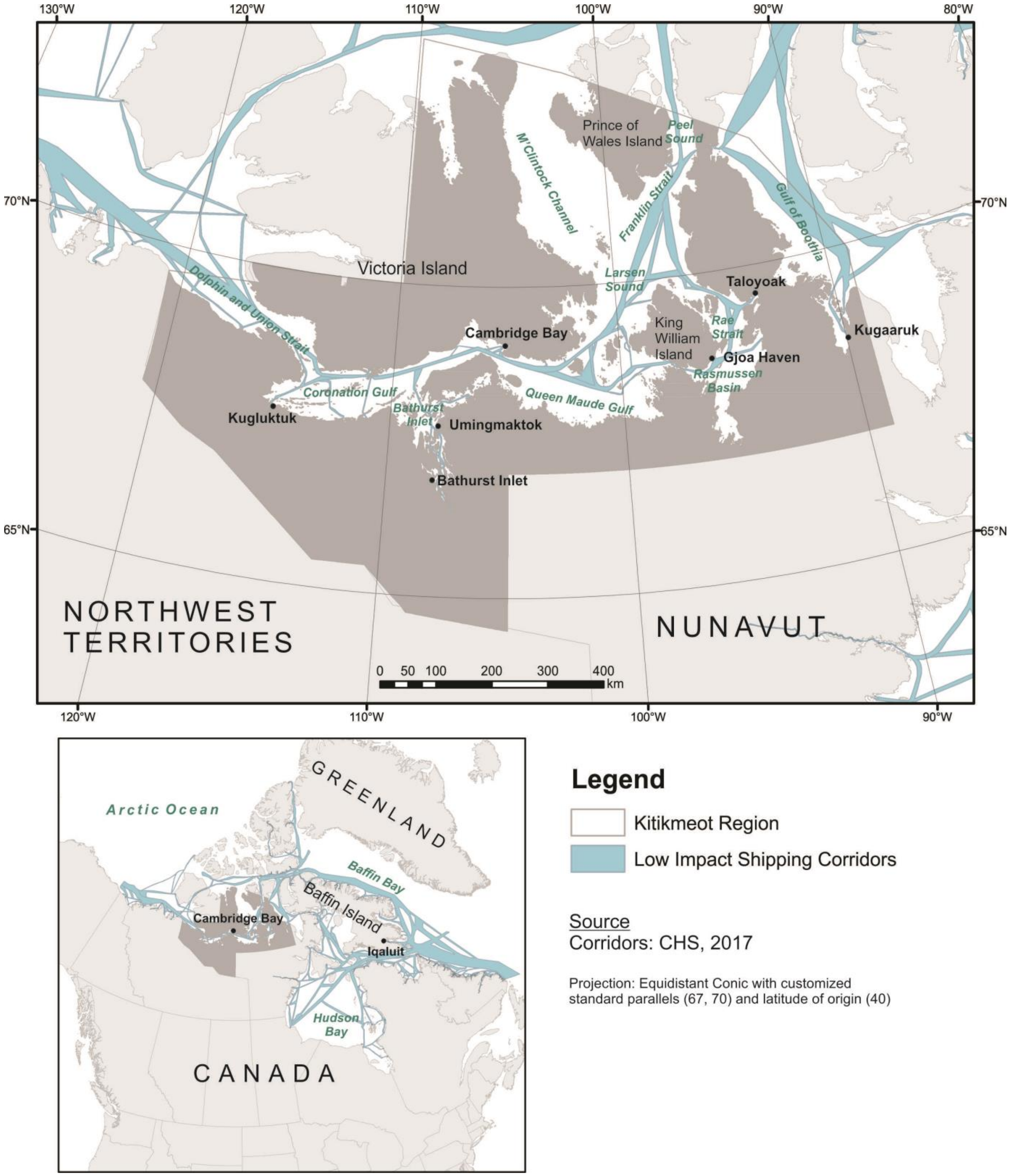

Figure 1. Kitikmeot region of Nunavut, Canada and the Low Impact Shipping Corridors. (Canadian Hydrographic Service, 2017)

Chapter 2: Study Context

This chapter provides a general overview of the existing literature on: 1) shipping trends in the Canadian Arctic, including related changes in sea ice and specific vessel types that can be found in the region; 2) potential environmental impacts of increased shipping, including noise pollution, icebreaking operations, ship strikes, accidental and regular discharges, light disturbance, and invasive species; 3) current Arctic shipping regulations and governance, including the Low Impact Shipping Corridors framework, the Arctic Marine Shipping Assessment (AMSA), and other international and national agreements related to shipping, and; 4) an outline of important areas for wildlife in the Canadian Arctic that were identified from both Traditional Knowledge Systems and Western Scientific Knowledge Systems.

2.1 Arctic Shipping Trends in a Changing Marine Environment

Arctic sea ice extent and thickness is declining throughout all months of the year (Comiso, 2012; Laxon, et al., 2013; Pistone, Eisenman, & Ramanathan, 2014; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Stroeve, et al., 2012; Tivy, et al., 2011). In the Canadian Arctic, substantial sea ice declines have been recorded in the central Arctic and the Canadian Arctic Archipelago (Howell, et al., 2013; Tivy, et al., 2011). Sea ice cover is thinning, and younger ice types are becoming more dominant (Comiso, 2012; Maslanik, Stroeve, Fowler, & Emery, 2011; Meier, et al., 2014; Parkinson, 2014). The Intergovernmental Panel on Climate Change (IPCC) (2014) global climate models have projected year-round declines in Arctic sea ice extent throughout the 21st century. Other global climate models have projected an ice-free Arctic as early as 2030 (Wang & Overland, 2012).

Declining sea ice is facilitating an increase in Arctic marine access for shipping activities (Arctic Council, 2009; Dawson, et al., 2016; Dawson, Copland, Mussells, & Carter, 2017; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Smith & Stephenson, 2013; Stephenson, Smith, & Agnew, 2011). Additionally, the shipping season is lengthening by an average of 5 days per decade into the shoulder months of June and November over the period of 1990 – 2015 (Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Stroeve, et al., 2012), which is attributed to an increase in mean annual melt season by 11 days per decade and a delay in mean freeze onset during the fall by 8 days per decade (Dawson, et al., 2016; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). The lengthening of the shipping season, and related increases in shipping activity, is predominantly occurring within the Central Arctic, the Canadian Arctic Archipelago and the Northwest Passage (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018; Haas & Howell, 2015; Khon, Mokhov, Latif, Semenov, & Park, 2010; Melia, Haines, & Hawkins, 2016; Sou & Flato, 2009).

Over the period of 1990 – 2015, Pizzolato, Howell and Dawson, et al. (2016) observed the thinning of sea ice is statistically correlated with increases in vessel traffic in certain regions of the Canadian Arctic – although noted weak correlations. As sea ice continues to decline, more ships will be able to transit the Canadian Arctic, primarily through the Northwest Passage, which presents an alternative route connecting Asia and North America instead of routes transiting the Panama and Suez Canals (Dawson, et al., 2016; Khon, Mokhov, Latif, Semenov, & Park, 2010; Lasserre & Têtu, 2015; PEW Charitable Trusts, 2016; Stephenson, Smith, & Agnew, 2011). The Northwest Passage route is significantly shorter than the Panama Canal and Suez Canal routes, potentially reducing cost of transit and reducing transit distance by 3500 nautical miles from St. Johns to Yokohama, and by 1650 nautical miles from New York to Yokohama (Dawson, Copland and Johnston, et al. 2016, Khon, et al. 2010, Lasserre and Têtu 2015, Ministry of Foreign Affairs of the People's Republic of China 2018, Stephenson, Smith and Agnew 2011, Somanathan, Flynn and Szymanski 2009). In the Canadian Arctic, ship traffic has already increased by over 75% in the last decade (Dawson, Copland, Mussells, & Carter, 2017; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Pizzolato, Howell, Dawson, Laliberté, & Copland, 2016). Over the past 25 years, the total annual distance travelled by all vessel types has almost tripled in the Canadian Arctic from 364179 km in 1990 to 918266 km in 2015 (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). Dawson, Pizzolato, et al. (2018) examined ship traffic during four time periods (1990-2000, 2001-2005, 2006-2010, and 2011-2015) and found that with each time period, shipping trends increased (Figure 2). From 2011-2015, average kilometers travelled by vessels increased by 90% from the baseline period of 1990-2000 (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). These trends of increased shipping activity in the Canadian Arctic will likely continue as sea ice declines and the demand for shipping increases.

In the Canadian Arctic, there are several vessels types that currently operate in Canadian Arctic waters (Table 2). Remote communities rely heavily on the shipping industry to provide goods and services, as these communities are typically only accessible by sea or air (Arctic Council, 2009; Dawson, Pizzolato, Howell, Copland, & Johnston, 2018; Hodgson, Russel, & Megganety, 2013; Prowse, et al., 2009). Cargo ships are responsible for the resupply of goods and services to remote communities (Dawson, et al., 2016). Bulk carriers and tanker ships transport materials and raw goods to and from mining operations in the North (e.g. Baffinland Mary River Iron Ore Mine) (Dawson, et al., 2016; Hodgson, Russel, & Megganety, 2013). Commercial fishing vessels are expanding operations further north to southeast Baffin Island (Dawson, et al., 2016; Hodgson, Russel, & Megganety, 2013). Pleasure craft and passenger ships service the increasing demand for exploration tourism in the Canadian Arctic (Dawson, et al., 2016; Dawson, Johnston, & Stewart, 2014; Hodgson, Russel, & Megganety, 2013; Lasserre & Têtu, 2015; Pistone, Eisenman, & Ramanathan, 2014).

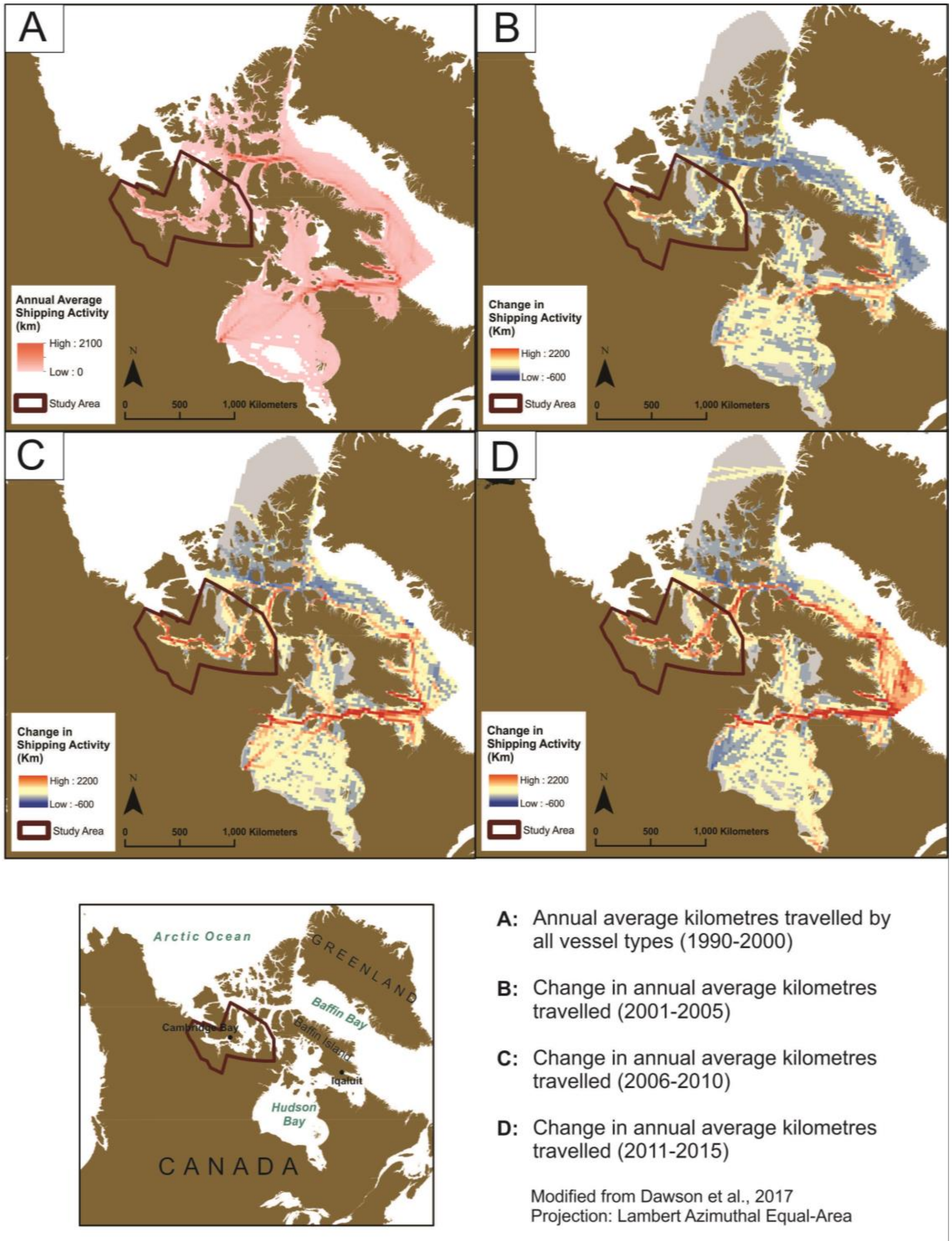

Figure 2. Annual average kilometres travelled by all vessel types (1990-2000), and change in annual average kilometers travelled from 2001-2005, 2006-2010, and 2011-2015 in Nunavut. Figure modified from Dawson, Copland, Mussells, et al. 2017.

Table 2. Description of vessel types found in the Canadian Arctic and their associated uses (compiled from NORDREG and Arctic Council (2009) categories, Tables 5.2 and 8.1). Source: Dawson, Copland and Johnston, et al. 2016

Classification	Description	Examples of Ship Types
Government Vessels and Icebreakers	• Designed to move and navigate in ice-covered waters • Must have a strengthened hull, an ice-clearing shape, and the power to push through ice	• Coastguard • Icebreakers (private, research, government) • Research vessels
Container Ships	• Cargo ships that carry their load in truck-size containers	• Cargo transport
General Cargo	• Carries various types and forms of cargo	• Community re-supply • Roll on/roll off cargo
Bulk Carriers	• Bulk carriage of ore (can carry either oil or loose or dry cargo, but not simultaneously)	• Timber • Oil, ore • Automobile carriers
Tanker Ships	• Bulk carriage of liquids or compressed gas	• Oil, natural gas, and chemical tankers
Passenger Ships	• Ships that carry passengers for remuneration	• Cruise ships • Ocean liners • Ferries
Pleasure Craft	• Recreational vessels that do not carry passengers for remuneration	• Motor yachts • Sail boats • Row boats
Tug / Barge	• Tug: Designed for towing or pushing, and general work duties • Barge: non-propelled vessel for carriage of bulk or mixed cargo	• Re-supply vessels • Bulk cargo transport
Fishing Vessels	• Fishing boats are used in commercial fishing activity • Generally small vessels, between 30 and 100 meters	• Small fishing boats • Trawlers • Whaling boats • Fish-processing boats
Oil and Gas Exploration Vessels	• Designed specifically for the exploration and extraction of natural gas and oil	• Seismic, oceanic, and hydrographic survey vessels • Oil drilling/storage vessels • Offshore re-supply • Portable oil platform vessels • Other oil and gas support vessels

Dawson, Pizzolato, et al. (2018) used NORDREG data from the CCG between 1990 and 2015 to analyze trends of different vessel types. They found significant differences in vessel type proportions of traffic based on kilometers traveled from 1990-2015 (Figure 3). In 1990, general cargo ships had the largest proportion of 28% of all vessel types, followed by government vessels and icebreakers (25%), bulk carriers

(20%), tanker ships (14%), fishing vessels (5%), and pleasure crafts (1%) (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). In 2015, the proportions of vessels changed to 21% general cargo ships, 18% government vessels and icebreakers, 15% tanker ships, 15% fishing vessels, and 8% pleasure crafts (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). During the baseline period of 1990-2000, vessel traffic was concentrated through Hudson Strait, towards the east coast of mainland Nunavut, and to the Port of Churchill (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). Traffic was also concentrated along eastern Baffin Island, through Lancaster Sound, and Queen Maud Gulf (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). In comparison to the baseline period, vessel traffic from 2011-2015 intensified through the southern route of the Northwest Passage, along eastern Baffin Island, and through Hudson Strait towards Baker Lake (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018). It is important to understand the historic temporal and spatial trends of shipping in the Canadian Arctic in order to manage these changes, as shipping activities can cause negative impacts to the environment.

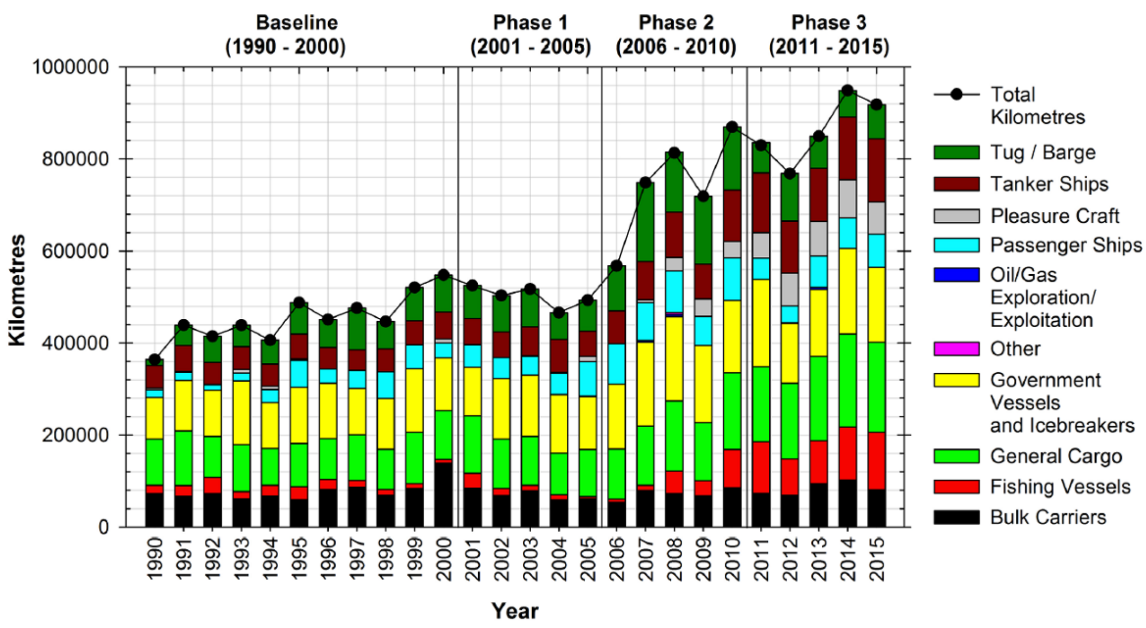

Figure 3. Total kilometers travelled annually by all vessel types in the Canadian Arctic. Source: Dawson, Pizzolato, et al. 2018.

2.2 Potential Environmental Impacts of Arctic Shipping

Shipping activity has the potential to negatively impact natural ecosystems in the Arctic and the important marine wildlife that reside in these ecosystems (Arctic Council, 2009; Dawson, et al., 2016; Hodgson, Russel, & Megganety, 2013; PEW Charitable Trusts, 2016). This section describes some of the known negative impacts shipping activity could have on the Arctic environment and marine wildlife, including noise pollution, icebreaking operation, ship strikes, accidental and regular discharge, light disturbance, and invasive species. The environmental impacts of Arctic shipping are extremely important to consider as shipping trends continue to increase in Arctic Canada.

2.2.1 Noise Pollution

Noise pollution from ships can adversely impact Arctic marine wildlife (Dawson, et al., 2016; Ghosh & Rubly, 2015; Hodgson, Russel, & Megganety, 2013; Hovelsrud, Poppel, van Oort, & Reist, 2011; Huntington, et al., 2015; Reeves, Rosa, George, Sheffield, & Moore, 2012). In the northern hemisphere, ambient ship noise is the dominant source of marine noise below 300 hertz (Arctic Council, 2009). Significant ambient ship noise can be problematic as many marine vertebrates rely on sounds for critical biological functions, such as communication, foraging, reproduction, navigation, and predator detection (Arctic Council, 2009; Ghosh & Rubly, 2015; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). For instance, toothed whales have biosonar capabilities used to feed and navigate; baleen whales use long-range communication systems for reproductive and social interactions; and pinnipeds use sounds for communication (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). The introduction of ship noise can alter animal behaviour, reduce communication ranges, and can lead to hearing loss (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). Noise can also cause habitat avoidance/abandonment, affect physiological functions, and can induce stress (Arctic Council, 2009; Ghosh & Rubly, 2015; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). Ship noise disturbances can be limited through changes in vessel design and construction, as outlined in the International Maritime Organization (IMO) guidelines for the reduction of underwater noise (International Maritime Organization, 2014) and the IMO's Polar Code (International Maritime Organization, 2016).

2.2.2 Icebreaking Operations

Icebreaking operations can cause disturbance to wildlife habitats through noise and open water channels created by ships (Arctic Council, 2009; Dawson, et al., 2016; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). For example, icebreakers can produce louder and more variable sounds in comparison to other ships, due to the backing up and ramming technique used to break ice, which can contribute to noise pollution discussed above (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; World Wildlife Fund, 2017). Additionally, year-round ice breaking can cause open water channels and reduce the amount of sea ice that is required by animals to move over ice (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). Open channels can confuse marine mammals and other species that typically reside in polynyas (Arctic Council, 2009). Polynyas are the only naturally occurring ice openings in the Arctic that are caused by persistent winds or ocean currents (Arctic Council, 2009; Meier, et al., 2014). Species may be trapped in the open water ship channels and far from the ice edge as the channel refreezes (Arctic Council, 2009). Furthermore, sea ice is very important for the livelihood of Arctic species, including polar bears, seals, and walruses (Hodgson, Russel, & Megganety, 2013). Continual icebreaking operations in the Arctic could reduce the already declining ice cover these species depend on (Hodgson, Russel, & Megganety, 2013).

2.2.3 Ship Strikes

Ship strikes are a major threat to marine mammals and can result in serious injury or death (AMAP, CAFF & SDWG, 2013; Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). Serious injuries may include massive trauma, hemorrhaging, broken bones, and wounds from propellers (Arctic Council, 2009; Huntington, et al., 2015). Mainly large whale species, small cetaceans, marine turtles, and sirenians (e.g. manatees) are impacted by ship strikes as these species can be found along the water surface (AMAP, CAFF & SDWG, 2013; Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Reeves, Rosa, George, Sheffield, & Moore, 2012). Ship strike occurrences with Arctic marine wildlife are fairly infrequent as ship traffic is relatively low compared to southern regions that do not experience year-round sea ice (Arctic Council, 2009). However, as ship traffic through the Arctic increases and overlaps with important areas for marine wildlife, the vulnerability of marine mammals to ship strikes will also increase (AMAP, CAFF & SDWG, 2013; Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). Modifying ship operations, speed restrictions, and identifying areas to be avoided in key areas of species aggregation can mitigate the number of ship strikes in the Arctic as shipping continues to increase (Arctic Council, 2009).

2.2.4 Accidental Discharges

A serious environmental threat of Arctic shipping is the accidental discharge of oil or toxic chemicals into the Arctic marine environment (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015; Reeves, Rosa, George, Sheffield, & Moore, 2012). For Arctic wildlife such as seabirds, polar bears, and seal pups, oil can reduce the insulating properties of feathers and fur making these species susceptible to hypothermia (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). Furthermore, oil spills are dangerous in areas of high aggregation of birds and mammals, such as leads and polynyas, and at certain times of the year, including during periods of breeding, nesting, bearing young, and molting

(Arctic Council, 2009; Huntington, et al., 2015). Birds are particularly vulnerable to oil spills, as they can transfer oil to nests by landing on oil slicks or can ingest oil while preening (Arctic Council, 2009).

Responding to oil spills in the Arctic is a major challenge due to variability in weather, light, hazards, and limited infrastructure (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013). In order to reduce the risk of accidental spills in the Arctic, preventative measures should be taken through enhanced construction standards and operating procedures (Arctic Council, 2009). For instance, further development of shipping regulations, offshore structures, and port facilities can reduce the risk of spills (Arctic Council, 2009; Dawson, et al., 2016; Huntington, et al., 2015).

2.2.5 Regular Discharges

Over time ships produce substances through normal operations that must be removed from the ship through discharge to the ocean, incineration, or transfer to port-based reception facilities (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). These regular discharges include oil, ballast water, bilge water, tank washings, oily sludge, sewage, garbage, and grey water (Arctic Council, 2009; Huntington, et al., 2015). The IMO regulates ship pollution and discharges into the marine environment through the *International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).* Under this regulation, oil can be released with bilge water at a maximum allowed concentration of 15 ppm after treatment, and with tank washings after treatment. Other substances like oily sludge, sewage, and garbage must be disposed of in reception facilities.

2.2.6 Light Disturbance

Bird species are at risk of collision with lighted structures as they are attracted to light (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015). Light attraction in the Arctic depends on the weather, season, and age of the bird but most light disturbance issues occur during fall migration (Arctic Council, 2009). Birds tend to be attracted to high intensity search lights used during the fall as navigational aids (Huntington, et al., 2015; Shwemmer, Mendel, Sonntag, Dierschke, & Gathe, 2011). Currently, light disturbance in the Arctic is not a large risk for bird species because most birds reside in the Arctic in summer months (Arctic Council, 2009). However, the risk of collision with lighted ships and structures increases during non-breeding and ice-free periods (Arctic Council, 2009).

2.2.7 Invasive Species

The introduction of invasive species through shipping activities has the potential to seriously impact Arctic ecosystems, economies, health, and the environment, such as the loss of native biological diversity (AMAP, CAFF & SDWG, 2013; Arctic Council, 2009; Dawson, et al., 2016; Fisheries and Oceans Canada, 2012; Ghosh & Rubly, 2015; Hodgson, Russel, & Megganety, 2013; Hovelsrud, Poppel, van Oort, & Reist, 2011; Huntington, et al., 2015; Johnston, Dawson, Stewart, & De Souza, 2013; Reeves, Rosa, George, Sheffield, & Moore, 2012). Invasive species are introduced to the marine environment through ballast water discharge, hull fouling, cargo operations, and casualties or shipwrecks (Arctic Council, 2009; Fisheries and Oceans Canada, 2012; Hodgson, Russel, & Megganety, 2013; Ruiz, Fofonoff, Steves, & Carlton, 2015). Trans-Arctic shipping between Northeast and west shipping routes could create a vector for invasive species to transfer to new areas where environmental conditions are similar to their native waters (Arctic Council, 2009; Fisheries and Oceans Canada, 2012; Ghosh & Rubly, 2015). Moreover, Goldsmit et al. (2018) projected that suitable habitat for invasive species will increase in the Canadian Arctic with future climate warming. The IMO has developed the *International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM)* in order to control invasive species, which calls for the treatment of ballast water before discharge. Other initiatives, such as the Arctic Invasive Alien

Species Strategy and Action Plan for the Arctic Council aims to raise awareness and inspire action on protecting the Arctic from invasive species, improve capacity for decision-making around invasive species, and undertaking programs for early detection and rapid response to invasive species in the Arctic (CAFF & PAME , 2017).

2.3 Arctic Shipping Regulations and Management

This section will discuss the significant international and national efforts made to improve shipping safety and reduce the risks associated with shipping activity in the Arctic. The Low Impact Shipping Corridors and the AMSA will be discussed followed by information on the international conventional and federal acts that form the basis of maritime governance.

2.3.1 Low Impact Shipping Corridors

The Low Impact Shipping Corridors (the Corridors) initiative provides an important foundation for maritime governance and ship traffic decision making in the Canadian Arctic. The Corridors were established collaboratively by the Canadian Coast Guard, the Canadian Hydrographic Service, and Transport Canada and are primarily based on historic shipping routes in the Canadian Arctic (Canadian Coast Guard, 2014). The goal of the Corridors is to increase ship safety by providing more predictable levels of service to mariners transiting through them (Canadian Coast Guard, 2014). For instance, response services and key navigational information, such as hydrography, icebreaking and navigation aids, are provided to ships transiting the Corridors (Canadian Coast Guard, 2014). The Corridors are a way for the Canadian Government to regulate shipping and prioritize and deploy services to minimize ship traffic risks.

The Corridors are defined based on the locations of vessels transiting the Canadian Arctic, which is determined from satellite AIS pings and Canadian Hydrographic Service paper and digital charts (Chenier, Abado, Sabourin, & Tardif, 2017). AIS pings broadcast the locations of AIS-equipped vessels with a tracking system to a database when transiting through Canadian waters, and contains information about the type of ship identified (Chenier, Abado, Sabourin, & Tardif, 2017). Based on 2012-2014 AIS Traffic pings, the Corridors are located where approximately 80% of vessels travel within the Canadian Arctic, and 90% of vessels travel within a 5 nautical mile radius of the Corridors (Chenier, Abado, Sabourin, & Tardif, 2017). Canadian Hydrographic Service charts contain important marine navigational information, such as anchorage areas, alignment lights, marine protected areas, water depths, and shoals, which assist in identifying safe routes through high-risk marine areas (Chenier, Abado, Sabourin, & Tardif, 2017). Canadian Hydrographic Service also used ice concentration from 1981-2010, General Bathymetric Charts of the Oceans when little or no bathymetric information was available and satellite imagery to optimize shipping routes (Chenier, Abado, Sabourin, & Tardif, 2017). Datasets from the North Warning System and Populated Places were used by the Canadian Hydrographic Service to determine areas for community resupply and places of refuge (Chenier, Abado, Sabourin, & Tardif, 2017).

There are limitations to the current Corridors, as they do not fully consider areas important to wildlife, areas of cultural significance, or areas of traditional marine use by Indigenous Peoples and northern residents. Currently, the Corridors only consider protected areas defined by Environment Canada, Parks Canada, and Fisheries and Oceans Canada (Chenier, Abado, Sabourin, & Tardif, 2017). This was identified as a significant gap in the AMSA Report (see Arctic Council, 2009). Studies have focused on identifying culturally significant marine areas across the Canadian Arctic and have further established recommendations for the corridors based on Indigenous Knowledge and local use of the marine environment (Carter, Dawson, Joyce, & Ogilvie, 2017a; Carter, Dawson, Joyce, & Ogilvie, 2017b; Carter, Dawson, Knopp, Joyce, & Ogilvie, 2018). Fisheries and Oceans Canada have also spent considerable time establishing Ecological and Biologically Significant Marine Areas (EBSASs) (Fisheries and Oceans Canada 2011, 2015, see also section 2.4.1). However, more research is needed to more fully understand the environmental and cultural implications of increased shipping in Artic Canada. There remains an urgent need to integrate important information into the current Corridors using both western science and Traditional Knowledge.

2.3.2 Arctic Marine Shipping Assessment

In 2004, the Arctic Council called for the Protection of the Arctic Marine Environment (PAME) working group to conduct a comprehensive assessment of Arctic shipping (Arctic Council, 2009). This decision followed the release of the Arctic Climate Impact Assessment (ACIA) and the Arctic Marine Strategic Plan (AMSP) in 2004 (Arctic Climate Impact Assessment, 2004; Arctic Council, 2009). The AMSA was released in 2009 with the purpose of enhancing marine safety and marine environmental protection (Arctic Council, 2009). The AMSA assesses shipping uses in the Arctic Ocean, the potential impacts of shipping on humans and the Arctic marine environment and shipping marine infrastructure requirements (Arctic Council, 2009). The AMSA focused on current and future Arctic shipping activities and developed recommendations based on key findings from the ACIA, which spanned all Arctic nations (Arctic Council, 2009). The recommendations were presented in three broad and inter-relating categories: enhancing Arctic marine safety, protecting Arctic people and the environment, and building Arctic marine infrastructure (Arctic Council, 2009). The Arctic Council (2015) reported the status on implementation of the AMSA 2009 recommendations and found that, despite efforts, several recommendations remain unfulfilled, including the recommendations to more fully understand the ecological risks related to Arctic shipping and to address the impacts on marine mammals from ship noise, disturbance, and strikes. In the *Fall 2014 Report of the Commissioner of the Environment and Sustainable Development*, the Office of the Auditor General of Canada (OAG) also identified a strong need for safe Arctic shipping (Office of the Auditor General of Canada, 2014). The OAG (2014) determined that the three federal departments responsible for supporting safe Arctic marine transportation – Transport Canada, Fisheries and Oceans Canada, and Environment and Climate Change Canada – had not yet coordinated departmental strategies or developed a long-term national vision for safe Arctic marine transportation.

2.3.3 International Governance and Management of Arctic Shipping

The IMO is an agency responsible for maintaining regulatory frameworks that govern the safety and security of international shipping and prevent marine pollution from ships. There are three key conventions that form the basis of international maritime governance, including 1) the *International Convention for the Safety of Life at Sea (SOLAS)*, 2) the *International Convention for the Prevention of Pollution from Ships*, and 3) the *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)*.

The IMO has also developed the International Code for Ships Operating in Polar Waters (Polar Code), which entered into force on January 1, 2017 (International Maritime Organization, 2016). The Polar Code aims to ensure safe shipping in Arctic and Antarctic waters by addressing design, construction, equipment, operational, training, search and rescue, and environmental protection matters associated with shipping in polar waters (International Maritime Organization, 2016). The IMO has also adopted Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life as a step towards the AMSA recommendation to address the impacts of shipping on marine mammals (International Maritime Organization, 2014). The aim of these guidelines is to present both technical and cost-effective measures to consider in ship design and operations to reduce the level of noise that is radiated from a ship (International Maritime Organization, 2014). For instance, these guidelines recommend performing regular cleaning of ship propellers and installing propellers designed to reduce cavitation, which is one cause of broadband noise underwater from ships (International Maritime Organization, 2014).

2.3.4 National Governance and Management of Arctic Shipping

There are numerous Federal Acts related to shipping in the Canadian Arctic (Table 3), including *the Oceans Act, the Arctic Waters Pollution Prevention Act, the Canada Shipping Act, the Marine Liability Act, the Navigable Protection Act, the Marine Transportation Security Act, and the Coasting Trade Act*. These Acts were adopted to govern all shipping activities in Canadian waters, including Arctic waters. Several federal departments are responsible for enforcing these Acts, namely Transport Canada and Fisheries and Oceans Canada. Other Federal Acts are in place to protect and conserve marine species habitat, including the *Fisheries Act*, which is enforced to protect and conserve marine and freshwater fish species habitat.

Table 3. Federal Acts regulating shipping in the Canadian Arctic. Table source: Dawson, Johnston, and Stewart 2014

Act	**Overview**
Oceans Act	Highlights the various zones of Canadian oceans, the Arctic included, as well as describing the Ocean Management Strategy within which power to create and regulate marine protected areas in Canadian oceans is given. The Act also outlines the regulations relating to Marine protected areas.
Arctic Waters Pollution Prevention Act	Provides measures to prevent pollution from ships, and in particular, the deposit of waste into Arctic waters. Includes regulations to deal with navigating including the need for ice navigators and a Zone/Date System (Z/DS) identifying safety zones and opening and closing dates for those zones for ships of different ice classes.
Canada Shipping Act	Represents Canada’s principal legislation for marine shipping and recreational boating in all Canadian waters including the Arctic.
Marine Liability Act	Requires that the owners and/or operators of vessels are responsible and liable for their vessels and the consequences of their operation.
Marine Transportation Security Act	Provides for the security of marine transportation and applies to marine facilities in Canada and Canadian ships outside of Canada.

Act	Overview
Navigable Protection Act	Protects the public right to navigate and ensure a balance between public right and need to build works, which may obstruct navigation.
Coasting Trade Act	Supports domestic marine interests by reserving the coasting trade of Canada to Canadian register vessels. The legislation provides a process to temporarily import a foreign vessel under a coasting trade license when a suitable Canadian registered vessel is not available or in the case of transportation of passengers. In this case duty taxes under Customs Tariff and Excise Tax Act apply.

Also at the national level, the Canadian Coast Guard releases an annual notice to mariners that advises mariners on important matters that may affect navigational safety within Canadian waters. Information in the annual notices includes aids to navigation and marine safety, pilotage services in Canadian waters, marine communications and traffic services, search and rescue, marine occurrences and pollution, national defense notices, and other general information (Fisheries and Oceans Canada, 2018a). Included in the aids to navigation and mariners' safety section of the notice is information on the location of critical habitat for endangered or at-risk species, such as the Southern Resident Killer Whale (Fisheries and Oceans Canada, 2018a). The annual notice also includes general requirements when in the vicinity of marine mammals, including minimum distance requirements for vessels from endangered marine mammals (Figure 4).

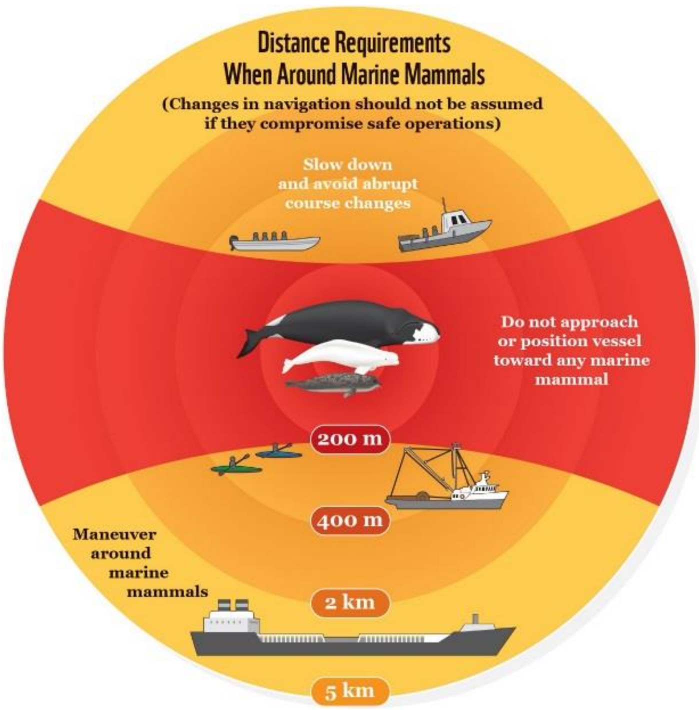

Figure 4. Distance requirements when around marine mammals. Source: Fisheries and Oceans Canada 2017

At a territorial level, few shipping regulations exist. However, territorial governments and Indigenous Peoples have developed management plans that include recommendations involving shipping in the Arctic. For example, the 2016 Draft Nunavut Land Use Plan (NLUP) was developed by the Nunavut Planning Commission to guide short- and long-term development in the Nunavut Settlement Area (Nunavut Planning Commission, 2016). It includes social, cultural, economic, and environmental factors to consider when developing land use plans and identifies land use designations that are dependent on the species importance and location (Nunavut Planning Commission, 2016).

The NLUP also identifies seasonal restrictions for shipping activities in some Protected Areas and Special Management Areas that are seasonal in nature (Nunavut Planning Commission, 2016). These seasonal restrictions are based on six Inuit seasonal cycles and systems in Nunavut, with varying start and end dates depending on the region (Nunavut Planning Commission, 2016). Minor variances of up to two weeks should be considered, and variations between years should be taken into account (Nunavut Planning Commission, 2016). Table 4 displays the six seasons and corresponding dates for the Kitikmeot region.

Table 4. Seasonal Dates in Kitikmeot, Nunavut. Source: Nunavut Planning Commission 2016

Region	Ukiuq **Sea Ice; Sun Returning; Very Cold**	Upingaksaaq **Sea Ice; Land Snow; Long Daylight**	Upingaaq **Sea Ice; Snow Free Land; Very Long Days**	Aujaq **Open Water**	Ukiaksaaq **Lake Ice; Snow on Land; Open Water**	Ukiaq **Sea Ice; Dark Days**
Aqunniq (East Kitikmeot & Melville Peninsula) & West Kitikmeot	February 16 – March 31	April 1 – May 31	June 1 – August 14	August 15 – September 14	September 15 – October 14	October 15 – February 15

2.4 Important Wildlife Areas in the Canadian Arctic

The Canadian Arctic is home to many important wildlife species, including marine mammals and fish. This section discusses important marine wildlife areas identified through western science and traditional knowledge systems, how these important areas are documented, and how they can be managed and protected in Canada.

2.4.1 Ecologically and Biologically Significant Areas (EBSAs)

Fisheries and Oceans Canada has made significant efforts in the management of sustainable development in the Canadian Arctic. Canada's *Ocean's Act* authorizes Fisheries and Oceans Canada to provide enhanced management of marine areas that are ecologically and biologically significant (Fisheries and Oceans Canada , 2004). Fisheries and Oceans Canada's Science sector has provided advice and support towards the Health of the Oceans Initiative in the identification and prioritization of Ecologically and Biologically Significant Areas (EBSAs) within the Canadian Arctic (Fisheries and Oceans Canada, 2009). Identifying EBSAs will provide support for ecosystem-based management of the marine environment; the development of Marine Protected Areas (MPAs) called for under the *Ocean's Act* and are publicly available for use in Canada (Fisheries and Oceans Canada, 2011).

In total, 61 EBSAs have been identified based on the guidance provided in the Fisheries and Oceans Canada EBSA criteria (Fisheries and Oceans Canada , 2004) within 5 of Canada's Arctic marine biogeographic units: Hudson Bay Complex, Eastern Arctic, Western Arctic, Arctic Basin and Arctic Archipelago (Fisheries and Oceans Canada, 2011). Fisheries and Oceans Canada provided a confidence level for each EBSA based on: 1) the information used to support the area as an EBSA, and 2) whether there was enough recent information to support the area as an EBSA (Fisheries and Oceans Canada, 2011). The Kitikmeot region is included in the Western Arctic biogeographic unit and has a total of 9 identified EBSAs (Figure 5).

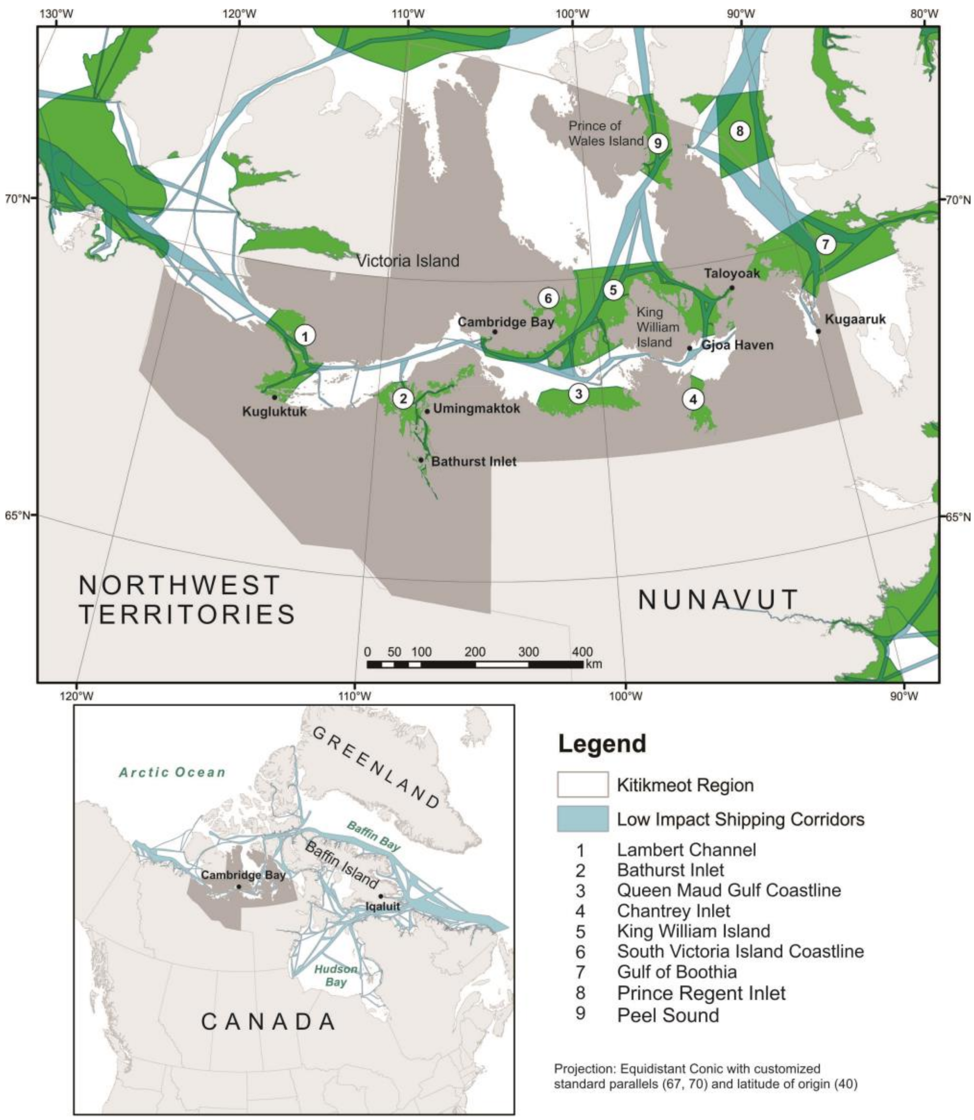

Figure 5. Ecologically and Biologically Significant Areas (EBSAs in the Kitikmeot region, Nunavut. Source: Fisheries and Oceans 2004, 2011.

2.4.2 Traditional Knowledge on Important Wildlife Areas

Traditional Knowledge is knowledge and insights gained by both Indigenous and non-Indigenous Peoples through extensive observation of an area or a species (Huntington, 2000). Traditional Knowledge is extremely valuable as it can improve scientific research and management when captured, especially in remote regions where little data exists (Huntington, 2000). Traditional Knowledge is typically passed down from generation to generation orally and is thus subject to extinction due to the rapidly changing natural and social environments (Huntington, 2000; Tripathi & Bhattarya, 2004). This information can be integrated into scientific research and management through participatory or community-based mapping, which is intended to preserve Indigenous and Traditional Knowledge passed on from generations of Peoples who have inhabited a region (Tripathi & Bhattarya, 2004). Participatory mapping can be performed using paper maps, Geographic Information Systems (GIS), or a combination of the two. GIS is a useful tool, as digitized Traditional Knowledge can be analyzed, and different scenarios can be tested, for example, in resource management (Tripathi & Bhattarya, 2004).

In the Canadian Arctic, a number of studies have used participatory mapping to capture and preserve Traditional Knowledge on important areas for wildlife (Carter, Dawson and Joyce, et al. 2017a, Carter, Dawson and Joyce, et al. 2017b, Carter, Dawson and Knopp, et al. 2018, Government of Nunavut 2010, Government of Nunavut 2011, Government of Nunavut 2012, Nunavut Planning Commission 2014a, Nunavut Planning Commission 2014b, Nunavut Planning Commission 2014c, Nunavut Planning Commission, 2014d). For instance, Carter, Dawson and Joyce, et al. (2017a, 2017b) and Carter, Dawson and Knopp, et al. (2018) used participatory mapping workshops in northern communities in Nunavut (Gjoa Haven, Arviat and Cambridge Bay, respectively) to gain further understanding around Inuit and northerners’ perspectives on the potential impacts of shipping activity on local use areas and community members. They documented temporal and spatial Traditional Knowledge on animals, community members' activities, marine features, and recommendations for the Corridors in these workshops using paper maps and then using GIS to digitize and analyze the data (Carter, Dawson, Joyce, & Ogilvie, 2017a; Carter, Dawson, Joyce, & Ogilvie, 2017b; Carter, Dawson, Knopp, Joyce, & Ogilvie, 2018). Figure 6 shows an example of the digitized Traditional Knowledge on locations of wildlife during the open water season from the Gjoa Haven participatory mapping workshop. Additionally, the Nunavut Coastal Resource Inventory (NCRI) used participatory mapping, interviews, research and reports to collect information on coastal resources and activities for Qikiqtarjuaq, Sanikiluaq, and Grise Fiord (See Government of Nunavut 2010, 2011, 2012, respectively). The purpose of the NRCI is to inform economic development opportunities, coastal management, and conservation, and to preserve traditional knowledge, and anticipate environmental changes (Government of Nunavut, 2010; Government of Nunavut, 2011; Government of Nunavut, 2012). Similarly, the NPC documented Traditional Knowledge from communities in Nunavut on important wildlife areas and cultural areas of importance using participatory mapping when developing the NLUP (see Nunavut Planning Commission 2014a, 2014b, 2014c, and 2014d). Once Traditional Knowledge is documented, it can be integrated into land use plans, resource management plans, wildlife management plans, etc. The information and recommendations from the Nunavut Planning Commission community workshops were integrated into the NLUP (Nunavut Planning Commission, 2016). The following section describes additional ways in which important wildlife areas are managed and protected in Canada.

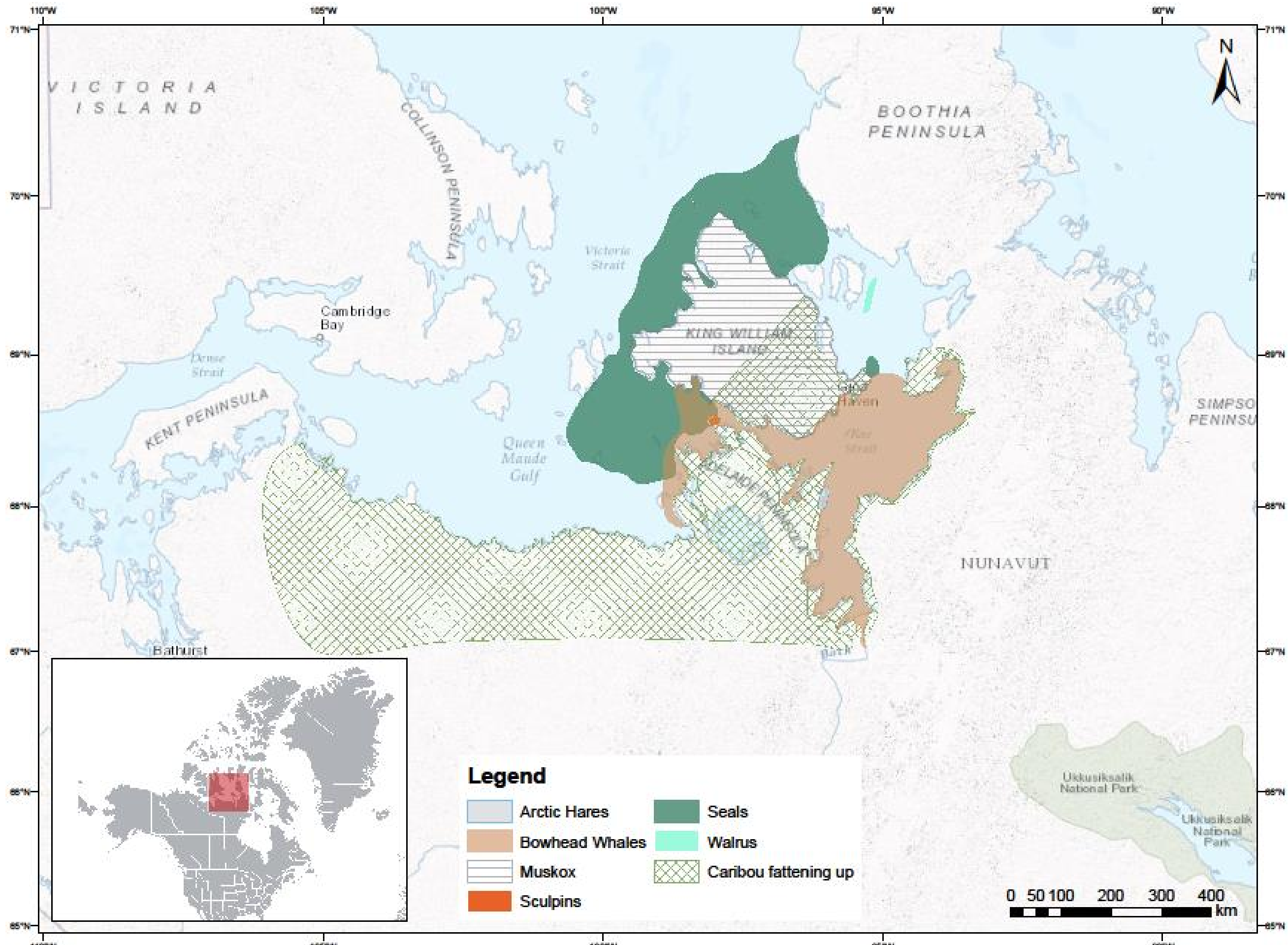

Figure 6. Location and behavioural activities of wildlife during the open water season in Gjoa Haven, Nunavut. Source: Carter, Dawson and Joyce, et al. 2017a

2.4.3 Managing and Protecting Important Wildlife Areas

Wildlife management plans have been developed in Canada to protect and preserve wildlife, the environment, and biological productivity. For instance, the Beaufort Sea Beluga Management Plan was developed to protect beluga whales in the Beaufort Sea from industrial development and resource extraction activities (Fisheries Joint Management Committee , 2013). The Plan identifies beluga whale management zones, protected areas, and regulations with the goal of preserving beluga whales so that Inuvialuit can hunt in perpetuity (Fisheries Joint Management Committee , 2013). Additionally, Fisheries and Oceans Canada (2013) proposed a management plan for the Bering-Chukchi-Beaufort Bowhead Whale population, which is listed as a species of Special Concern under the *Species at Risk Act*. This population of Bowhead Whale was depleted in the 19th and 20th century by intensive commercial whaling (Fisheries and Oceans Canada, 2013). Therefore, this Plan was developed to protect the remaining population and their habitat, and to provide guidelines on the evaluation of development proposals which may affect bowhead whales in the eastern Beaufort Sea (Fisheries and Oceans Canada, 2013). In the Kitikmeot region, there are no management plans specific to marine mammals or fish, however management plans that do exist tend to focus on caribou. For example, Environment and Climate Change Canada (2017) has developed a management plan for the Barren-ground Caribou, which is a species of special concern under the *Species at Risk Act*.

In addition to management plans, there are also MPAs in Canada, which are legally protected areas of the ocean designated by Fisheries and Oceans Canada to protect important fish and marine mammal habitats and endangered marine species (Fisheries and Oceans Canada, 2018b). In the Canadian Arctic, there are 2 MPAs, including Anguniaqvia niqiqyuam located within the Amundsen Gulf, and Tarium Niryutait located within the Beaufort Sea (Fisheries and Oceans Canada, 2018b). Also, in August 2017, the Federal Government of Canada, the Government of Nunavut, and the Qikiqtani Inuit Association agreed on a boundary for Canada's largest National Marine Conservation Area to be protected in Tallurutip Imanga (formerly known as Lancaster Sound) (Government of Nunavut, 2017). The agreement also launched an Inuit Impact Benefit Agreement for Inuit in the region and confirmed a moratorium on future offshore oil and gas exploration and development (Government of Nunavut, 2017). The development of management plans and protected areas for marine mammals and fish in the Canadian Arctic is important for the preservation of these species as shipping activities increase.

Chapter 3: Assessing the disturbance potential of marine mammals and fish from vessel noise in the Kitikmeot region of Nunavut, Canada

Abstract

Climate change and the subsequent decline in sea ice is resulting in an extension of the open water season and an increase in ship traffic in the Canadian Arctic. This increase in shipping has the potential to impact marine mammals and fish through noise disturbance, as these species rely on sound for their survival. The objective of this study was to assess the disturbance potential of marine mammals and fish based on vessel noise from ships transiting through shipping corridors in the Kitikmeot region of Nunavut – an extremely remote region of the Canadian Arctic. The Kitikmeot region has experienced an increase in ship traffic and a change in the variety of ship types present over the last two decades (i.e. from primarily tugs/barges and government vessels and icebreakers in 1990 – 2000 to an increase in passenger ships, pleasure crafts, general cargo ships, and tanker ships in 2011 – 2015). The results of this study indicate that ships transiting the currently designated shipping corridors, especially through the Gulf of Boothia, Bathurst Inlet, and waterways surrounding King William Island, have the potential to impact marine mammals and fish during the Nunavut seasons of Upingaaq (June 1 – August 14), Aujaq (August 15 – September 14), Ukiaqsaaq (September 15 – October 14), and Ukiaq (October 15 – February 15), and that louder vessel types (i.e. tanker ships) will have a greater impact than quieter vessel types (i.e. pleasure crafts).

Key words: *Canadian Arctic; underwater noise; ship traffic; marine mammal; fish*

3.1 Introduction

Declining sea ice, primarily attributed to climate change, is increasing the accessibility and navigability of Canadian Arctic waters. Due to these changes, Pizzolato, Howell and Derksen, et al. (2014) identified an increase in shipping and a lengthening of the shipping season in the Canadian Arctic into the shoulder months of early June and into November. The Kitikmeot region of Nunavut is an extremely remote area of the Canadian Arctic and is a region that has experienced some of the greatest increases in shipping activity over the last two decades (Dawson, Copland, Mussells, & Carter, 2017). Increased shipping has the potential to negatively impact the environment through, for example, accidental and regular discharges, invasive species introduction, and could also have negative implications for marine wildlife (Arctic Council, 2009; Dawson, Copland, Mussells, & Carter, 2017; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015; Reeves, Rosa, George, Sheffield, & Moore, 2012). Currently, there is limited understanding of the potential environmental impacts of shipping in the remote regions of the Canadian Arctic – and in particular there has been little research attention paid to the potential increased impacts related to noise caused by Arctic ships.

The impacts of noise pollution from shipping is becoming increasingly important, especially for wildlife that rely on sound for communication, mating, navigation, foraging, and predator/prey detection, namely marine mammals and fish species (Ghosh & Rubly, 2015; Halliday, Insley, Hilliard, de Jong, & Pine, 2017; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015; Tyack, 2008; World Wildlife Fund, 2017). Vessel noise can mask acoustic signals, and cause behavioural disturbance, temporary or permanent hearing loss, and physiological stress for marine mammals and fish (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015; World Wildlife Fund, 2017). The National Oceanic and Atmospheric Administration developed a technical guidance document on the underwater acoustic thresholds of all marine mammals (National Marine Fisheries Service, 2016). This guidance indicates that all marine mammals will exhibit behavioural disturbance for continuous noise (e.g. vibratory pile driving, drilling) at a hearing threshold of 120 dB re 1 μPa (National Marine Fisheries Service, 2016). Hastings (2002) identified that fish species will experience behavioural disturbance at a hearing threshold of 150 dB re 1 μPa. Ambient vessel noise is the dominant source of marine noise below 300 hertz in most regions of the northern hemisphere (Arctic Council, 2009). Currently, we do not have a good understanding of the acoustic impacts increased ship traffic could have on marine mammals and fish residing in the Canadian Arctic, and there are no management plans that fully consider the acoustic impacts vessels could have on these species. This study focuses on the potential for vessel noise to disturb marine mammals and fish.

Canadian policymakers are attempting to manage the impact of increased ship traffic in Arctic Canada by proposing shipping corridors that were developed based on historic vessel routes. This initiative, termed the Low Impact Shipping Corridors (the Corridors) is co-led by the Canadian Coast Guard, the Canadian Hydrographic Service and Transport Canada, and provides an important framework for ship traffic and decision making within the Canadian Arctic that can help to minimize traffic risks (Canadian Coast Guard, 2014). Canadian Hydrographic Service used AIS satellite pings from vessels transiting the Canadian Arctic and Canadian Hydrographic Service charts when identifying the locations of the Corridors (Chenier, Abado, Sabourin, & Tardif, 2017)The Corridors are currently located where approximately 80% of vessels travel based on AIS traffic pings from 2012-2014 (Chenier, Abado, Sabourin, & Tardif, 2017). The goal of the Corridors is to increase ship safety by providing predictable levels of service to mariners navigating through them (Canadian Coast Guard, 2014). However, these Corridors do not explicitly consider the potential for shipping to disturb marine mammal or fish species residing in the Canadian Arctic. This is an important issue as the Corridors have a high level of congruence with important wildlife areas and migratory routes used by fish and marine mammals, including beluga whales, bowhead whales and narwhal (PEW Charitable Trusts, 2016). This study responds directly to this need to better understand the impacts of increased shipping activity and aims to spatially evaluate the likelihood that existing marine mammals and fish will experience behavioural disturbance as a direct result of increased ship traffic and related noise levels that have occurred in the Kitikmeot region of the Canadian Arctic.

3.2 Shipping in the Kitikmeot

Shipping in the Canadian Arctic is increasing, which is directly linked to socio-economic factors including globalization, tourism trends, commodity prices, and natural resource extraction (Bensassi, Stroeve, Martinez-Zarzoso, & Barrett, 2016; Brigham, 2011; Dawson, Johnston, & Stewart, 2014; Dawson, Copland, Mussells, & Carter, 2017; Eguíluz, Fernández-Gracia, Irigoien, & Duarte, 2016; Pizzolato, Howell, Dawson, Laliberté, & Copland, 2016). These socio-economic factors along with substantial reductions in sea ice in the Canadian Arctic Archipelago (Howell, et al., 2013; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Tivy, et al., 2011), are drawing the attention of the global shipping industry towards the Canadian Arctic – in particular, the Northwest Passage – for an alternative shipping route to the Panama Canal (Dawson, Copland, Mussells, & Carter, 2017; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Pizzolato, Howell, Dawson, Laliberté, & Copland, 2016). The once predominantly thick perennial Arctic sea ice is shifting toward a younger, thinner, and seasonal ice regime (Comiso, 2012; Maslanik, Stroeve, Fowler, & Emery, 2011; Parkinson, 2014; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). This shift in sea ice regime is increasing the accessibility of the region and lengthening the shipping season (Dawson, Copland, Mussells, & Carter, 2017; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). For the period between 1990 and 2012, Pizzolato, Howell and Derksen, et al. (2014) identified a lengthening of the shipping season in the Canadian Arctic by 5 days per decade from June 25 to October 15 into the shoulder months of early June and November.

The Kitikmeot is the most western region of Nunavut and is also experiencing an increase in ship traffic. Dawson, Copland and Mussells, et al. (2017) looked at the distribution of vessel activity by kilometres travelled in the Kitikmeot region from 1990 – 2000 (baseline period), 2001 – 2005, 2006 – 2010, and 2011 – 2015 (Figure 7). Between 1990 and 2000, the Kitikmeot region was dominated by government vessels and icebreakers (46%) and tug and barge vessels (42%) likely supporting general cargo (Dawson, Copland, Mussells, & Carter, 2017). Over time, the distribution of government vessels and icebreakers and tug and barge vessels decreased to 27% and 16% respectively during 2011 – 2015, and the variety of other vessel types increased (Dawson, Copland, Mussells, & Carter, 2017). The number of kilometres travelled by these vessel types has actually increased over time, but the decrease in distribution is due to the increase in other vessel types now transiting the region (Dawson, Copland, Mussells, & Carter, 2017). During 2011 – 2015, we are now seeing general cargo vessels (11%), passenger ships (11%), pleasure crafts (25%), and tanker ships (10%) in addition to government vessels and icebreakers and tug/barge traffic (Dawson, Copland, Mussells, & Carter, 2017).

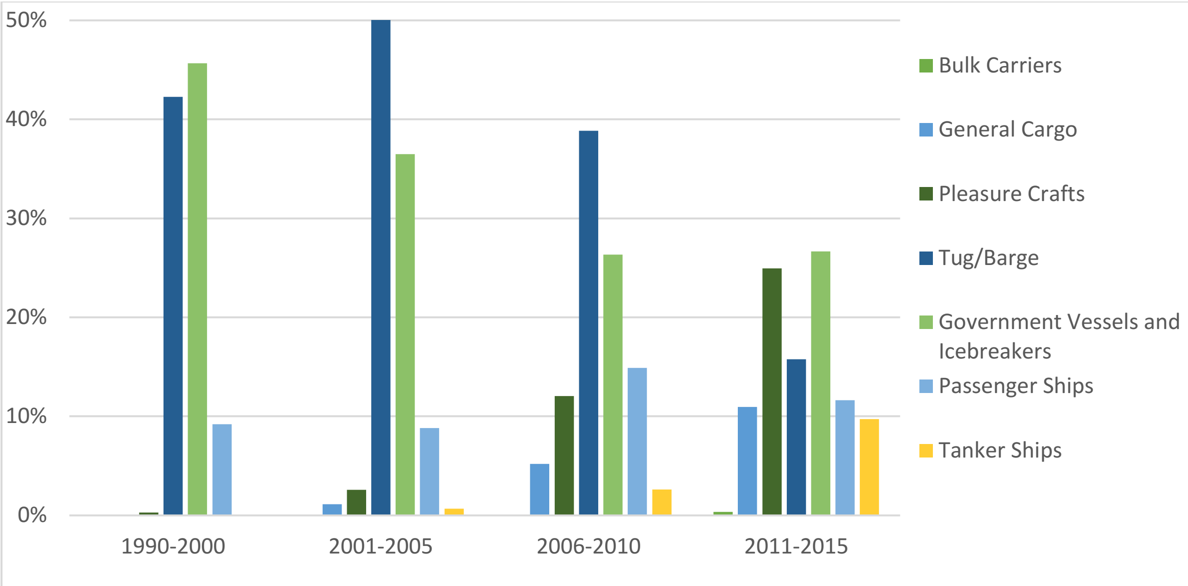

Figure 7. Relative proportions of ship traffic in the Kitikmeot region based on annual distance travelled, 1990-2015. Modified from Dawson, Copland, Mussells, & Carter, 2017.

Figure 8 displays the spatial distribution of kilometres travelled by all vessel types from 1990 – 2000 as a baseline period, and the change in activity from this baseline to three other time periods: 2001 – 2005, 2006 – 2010, and 2011 – 2015. From 1990 – 2000, vessel traffic was limited and concentrated in the southern route of the Northwest Passage through Coronation Gulf and Dolphin and Union Strait. Compared to the baseline period, from 2001 – 2005, vessel traffic increased in Coronation Gulf, Dolphin and Union Strait, and Queen Maude Gulf with clear routes to the communities of Cambridge Bay and Gjoa Haven, and through Franklin Strait to the Gulf of Boothia. These trends intensified from 2006 – 2010, with more vessel traffic extending around King William Island and through M'Clintock Channel. Relative to the baseline period, vessel traffic from 2011 – 2015 dramatically intensified within the Kitikmeot region, with a clear route along the Northwest Passage, and also through M'Clintock Channel, around King William Island, and through Franklin Strait with passage to the Gulf of Boothia.

Currently, no formal legislation for the Kitikmeot region of Nunavut effectively addresses the issue of vessel noise. The 2016 Draft NLUP identified concerns from communities, governments, and interest groups about the potential effects on wildlife from increased shipping; one concern being the effects of noise that can alter the behaviour and distribution of marine mammals (Nunavut Planning Commission, 2016). The NLUP provides recommendations for shipping, including the recognition of marine setback distances and seasonal restrictions for a number of important wildlife areas, development of a Notice to Mariners and/or Vessel Traffic Zones and/or MPAs as tools or regulations for certain ecological and cultural sites, and more specific shipping recommendations related to nautical charting, alternative shipping routes around islands and through straits (Nunavut Planning Commission, 2016).

The 2018 Notice to Mariners, developed by Fisheries and Oceans Canada (2018a), identifies marine mammal guidelines for shipping, including distance requirements for vessels when around marine mammals and slow zones, where vessels must reduce speed. The Notice also lists relevant legislation, including species listed under the *Species at Risk Act,* and the *Marine Mammals Regulations* under the *Fisheries Act*, which prohibits any form of disturbance to marine mammals, except when fishing for them (Fisheries and Oceans Canada, 2018a).

Additionally, other studies have focused on the development of management strategies specifically for the Corridors. Carter, Dawson and Joyce, et al. (2017a, 2017b) and Carter, Dawson and Knopp, et al. (2018) gathered community perspectives on the potential impacts of marine transportation on areas of local marine use and identified recommendations for the Corridors and for Arctic marine vessel management. Wang (2017) evaluated the current management arrangement for marine shipping activities in the Corridors and used Multiple Criteria Decision Analysis to identify the most appropriate management arrangement. This study uses spatial analysis to tie together Traditional Knowledge and western science into a decision-making tool and identifies recommendations for the mitigation of impacts on marine mammals and fish associated with vessel noise.

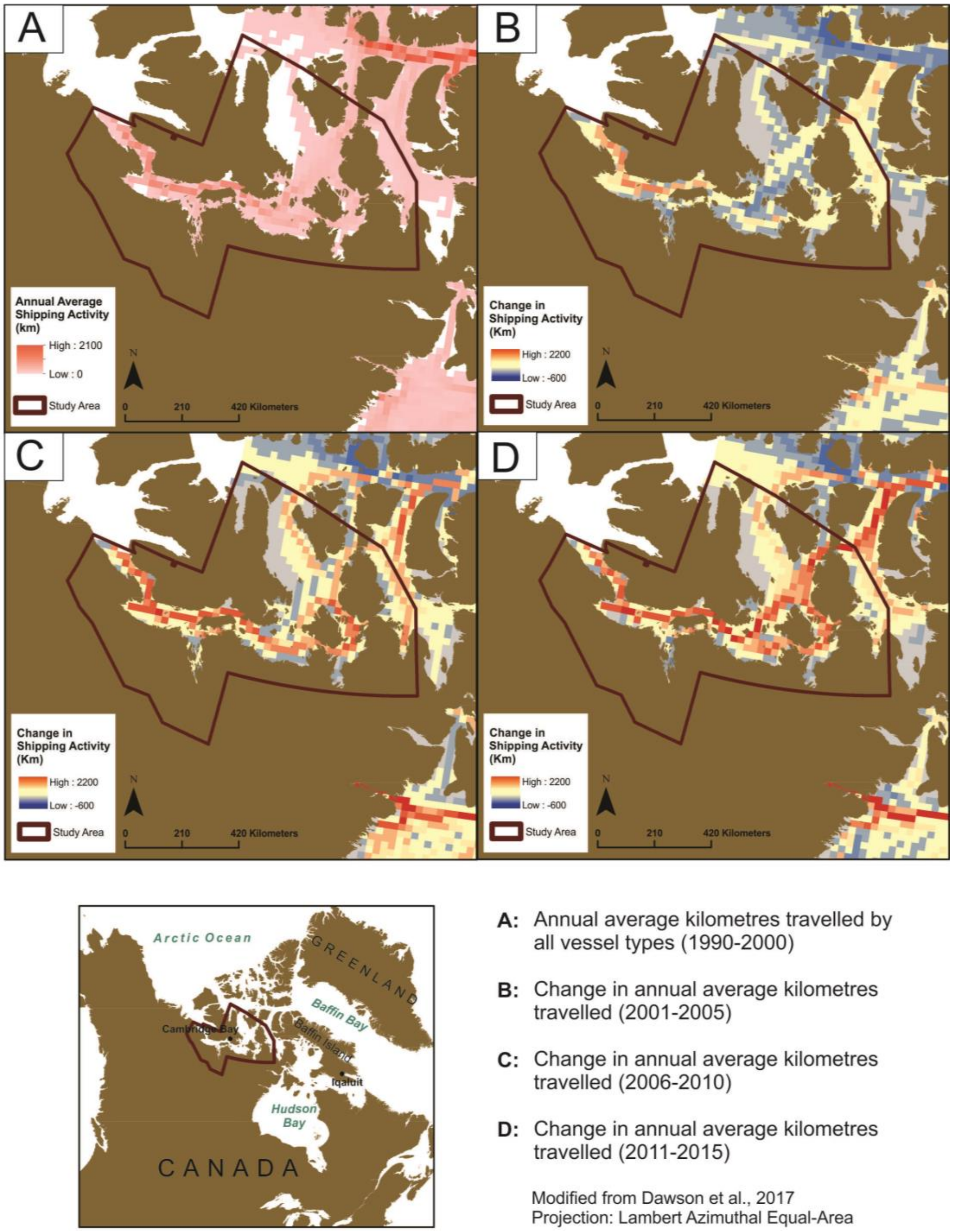

Figure 8. Annual average kilometres travelled by all vessel types (1990-2000), and change in annual average kilometers travelled from 2001-2005, 2006-2010, and 2011-2015 in the Kitikmeot region, Nunavut. Figure modified from Dawson, Copland, Mussells, et al. 2017.

3.3 Important Marine Mammal and Fish Areas in the Kitikmeot

The Kitikmeot region is home to a variety of marine mammals, including beluga whale, bowhead whale, narwhal, seal species, and a number of fish species, namely Arctic char. However, the exact spatial location of these species can be difficult to determine. This has been a major challenge in marine biology and other fields of research that examine the spatial location of Arctic marine wildlife, as this data can be extremely difficult and costly to gather in the remote regions of the Canadian Arctic. Despite this challenge, there is information that exists by way of western science and Traditional Knowledge on the general spatial locations of marine mammals and fish residing and migrating through regions of the Canadian Arctic. For example, Fisheries and Oceans Canada developed EBSAs, which are areas that have particularly high ecological or biological significance and are used as management tools in marine planning (Fisheries and Oceans Canada, 2015). There are 9 EBSAs identified in the Kitikmeot region; all of which are important areas for marine mammals and/or fish communities, with the exception of Lambert Channel, which is identified as an important area for seabirds (Table 5).

Table 5. Ecologically and Biologically Significant Areas (EBSAs) in the Kitikmeot region of Nunavut. Source: Fisheries and Oceans Canada 2011, 2015

EBSA	Description
King William Island	Tidal mixing zones, Ringed Seal and Polar Bear feeding, high benthic diversity
Southern Victoria Island Coastline	Estuaries, Arctic Char migration corridor
Lambert Channel	Polynya, estuary, seabird feeding and staging
Chantrey Inlet	Estuary, low salinity, Arctic Char migration corridor, Ringed Seal feeding
Bathurst Inlet	Strong currents, seabird feeding, marine fish communities, Ringed Seal, benthic epifaunal communities
Queen Maud Gulf Coastline	Several estuaries, Arctic Char migration corridor
Prince Regent Inlet	Narwhal rearing (July-mid-Nov), Bowhead whale feeding and rearing (July-mid-Nov)
Gulf of Boothia	Bowhead whale rearing and feeding (late June-mid-Nov); Narwhal rearing (July-Aug); Bowhead whale and narwhal seasonal refugia from Killer Whale
Peel Sound	Bowhead whale migration and nursery area; Polar Bear habitat

Identifying the seasonal presence of marine mammal and fish in the Kitikmeot is important as species reside in this region both year-round and seasonally (Figure 9). An example of seasonal residence are beluga and bowhead whales whereas seal species are typically in the region year-round. Seasonal species may only be present during certain times of the year. For example, narwhal and bowhead whales will migrate to Prince Regent Inlet to rear their young from July to mid-November (Table 5). Therefore, the seasonal abundance of species varies in the region. The NLUP identified 6 seasons in Nunavut, each which varies in dates based on the region. In the Kitikmeot region, the seasons are Ukiuq (February 16 – March 31), Upingaksaaq (April 1 – May 31), Upingaaq (June 1 – August 14), Aujaq (August 15 – September 14), Ukiaksaaq (September 15 – October 14), and Ukiaq (October 15 – February 15) (NPC, 2016). This study only considered the presence of marine mammals and fish in the Kitikmeot region during the shipping season and shoulder months, which include the seasons of Upingaaq, Aujaq, Ukiaksaaq, and the beginning of Ukiaq (Figure 9).

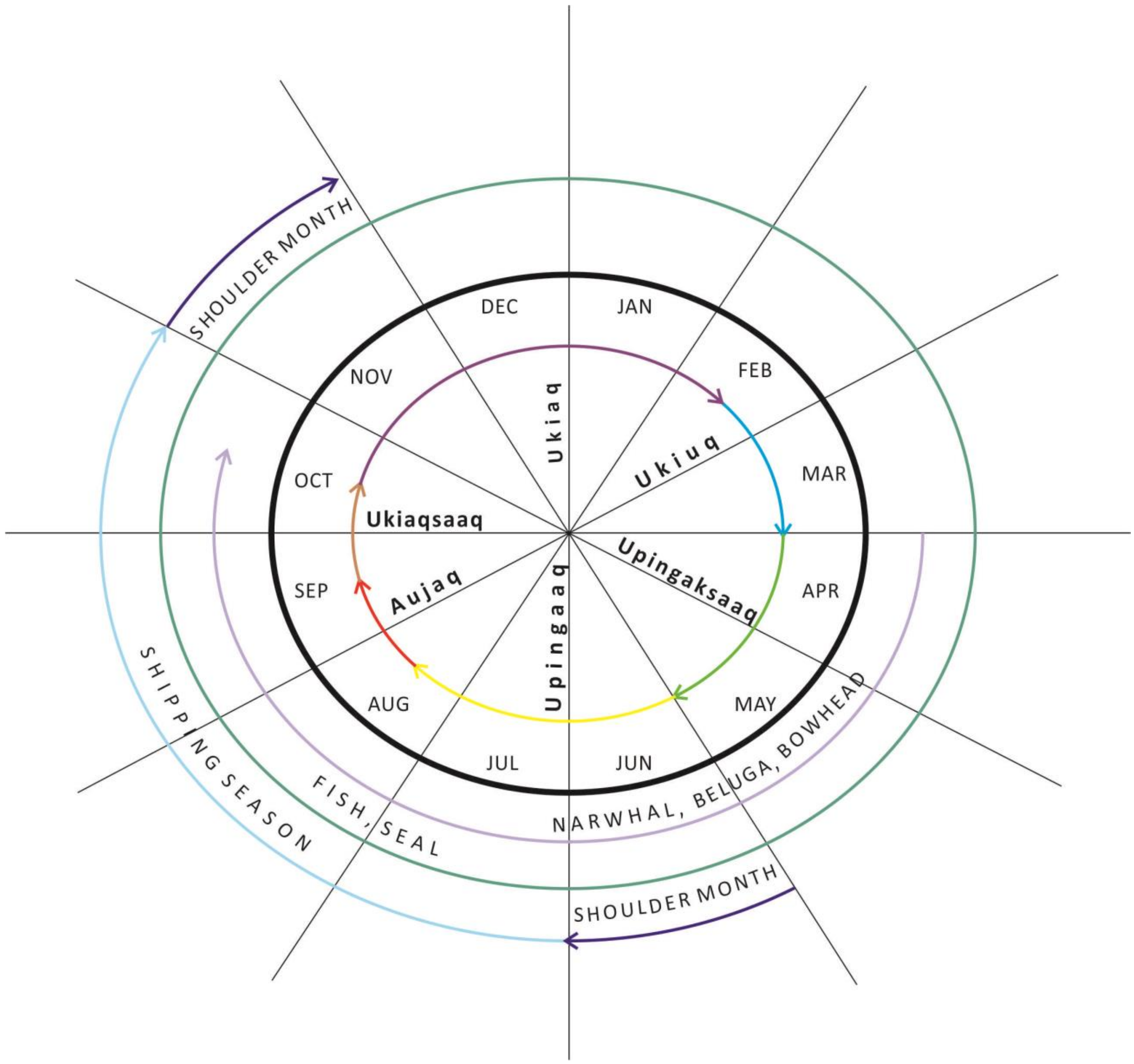

Figure 9. Seasonal cycle and corresponding months, seasonal presence of marine mammals and fish, and the shipping season and shoulder months in Kitikmeot, Nunavut.

3.4 Impacts of Vessel Noise on Marine Mammals and Fish

Increased shipping can negatively impact marine mammals and fish through noise pollution (Halliday, Insley, Hilliard, de Jong, & Pine, 2017; World Wildlife Fund, 2017). Individual vessels can have acoustic source levels close to 200 dB re 1 µPa at 1 m, which is high enough to cause behavioural disturbance in marine mammals and fish (see Table 11) (Erbe & Farmer, 2000; Halliday, Insley, Hilliard, de Jong, & Pine, 2017; Veirs, Veirs, & Wood, 2016). Vessel noise is generated through propeller cavitation and singing, and propulsion or other reciprocating machinery and occurs at low frequency (5 to 500 Hz) (Hildebrand, 2009; Wales & Heitmeyer, 2002; World Wildlife Fund, 2017). For comparison, the general hearing and vocalizing ranges of some marine mammals can be seen in Table 6. Vessel noise has the ability to propagate efficiently in marine environments because of sound fixing and ranging channels, which are naturally occurring layers in the water column where the speed of sound is at its minimum, and thus low-frequency sound waves can travel for over long ranges before dissipating (McKenna, Ross, Wiggins, & Hildebrand, 2012; National Research Council, 2003). For example, McKenna et al. (2012) determined that a container ship weighing 54.6 kGT with an initial broadband source level of 166 dB re 1 μPa^2 s would have a broadband source level of 148 dB re 1 μPa^2 s at a distance of 5 km. In the Arctic marine environment, sound fixing and ranging channels exist at shallower depths (approximately 100 – 300 m) than in temperate waters are and are within the swimming depths of marine mammals (World Wildlife Fund, 2017).

Table 6. General hearing and vocalizing ranges of marine mammals. Source: WWF 2017

Marine Mammal	Hearing Sensitivity (Hz)	Peak Frequency (Hz)
Mysticete (baleen whales)	20 to 20,000-30,000	10 to 2,000
Ondontocete (toothed whales)	~100 to 160,000	
• **Click (echolocation)**	5,000 to 150,000	
• **Whistle (communication)**	1,000 to 25,000	
Pinniped (seals)	1,000 to 20,000	<1,000 to 4,000

Exposure to vessel noise can cause behavioural reactions in marine mammals and fish. Marine mammals can experience increased stress hormones, decreased reproduction, and temporary and permanent hearing loss (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; World Wildlife Fund, 2017). Fish can experience behavioural disturbance, reduced reproduction, and internal injuries, including hearing loss, damage to auditory tissues and/or death (Ivanova, 2016; Picciulin, Sebastianutto, Codarin, Farina, & Ferrero, 2010; Slabbekoorn, et al., 2010). Ivanova (2016) found that Arctic Cod spent more time travelling greater distances at faster rates when vessels were present. Many marine mammals can hear icebreaking over large distance and can exhibit a flee response (Erbe & Farmer, 2000; World Wildlife Fund, 2017). For instance, beluga whales can hear icebreaking up to 78 km away and tend to avoid the area for 1-2 days (Erbe & Farmer, 2000; Hatch, et al., 2012; Southall, et al., 2007). Alternatively, marine mammals can also exhibit a freeze response in the presence of icebreakers, which can result in ship strikes (Au, et al., 2006; World Wildlife Fund, 2017). Vessel noise can overlap with and mask the hearing frequency of marine mammals used for communication and echolocation (World Wildlife Fund, 2017). Responses to vessel noise may differ for each marine mammal due to a number of factors, including species, age, gender, prior experience with noise, and behavioural state (World Wildlife Fund, 2017).

Only a few studies have focused efforts of examining the acoustic impacts of shipping on marine mammals and fish species in other regions of the Canadian Arctic, namely the Canadian Beaufort Sea. For instance, Halliday et al. (2017) modelled the acoustic propagation of vessels navigating the Corridors in the Beaufort Sea and associated impacts on marine mammals, Erbe and Farmer (2000) modelled the zones of impact for beluga whales from icebreakers in the Beaufort Sea, and Ellison et al. (2016) modelled the acoustic impacts of multiple industrial activities on bowhead whales in the Beaufort Sea; and Li, MacGillivray and Wladichuk (2011) modelled the acoustic impacts of Tugs and Barges on marine mammals and Arctic Char in Hudson Bay. In contrast, this study assesses disturbance potential of marine mammals and fish based on noise from shipping traffic in the extremely remote area of the Kitikmeot region, where little research of this nature has been conducted.

3.5 Methods

This research assessed the disturbance potential that different levels of vessel noise could have on marine mammals and fish while navigating through the Corridors in the Kitikmeot region of Nunavut. This region is an extremely remote area of the Canadian Arctic located in western Nunavut (Figure 10). It is also home to the southern portion of the Northwest Passage, which is becoming increasingly enticing for the global shipping industry as sea ice declines and opens an alternative shipping route to the Panama Canal. This study region was chosen because little research of this nature has been conducted in the Kitikmeot and as shipping trends continue to increase there is a need to better understand the impacts vessel noise could have on marine mammals and fish. This research was conducted through an iterative three-part approach (Figure 11). The three parts will be discussed in the following section.

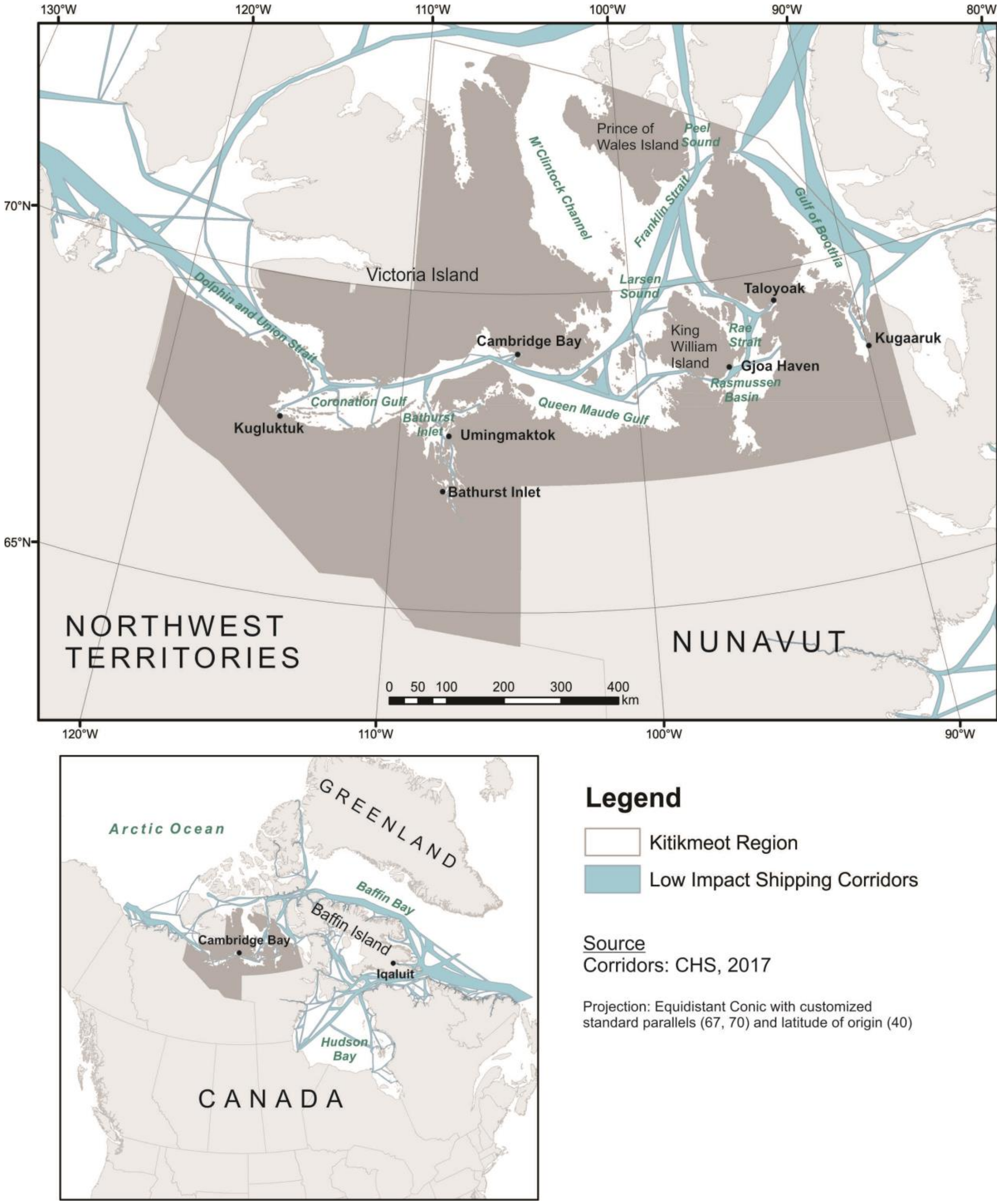

Figure 10. The Kitikmeot region of Nunavut and the Low Impact Shipping Corridors.

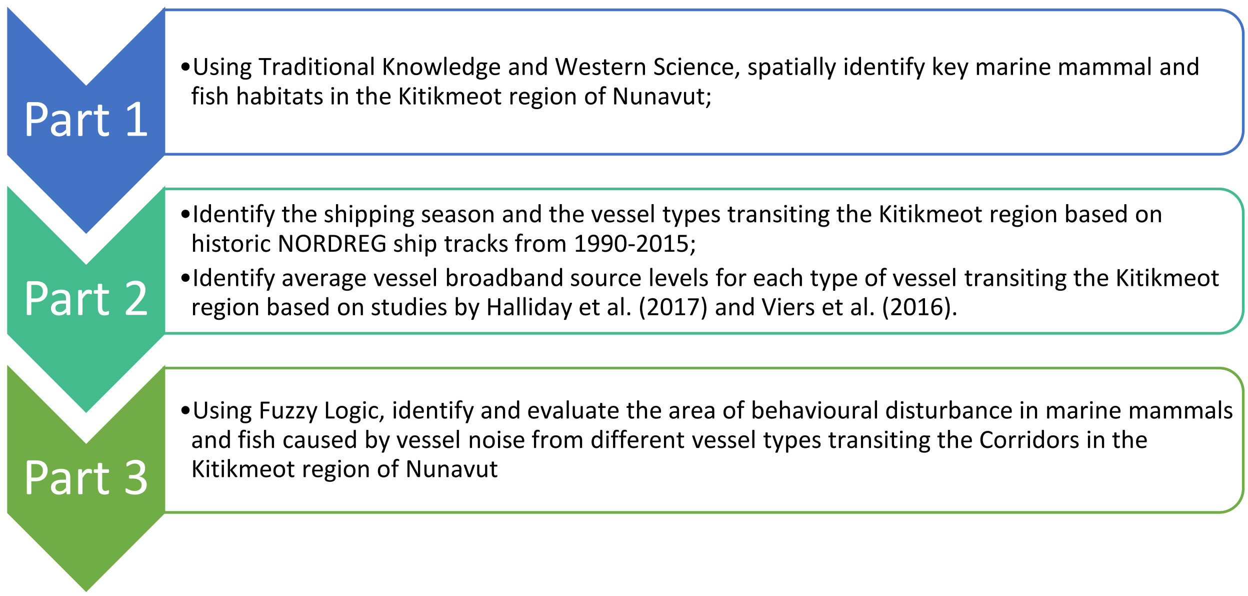

Figure 11. Conceptual model of the three-part approach.

3.5.1 Part 1: Location of Important Areas for Marine Mammals and Fish

The objective of part 1 was to identify important areas and seasonal presence for marine mammals and fish. This was completed by geospatially locating important areas for marine mammal and fish within the Kitikmeot region of Nunavut using both western science, such as EBSA's, and Traditional Knowledge. Indigenous Peoples and northerners residing in the Arctic have long relied on traditional activities like hunting and fishing for subsistence (AMAP, CAFF & SDWG, 2013; Aporta, Taylor, & Laidler, 2011; Inuit Circumpolar Council, 2012; Laidler, et al., 2011; Meier, et al., 2014). Knowledge of where the wildlife is, including important areas for marine mammals and fish, migratory routes, and hunting and fishing areas is passed down from generation to generation, so Indigenous Peoples will know where to hunt and fish (Huntington, 2000). This knowledge, often called Indigenous or Traditional Knowledge, is extremely valuable when developing land use plans, management strategies, or policies and other legislation in the Arctic, as Indigenous Peoples and northerners are primary observers of the environment (Huntington, 2000).

Studies have begun to document Traditional Knowledge, primarily through participatory mapping workshops, community meetings, and interviews with experts in hunting, fishing, and the Arctic environment. The Nunavut Planning Commission conducted community meetings in each Nunavut community to discuss land use and resource management issues in preparation for the 2016 Nunavut Land Use Plan. Within the Kitikmeot region, community meetings were held in Gjoa Haven, Kugaaruk, Kugluktuk and Taloyoak (See Nunavut Planning Commission 2014a, 2014b, 2014c, and 2014d, respectively). A mapping session was facilitated at each community meeting where participants identified areas and issues important for inclusion in the NLUP. Information provided by the community participants included important areas for marine mammal and fish. Data collected is publicly accessible through the Nunavut Planning Commission's website and was used in this study. The scale of the basemaps used in these mapping sessions can be seen in Table 7.

Carter el al. also conducted participatory mapping workshops in Nunavut in the communities of Gjoa Haven and Cambridge Bay (See Carter, Dawson and Joyce, et al. 2017a, 2017b, and Carter, Dawson and Knopp, et al. 2018, respectively) to gain understanding on Inuit and northerners perspectives on potential impacts of shipping in the Corridors on local marine use areas and community members. Local experts on marine use shared their Traditional Knowledge and manually identified on topographic maps important areas for animals and community members during different seasons of the year, specific to the community. From this data, important areas for marine mammals and fish near Gjoa Haven and Cambridge Bay were used in this study.

Table 7. Scales of basemaps used in this study.

Source	Scale of Basemap
NPC 2014a, 2014b, 2014c, 2014d	1:1000000
Carter, Dawson and Joyce, et al. 2017b	1:500000
Carter, Dawson and Knopp, et al. 2018	1:250000

Temporal information on when marine mammals and fish were present in the Kitikmeot was included in these datasets and was translated into the 6 seasons identified in the NLUP (Figure 9). Carter, Dawson and Joyce, et al. (2017b) and Carter, Dawson and Knopp, et al. (2018) identified seasons unique to Gjoa Haven and Cambridge Bay based on the perspectives of the participatory mapping workshop participants (See Table 8 and Table 9, respectively). Seasonal information for Gjoa Haven and Cambridge Bay were translated into the NLUP 6 seasons in Nunavut for this study.

Table 8. Seasonal Dates in Gjoa Haven, Nunavut. Source: Carter, Dawson and Joyce, et al. 2017b

Season	**Months in which it happens**	**Ocean Condition**	**Associated Inuit Season**
Start of Spring	April	Frozen	Upingaksaaq
Spring to Early Summer	May and June	Break-up (in June)	Upingaksaaq and Upingaaq
Summer	July to beginning of August	Open water	Upingaaq
Late Summer	August	Open water	Aujaq
Early Fall to Late Fall	September and October	Freeze-up (in October)	Ukiaksaaq
Winter	November through March	Frozen	Ukiaq and Ukiuq

Table 9. Seasonal Dates in Cambridge Bay, Nunavut. Source: Carter, Dawson and Knopp, et al. 2018

Season	**Months in which it happens**	**Ocean Condition**	**Associated Inuit Season**
Spring	May and June	Frozen	Upingaksaaq and Upingaaq
Summer	July	Break-up	Upingaaq, Aujaq and Ukiaksaaq
	August and September	Open water	
Fall	October and November	Freeze-up	Ukiaq
Winter	December through April	Frozen	Ukiaq and Ukiuq

It is important to note that the species datasets used in this study are merely a snapshot of the species present within this region. These datasets capture which animals are typically within the region and during which season but do not represent the full extent of marine mammals and fish that may be present.

3.5.2 Part 2: Vessels Types and Source Levels

The objective of part 2 was to identify vessel types and the seasonal presence of vessels using the NORDREG dataset, from 1990-2015, and identify vessel source levels using results from Halliday et al. (2017) and Viers et al. (2016).

The NORDREG dataset was used to identify which vessel types were present in the Kitikmeot region and during which months for time period from 1990-2015. NORDREG was developed and is managed by the Canadian Coast Guard and provides vessel information including positional data daily within the NORDREG zone, vessel name, call sign, International Maritime Organization (IMO) number, and flag state for each recording vessel report (Canadian Coast Guard, 2013; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). On July 1, 2010, NORDREG legislation was adapted to make daily positional reporting mandatory for vessels 200 gross tonnage or more, vessels engaged in towing or pushing, vessels either towing or pushing other vessels if the combined weight is 500 gross tonnage or more, and vessels carrying, towing or pushing a vessel carrying pollutants or dangerous goods as cargo (Canadian Coast Guard, 2013; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). Prior to this change, reporting for all vessels was not mandatory but there is a reported 98% compliance in the NORDREG reporting system (Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Rompkey & Cochrane, 2008).

Pizzolato, Howell and Derksen, et al. (2014) acquired the NORDREG record of monthly Arctic marine transportation activities from the Canadian Coast Guard for 1990 to 2015. They performed extensive quality control on the dataset and reclassified the original 36 NORDREG classifications into 10 AMSA vessel classification categories (Arctic Council, 2009; Pizzolato, Howell, Derksen, Dawson, & Copland, 2014). They also identified total vessel reporting records and unique vessels for each AMSA vessel classification type.

In this study, the dataset was used to identify vessels transiting through the Kitikmeot region from 1990 to 2015 (Table 10). The table also identifies vessel reporting records and unique vessels in the Kitikmeot region for the study period.

Based on the NORDREG dataset, vessels typically navigate through the Kitikmeot region from July to October, with some vessels navigating in early November (Table 10). The shipping season was translated into seasonal dates in the Kitikmeot region, as identified by the 2016 NLUP (Figure 9), which include the second half of Upingaaq, Aujaq, and Ukiaksaaq. The shoulder months of the shipping season, as identified by Pizzolato, Howell and Derksen, et al. (2014) are June and November. These months translate into the beginning of Upingaaq and the beginning of Ukiaq.

Table 10. NORDREG vessel types based on AMSA classification transiting through Kitikmeot, Nunavut from 1990-2015, months ships transited the Kitikmeot during this time period, reporting records of vessels and unique vessels, and associated source levels used in study. Table adapted from Pizzolato, Howell and Derksen, et al. (2014).

AMSA vessel classification	**Classification in NORDREG dataset**	**Shipping season (months)**	**Reporting records***	**Unique vessels****	**Source level (dB re 1 µPa @ 1 m)*****	**Source level study**
Pleasure Crafts	Pleasure Craft, Sail/Row Boat, Home Made Boat	July – September	758	123	159 ± 9	Veirs, Veirs and Wood 2016
Government Vessels and Icebreakers	CCG Icebreaker, Icebreaker, USCG(C) Icebreaker, USCG Cutter, CCG Vessel, Fisheries Patrol Vessel, CCG Navaids, SAR Vessel, Navy Ship, Fisheries Research Vessel	July – October	3557	88	176	Halliday, et al. 2017
Passenger Ships	Passenger Ships	July – November	652	62	166 ± 8	Veirs, Veirs and Wood 2016
Tugs/Barges	Tug, Tug/Supply, Tug/Icebreaker, Self-Powered Barge, Powered Barge	July – November	1937	134	170 ± 5	Veirs, Veirs and Wood 2016

AMSA vessel classification	Classification in NORDREG dataset	Shipping season (months)	Reporting records*	Unique vessels**	Source level (dB re 1 µPa @ 1 m)***	Source level study
Bulk Carriers	Bulk Carrier, Grain Ship (Churchill)	July – September	13	3	173 ± 5	Veirs, Veirs and Wood 2016
General Cargo	General Cargo, Heavy Lift Ship, Heavy Load Vessel, Heavy Load Carrier Ship	July – October	227	24	175 ± 5	Veirs, Veirs and Wood 2016
Tanker Ships	Chemical Tanker, Tanker	August – October	181	22	184	Halliday, et al. 2017
	*Total reporting records included in the analysis over the 1990-2015 study period from NORDREG data **Total unique vessels over the entire 1990-2015 study period from NORDREG data *** Variability reported as a standard deviation of the mean					

Underwater broadband source levels for the 7 categories of vessels listed in Table 10 were gathered from two studies: Halliday et al. (2017) and Veirs, Veirs and Wood (2016). Halliday et al. (2017) estimated the source level of two vessels navigating through the Corridors in the Beaufort Sea and Amundsen Gulf. The CCGS Amundsen, a Canadian Coast Guard icebreaker and research vessel, had a source level of 176 dB re 1 µPa at 1 m and the Awanuia, a medium sized tanker vessel, had a source level of 184 dB re 1 µPa at 1 m (Halliday, Insley, Hilliard, de Jong, & Pine, 2017). The Awanuia is an example of a vessel that will likely use the Northwest Passage when it is ice-free (Halliday, Insley, Hilliard, de Jong, & Pine, 2017). These two vessel source levels from Halliday et al. (2017) were used in this study to represent source levels of government vessels and icebreakers (CCGS Amundsen source level) and tanker ships (Awanuia), as the acoustic data used to calculate source levels were collected from hydrophones near Sachs Harbour in the Northwest Territories, which is a good representation of a remote Arctic environment and is geographically situated adjacent to the Kitikmeot region.

Veirs, Veirs and Wood (2016) estimated mean broadband sound pressure levels from 1582 unique ships transiting through Haro Strait near Victoria, BC, which is a critical habitat of the endangered Southern Resident Killer Whale. Estimated source levels from Veirs, Veirs and Wood (2016) were used in this study for pleasure crafts, passengers, tugs/barges, bulk carriers, and general cargo. The acoustic data used to estimate source levels in Veirs, Veirs and Wood (2016) is not representative of an Arctic environment; however, Halliday et al. (2017) compared sources levels and found that those measured by Veirs, Veirs and Wood (2016) were slightly lower than the averages they measured. This is likely because sound may propagate differently in Arctic waters and can potentially travel further distances in comparison to southern, more temperate waters (WWF, 2017). In the Arctic marine environment, sound fixing and ranging channels, which are naturally occurring layers in the water column where the speed of sound is at its minimum and thus low-frequency sound waves can travel for over long ranges before dissipating, exist at shallower depths (approximately 100 – 300 m) than in temperate waters (World Wildlife Fund, 2017). Halliday et al. (2017) also compared their estimated source levels with other studies including Erbe and Farmer (2000), and found their source levels were much lower. Therefore, source levels estimated by Halliday et al. (2017) can be considered conservative estimates of areas impacted whereas source levels from Veirs, Veirs and Wood (2016) are slightly less conservative estimates. It is important to note that source levels of vessels transiting the Corridors in the Kitikmeot may be higher than the source levels used in this study.

3.5.3 Part 3: Data Analysis

The area of behavioural disturbance was geospatially identified around important areas for marine mammal and fish during the four Inuit seasons in the Kitikmeot region (Upingaaq, Aujaq, Ukiaqsaaq, and Ukiaq) that correspond to the shipping season (July – October) and the shoulder months (June and

November) for each vessel type (based on the AMSA vessel classification, see Figure 9) that transited through the Kitikmeot region during the period of 1990 – 2015. This was completed using Fuzzy Logic, which is commonly used as an overlay analysis technique for developing suitability models that identify the best location for a specific phenomenon (ESRI, 2018a). This type of analysis takes into account the inaccuracies in attribute data and geometry of spatial data and provides techniques to address these inaccuracies (ESRI, 2018a). Therefore, fuzzy logic will account for inaccuracies when data is collected manually through participatory mapping, as is the case for the data used in this study. The following section describes the methods used to complete the data analysis in this study.

Calculating source levels in water

The software ArcGIS version 10.4.1 was used with the language Python version 2.7.10 to map the Euclidean distance from each important area for beluga whale, bowhead whale, narwhal, seal, and fish during the seasons of Upingaaq, Aujaq, Ukiaksaaq, and Ukiaq. Next, the following equation from Pike and Sherman (1998) was used to approximate the decibel (dB) level in water of each vessel according to distance:

$$Ps = 20 \times 10^{(dBx/20)}$$

$$Ls = 20 \times \log_{10} Ps$$

$$Ls\ at\ d = Ls + 20 \times \log_{10}(1\,/d)$$

Where Ps is the source pressure in µPa, dBx is the vessel source level in dB, Ls is the source intensity in dB and assumes the reference source pressure in water is 1 µPa, and Ls at d is the source intensity in dB at a given distance (d) in meters. Euclidean distance layers for each species were input as d.

Fuzzy Membership

The fuzzy membership function Fuzzy Large was then used to transform the newly calculated source intensity layers to a scale from 0 to 1, where 0 indicates no membership (no noise impact to marine mammals and fish) and 1 indicates membership (noise impact to marine mammals and fish). The Fuzzy Large function is used when large input values have a higher membership. In this study, a midpoint of 120 dB re 1 µPa for marine mammals and 150 dB re 1 µPa for fish was used (i.e. the hearing threshold levels that would cause behavioural disturbance) and the default spread parameter of 5 was used.

Fuzzy Overlay

Next, the Fuzzy overlay tool was used with the default Gamma value of 0.9 in ArcGIS to model the potential disturbance for marine mammals and fish from each vessel type during the seasons of Upingaaq, Aujaq, Ukiaksaaq, and Ukiaq. Fuzzy overlay is an ArcGIS tool that analyzes the possibility of a phenomenon belonging to multiple sets and the relationship between the membership of multiple sets of criteria (ESRI, 2018b). Each Fuzzy Overlay output was overlaid with the Corridors and assessed where the Corridors overlaid areas of high membership, or areas where vessels have a high likelihood of causing behavioural disturbance in marine mammals and fish.

3.6 Results

Study results are presented in two sections: section 1 discusses the seasonal location and distribution of species in the Kitikmeot; and section 2 outlines an analysis of the likelihood of different vessel types causing behavioural disturbance in marine mammals and fish while transiting the Corridors.

3.6.1 Seasonal Location of Species

The seasonal locations of narwhals, beluga whales, fish, bowhead whales, and seals were mapped for the shipping season and shoulder months (Upingaaq, Aujaq, Ukiaqsaaq, and Ukiaq) in the Kitikmeot region (Figure 12). We found that each species resides in the Kitikmeot region during the 4 Inuit seasons that correspond to the lengthened shipping season. However, species could be found in different areas depending on the season. For instance, narwhal can be found in Franklin Strait during the Upingaaq and Aujaq where they are feeding and rearing their young, but not during Ukiaqsaaq or Ukiaq.

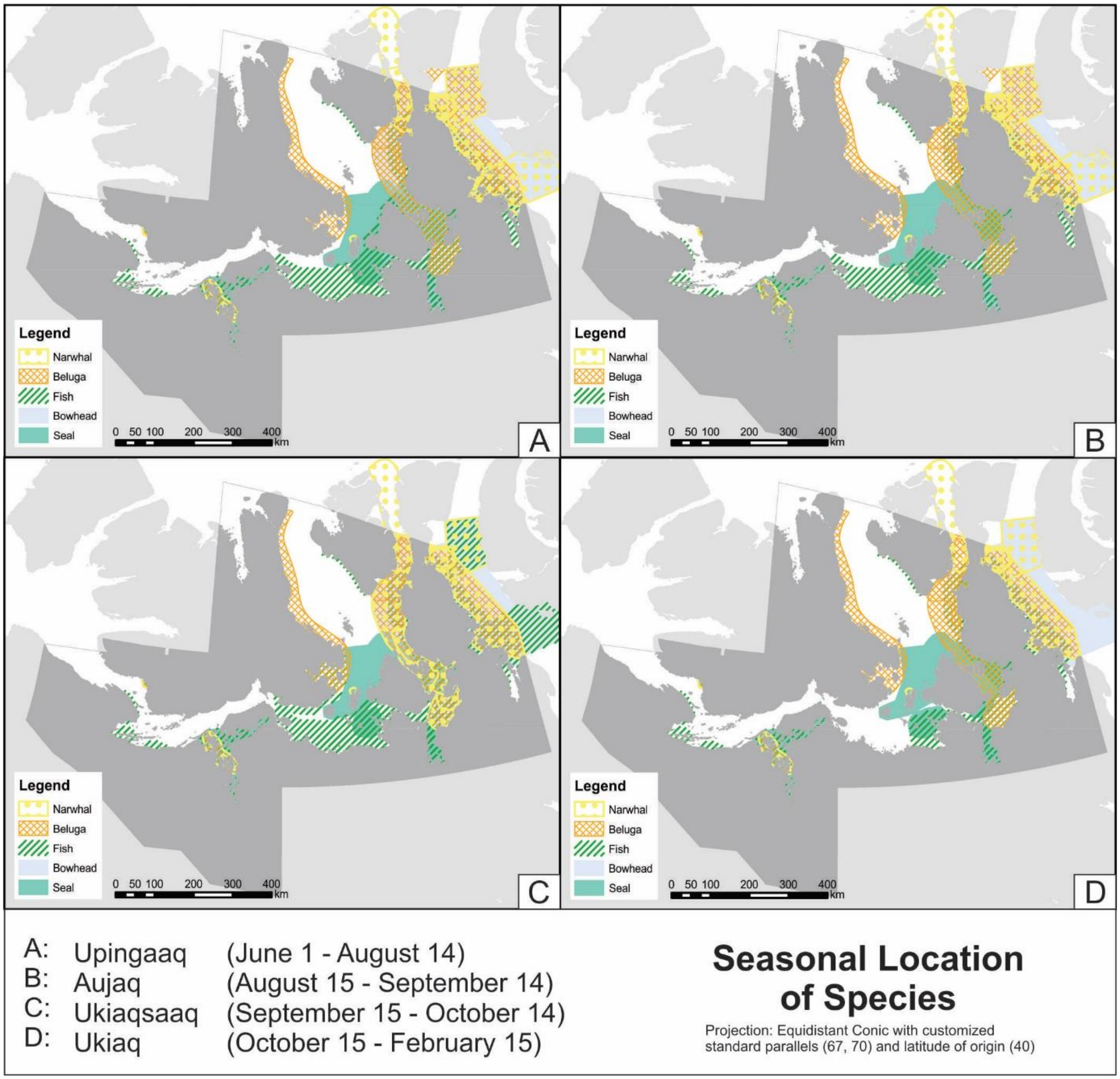

Figure 12. Seasonal location of narwhal, beluga whale, fish, bowhead whale, and seal in the Kitikmeot region, Nunavut during the seasons of Upingaaq (A), Aujaq (B), Ukiaqsaaq (C), and Ukiaq (D). Sources: Fisheries and Oceans Canada 2011, 2015, Nunavut Planning Commission 2014a, 2014b, 2014c, 2014d, Carter, Dawson and Joyce, et al., 2017b, Carter, Dawson and Knopp, et al. 2018

Distribution of Species

During the lengthened shipping season, there is a high concentration of species residing in the Gulf of Boothia, Franklin Strait, around King William Island through Rae Strait and Rasmussen Basin, and in

Bathurst Inlet. The seasonal distribution of each species varies during the lengthened shipping season (Figure 13); however, the highest concentration of species occurrence is during Upingaaq and Aujaq, except for fish species who have the highest concentration during Ukiaqsaaq. The lowest concentration of species occurs during the winter months of Ukiaq when species migrate from the area, except for seal species who are year-round residents in the Kitikmeot region.

It is also important to note this is not an exhaustive list of species present in the Kitikmeot region during the seasons of Upingaaq, Aujaq, Ukiaqsaaq, and Ukiaq. This is merely a snapshot of important areas for marine mammals and fish during these seasons based on Traditional Knowledge from Inuit and northern residents, and EBSAs developed through western science by Fisheries and Oceans Canada.

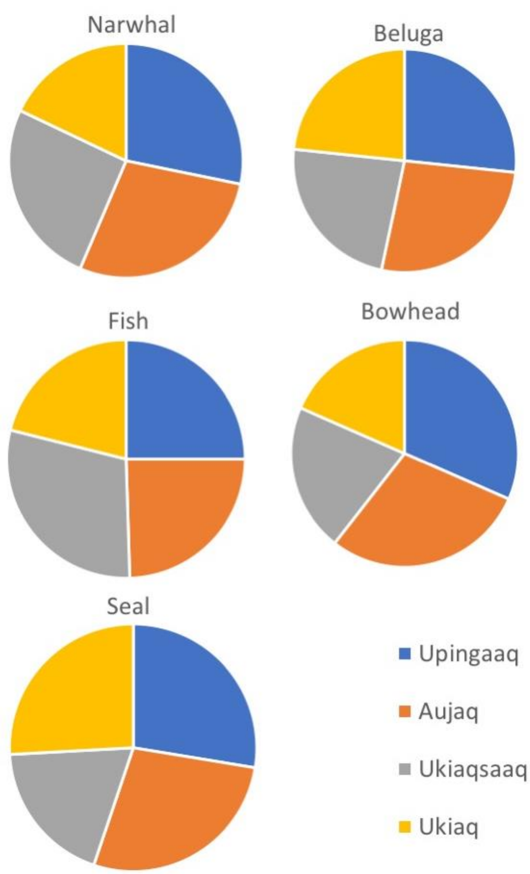

Figure 13. Seasonal distribution of species in the Kitikmeot region, Nunavut during the lengthened shipping season (Upingaaq, Aujaq, Ukiaqsaaq, and Ukiaq).

3.6.2 Likelihood of Vessels causing Behavioural Disturbance

The likelihood of vessels causing behavioural disturbance in marine mammals and fish while transiting the Corridors was analyzed. The noise impact of each vessel type (bulk carrier, general cargo, government vessel and icebreaker, passenger ship, pleasure craft, tug/barge, and tanker ship) was analyzed during the shipping season and shoulder months (Upingaaq, Aujaq, Ukiaqsaaq, and Ukiaq).

Vessel types were analyzed individually because different vessels have different noise profiles and thus can have varying impacts on marine mammals and fish (see Table 10). The potential for behavioural disturbance in marine mammals and fish also varies with distance. This study analyzed the behavioural disturbance level from different ship types based on distance from the boundary of identified important areas to marine mammals and fish (see Figure 12). The further vessels are navigating away from these important areas, the less potential for causing behavioural disturbance in marine mammals and fish, as noise levels dissipate with distance (Figure 14).

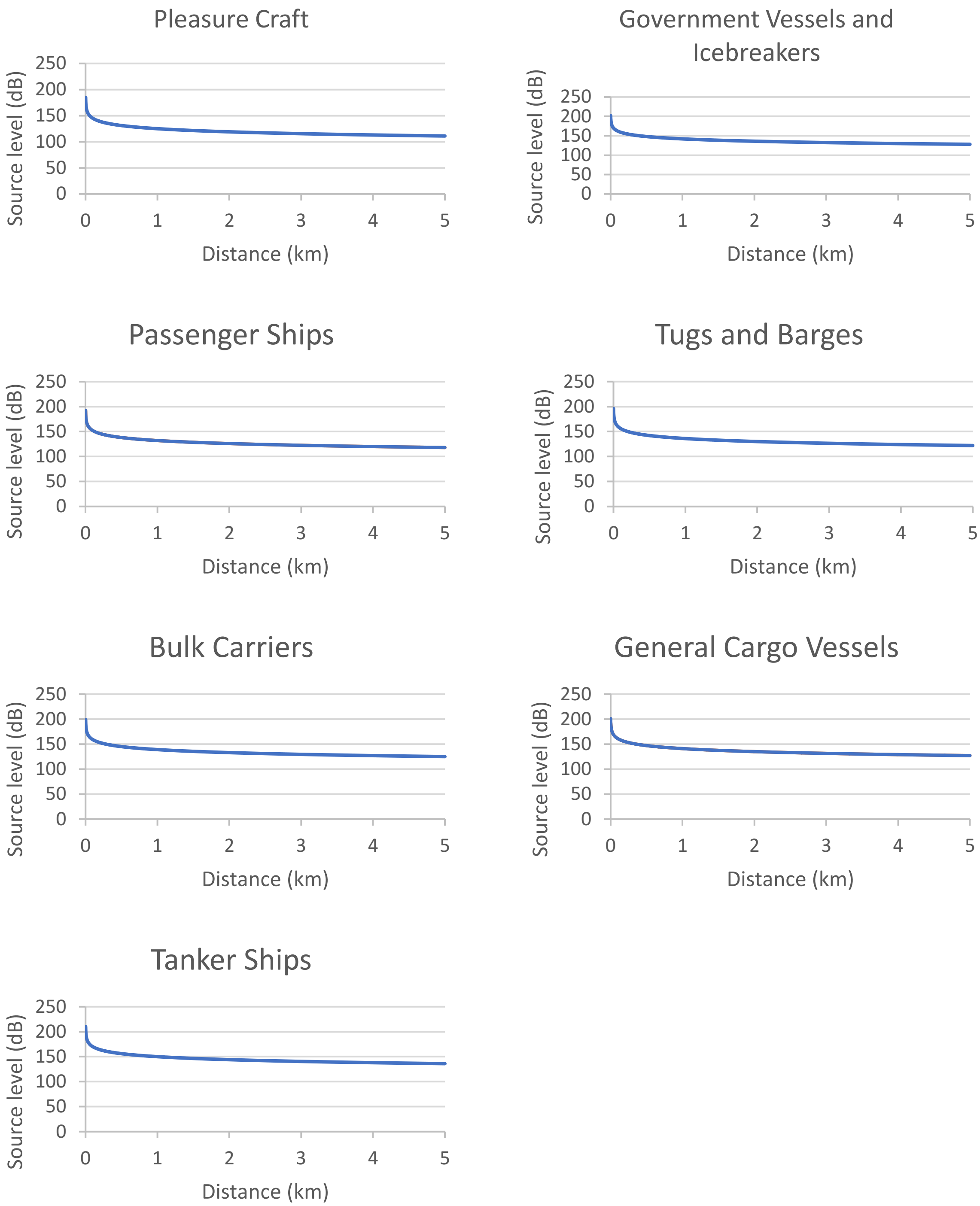

Figure 14. Propagation of sound from vessels (db) in water over a distance of 5 km for a pleasure craft (broadband source level = 159 dB re 1 µPa @ 1 m), government vessels and icebreakers (broadband source level = 176 dB re 1 µPa @ 1 m), passenger ships (broadband source level = 166 dB re 1 µPa @ 1 m), tugs and barges (broadband source level = 170 dB re 1 µPa @ 1 m), bulk carriers (broadband source level = 173 dB re 1 µPa @ 1 m), general cargo vessels (broadband source level = 175 dB re 1 µPa @ 1 m), and tanker ships (broadband source level = 184 dB re 1 µPa @ 1 m).

Bulk Carriers

Bulk carriers are vessels that transport dry or loose cargo, timber and ore typically to and from mines (Dawson, Copland, Mussells, & Carter, 2017). From 1990-2015, there were 13 reporting records of bulk carriers in the Kitikmeot region from 3 unique vessels that travelled through the Northwest Passage (Table 10). Veirs, Veirs and Wood (2016) identified a source level of 173 ± 5 dB re 1 μPa at 1 m for bulk carriers. Figure 15 shows the areas where vessel noise from bulk carriers, general cargo, and government vessels and icebreakers would likely cause behavioural disturbance in marine mammals and fish. The noise from these three vessel types range from 173 – 176 dB re1 μPa at 1 m; therefore, results were very similar and are displayed in one figure. Figure 20 in the Appendix section displays results specific to bulk carriers.

At this source level, bulk carriers have a high likelihood of causing behavioural disturbance in marine mammals and fish when transiting the Corridors through Franklin Strait, down around King William Island through Rae Strait, and through Bathurst Inlet during the season of Ukiaqsaaq. The likelihood of bulk carriers causing behavioural disturbance in Upingaaq is similar to Ukiaqsaaq, except bulk carriers would have a medium to high likelihood of causing behavioural disturbance when transiting the Corridors through Franklin Strait and Rae Strait. This is because narwhals are present in these regions during Ukiaqsaaq but not Upingaaq.

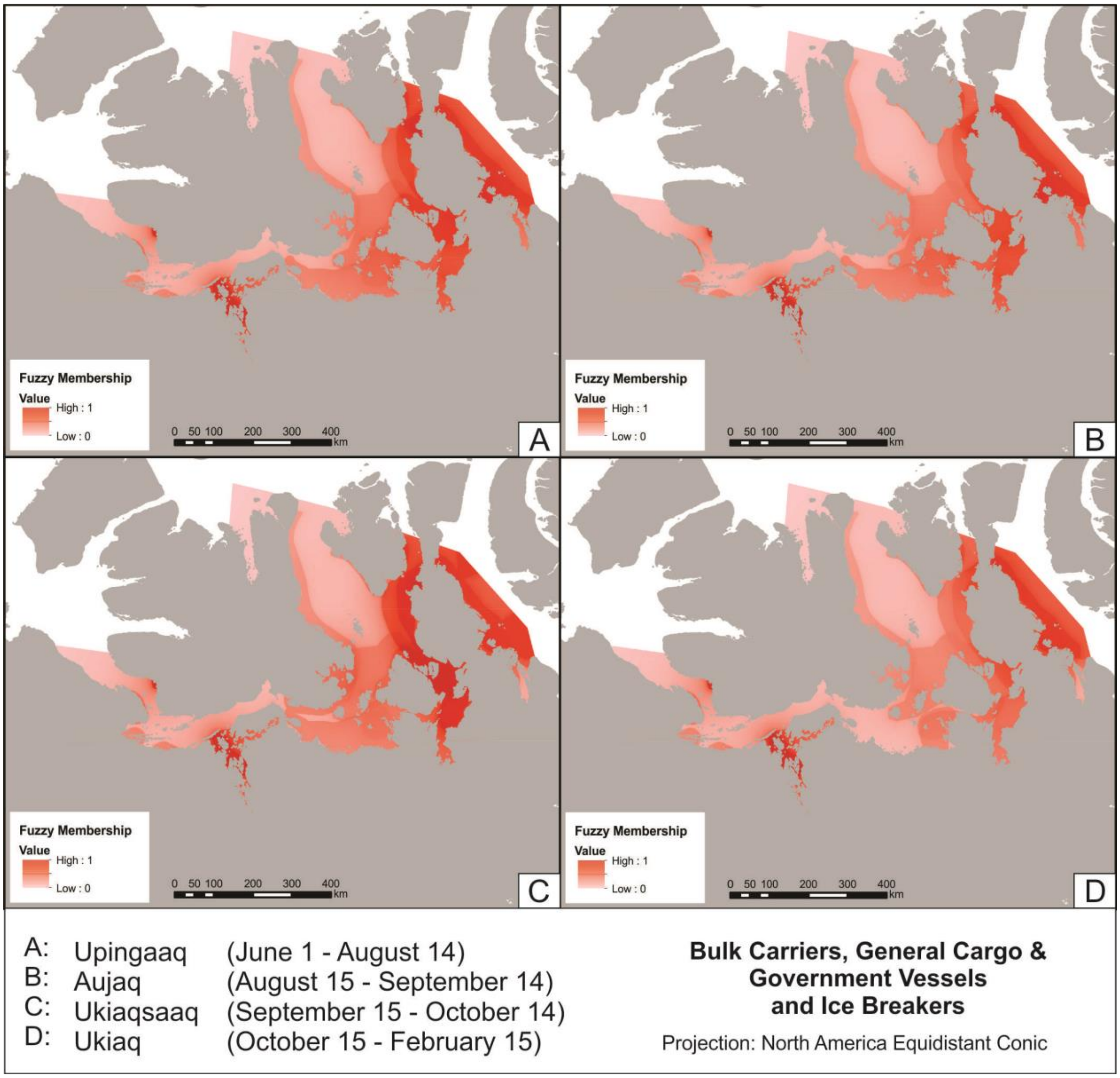

Figure 15. Areas of potential behavioural disturbance to marine mammals and fish from bulk carrier vessel noise (source level = 173 ± 5 dB re 1 µPa @ 1 m), general cargo vessel noise (source level = 175 ± 5 dB re 1 µPa @ 1 m), and government vessel and icebreaker noise (source level = 176 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

Bulk carriers have a medium to high likelihood of causing behavioural disturbance when transiting the Corridors through Peel Sound, Gulf of Boothia, and Rasmussen Basin during Upingaaq and Ukiaqsaaq. During Aujaq and Ukiaq, bulk carriers have a high likelihood of causing behavioural disturbance when transiting the Corridors through Bathurst Inlet, and a medium to high likelihood of causing behavioural disturbance when transiting the Corridors through Gulf of Boothia. During Aujaq, Bulk Carriers have a medium likelihood of causing behavioural disturbance when transiting the Corridors through Rae Strait and Rasmussen Basin. During all four seasons, bulk carriers have a medium to low likelihood of causing behavioural disturbance when transiting the Corridors through Victoria Strait and eastern Queen Maude Gulf. Bulk carriers have a low likelihood of causing behavioural disturbance when transiting the Corridors through Coronation Gulf and Dolphin and Union Strait during all four seasons.

General Cargo

General cargo vessels are used for community resupply in Nunavut and are therefore more frequently present in the Kitikmeot region in comparison to bulk carriers. From 1990-2015, there were 227 reporting records of cargo vessels in the Kitikmeot region from 24 unique vessels (Table 10). Veirs, Veirs and Wood (2016) identified a source level of 175 ± 5 dB re 1 µPa at 1 m for general cargo vessels, which is slightly higher than the source level of bulk carriers. Figure 15 shows the areas where vessel noise from general cargo vessels, bulk carriers, and government vessels and icebreakers would likely cause behavioural disturbance in marine mammals and fish. Figure 21 in the Appendix section displays results specific to general cargo vessels. The likelihood of general cargo vessels causing behavioural disturbance in marine mammals and fish is very comparable to the results seen for bulk carriers. This is due to the similar source level of bulk carriers (173 dB re 1 µPa at 1 m) and general cargo vessels (175 re 1 µPa at 1 m). Areas where the likelihood of behavioural disturbance is medium to high are concentrated in the Corridors through Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet, and areas where the likelihood of behavioural disturbance is low are concentrated in the Corridors through Coronation Gulf and Dolphin and Union Strait. General cargo vessels transiting the Corridors in Upingaaq and Ukiaqsaaq have a higher likelihood of causing behavioural disturbance than vessels transiting the Corridors in Aujaq and then Ukiaq. These results are consistent with the concentration of important areas for marine mammals and fish and the seasonal presence of species.

Government Vessels and Icebreakers

Government vessels and icebreakers in the Kitikmeot region include Canadian Coast Guard vessels, private icebreaking vessels, and public or private research vessels. From 1990-2015, there were 3557 reporting records of cargo vessels in the Kitikmeot region from 88 unique vessels (Table 10). Halliday et al. (2017) identified a source level of 176 dB re 1 µPa at 1 m for the CCGS Amundsen, which was used to represent the source level of government vessels and icebreakers in this study during the open water season, meaning the vessel was not breaking ice. The CCGS Amundsen is typically used for research and is often in the western Canadian Arctic during the summer. It should be noted that icebreaking ships produce a different noise signature than other vessels, as they generate higher and more variable noise levels (100 to 20,000 Hz) when backing and ramming into the ice (Erbe & Farmer, 2000; World Wildlife Fund, 2017). Therefore, the source level used in this study only represents government vessels and icebreakers that are not breaking ice. Figure 15 shows the areas where vessel noise from government vessels and icebreakers, bulk carriers, and general cargo would likely cause behavioural disturbance in marine mammals and fish. Figure 22 in the Appendix section displays results specific to government vessels and icebreakers.

The likelihood of government vessels and icebreakers causing behavioural disturbance in marine mammals and fish is very similar to the results seen for general cargo vessels, since the source levels for these two vessel types are only 1 dB apart. However, it is important to note the area of behavioural disturbance in marine mammals and fish would likely increase if a vessel was breaking ice. An icebreakers noise signature can increase approximately 10 dB between 20 Hz and 2 kHz when performing icebreaking maneuvers and may also have bubbler systems that blow high pressure air into the water aiming to push away floating ice, which can create an additional noise source over short ranges (Roth, Schmidt, Hildebrand, & Wiggins, 2013; World Wildlife Fund, 2017).

Passenger Ships

In the Kitikmeot region, passenger ships are typically used in expeditions carrying around 400 tourists and crew combined. Recently, larger cruise vessels have transited the region, including the Crystal Serenity transiting the Northwest Passage during summer 2016 and 2017 that could carry more than 1000 tourists. From 1990-2015, there were 652 reporting records of cargo vessels in the Kitikmeot region from 62 unique vessels (Table 10). Veirs, Veirs and Wood (2016) identified a source level of 166 ± 8 dB re 1 µPa at 1 m for passenger vessels (primarily cruise ships and some ferries) – lower than the source level of previously discussed vessels. Figure 16 shows the areas where vessel noise from passenger ships would likely cause behavioural disturbance in marine mammals and fish.

Despite the lower source level of passenger ships, the likelihood of this vessel type causing behavioural disturbance in marine mammals and fish while transiting the Corridors is comparable to bulk carriers, general cargo vessels, and government vessels and icebreakers transiting in open water. Similarly, passenger ships would have the greatest impact while transiting the Corridors during Ukiaqsaaq through Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet. Importantly, passenger ships tend to seek out areas known to have high concentrations of species so tourists can spot wildlife (Dawson, et al., 2016).

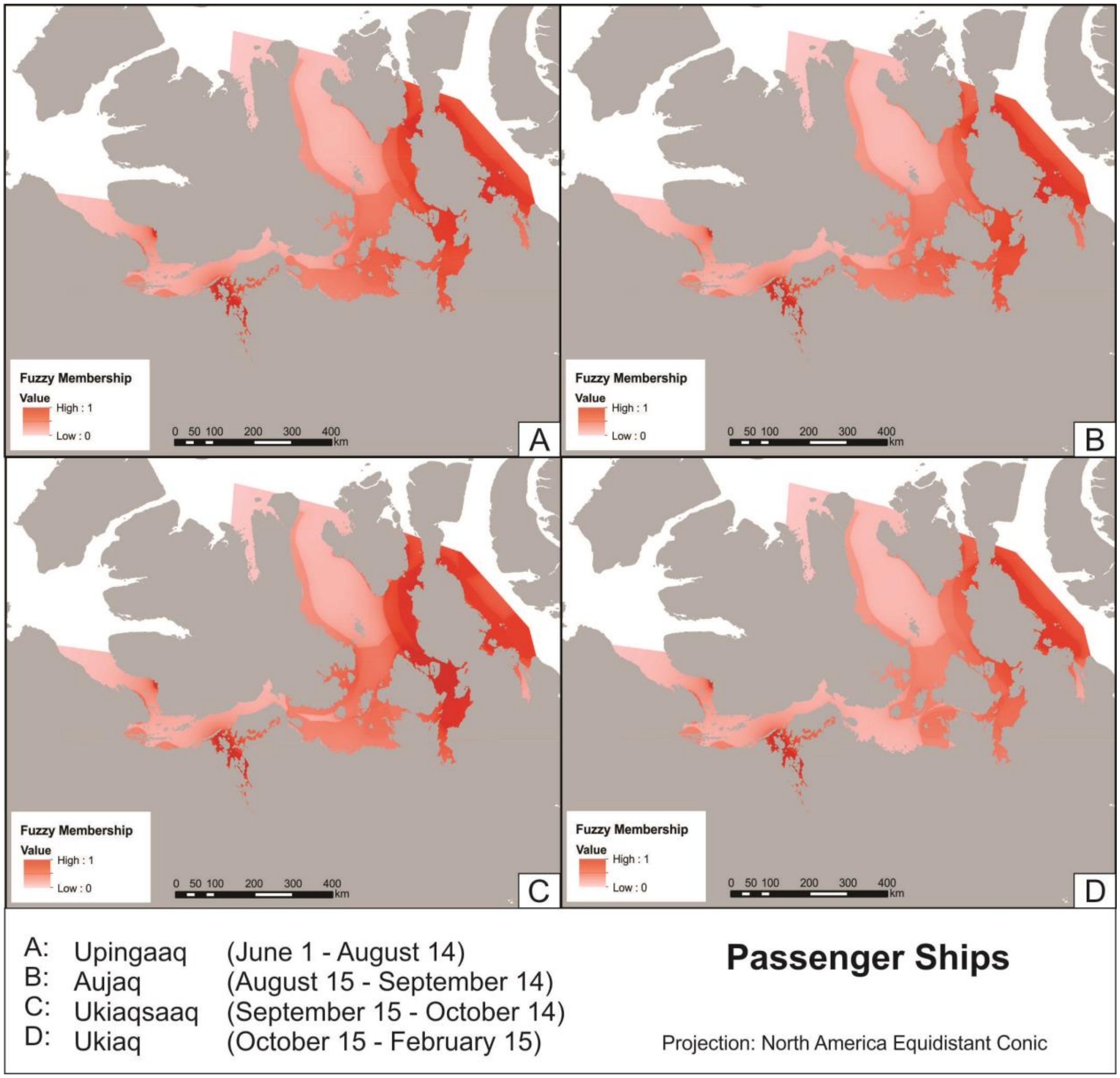

Figure 16. Areas of potential behavioural disturbance to marine mammals and fish from passenger vessel noise (source level = 166 ± 8 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

Pleasure Crafts

Pleasure crafts are non-commercial vessels that range in size from small sail boats carrying 1 person to large luxury yachts carrying 50 people. From 1990-2015, there were 758 reporting records of pleasure crafts in the Kitikmeot region from 123 unique vessels (Table 10). Veirs, Veirs and Wood (2016) identified a source level of 159 ± 9 dB re 1 µPa at 1 m for pleasure crafts (including sailing vessels, motor yachts, and yachts) – the lowest source level in comparison to previously discussed vessels. Figure 17 shows the areas where vessel noise from pleasure crafts would likely cause behavioural disturbance in marine mammals and fish.

The likelihood of pleasure crafts causing behavioural disturbance in marine mammals and fish is lower in comparison to the vessel types discussed thus far. Pleasure crafts have a medium to high likelihood of causing behavioural disturbance when transiting the Corridors through Peel Sound, Franklin Strait, Rae Strait, and Rasmussen Basin during Ukiaqsaaq, and Bathurst Inlet for all seasons. During Upingaaq, Aujaq and Ukiaq, pleasure crafts have a medium to low likelihood of causing behavioural disturbance when transiting the Corridors through Gulf of Boothia, Franklin Strait, Larsen Sound, and Queen Maude Gulf. Areas where the likelihood of behavioural disturbance is low are concentrated in the Corridors through Coronation Gulf and Dolphin and Union Strait for all seasons.

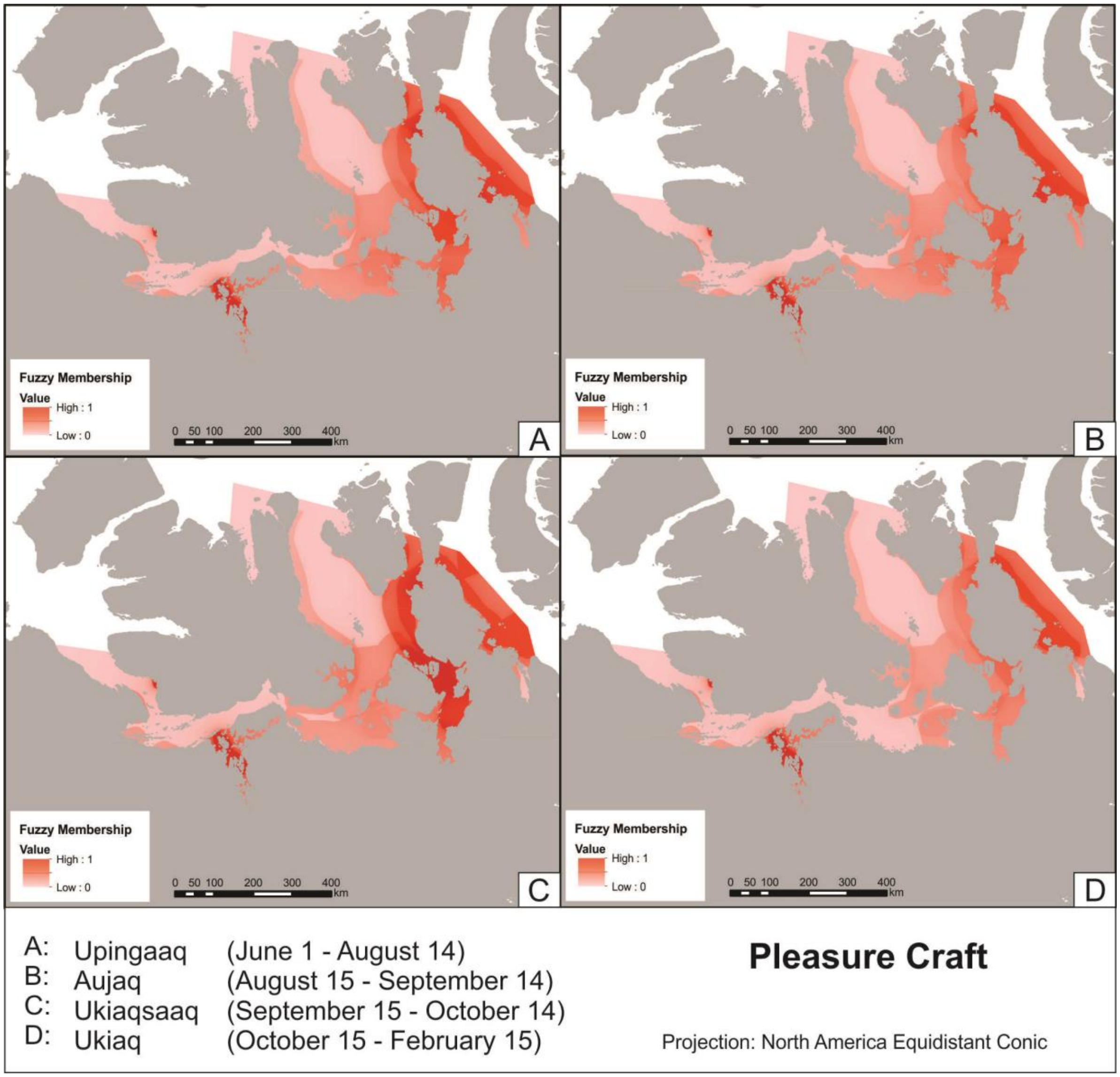

Figure 17. Areas of potential behavioural disturbance to marine mammals and fish from pleasure craft noise (source level = 159 ± 9 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

Tugs and Barges

Tugs and barges are frequently found around communities as they support community resupply and economic development in the region. From 1990-2015, there were 1937 reporting records of cargo vessels in the Kitikmeot region from 134 unique vessels (Table 10). Veirs, Veirs and Wood (2016) identified a source level of 170 ± 5 dB re 1 μPa at 1 m for tug and barge vessels. Figure 18 shows the areas where vessel noise from tugs and barges would likely cause behavioural disturbance in marine mammals and fish.

The likelihood of tugs and barges causing behavioural disturbance in marine mammals and fish is higher than the results seen in pleasure crafts but lower than bulk carriers, general cargo vessels, and government vessels and icebreakers. In comparison to bulk carriers, general cargo vessels, and government vessels and icebreakers, the likelihood of tugs and barges causing behavioural disturbance decreases mainly in Larsen Sound during Upingaaq and Ukiaq, and in Gulf of Boothia and Franklin Strait during Ukiaq.

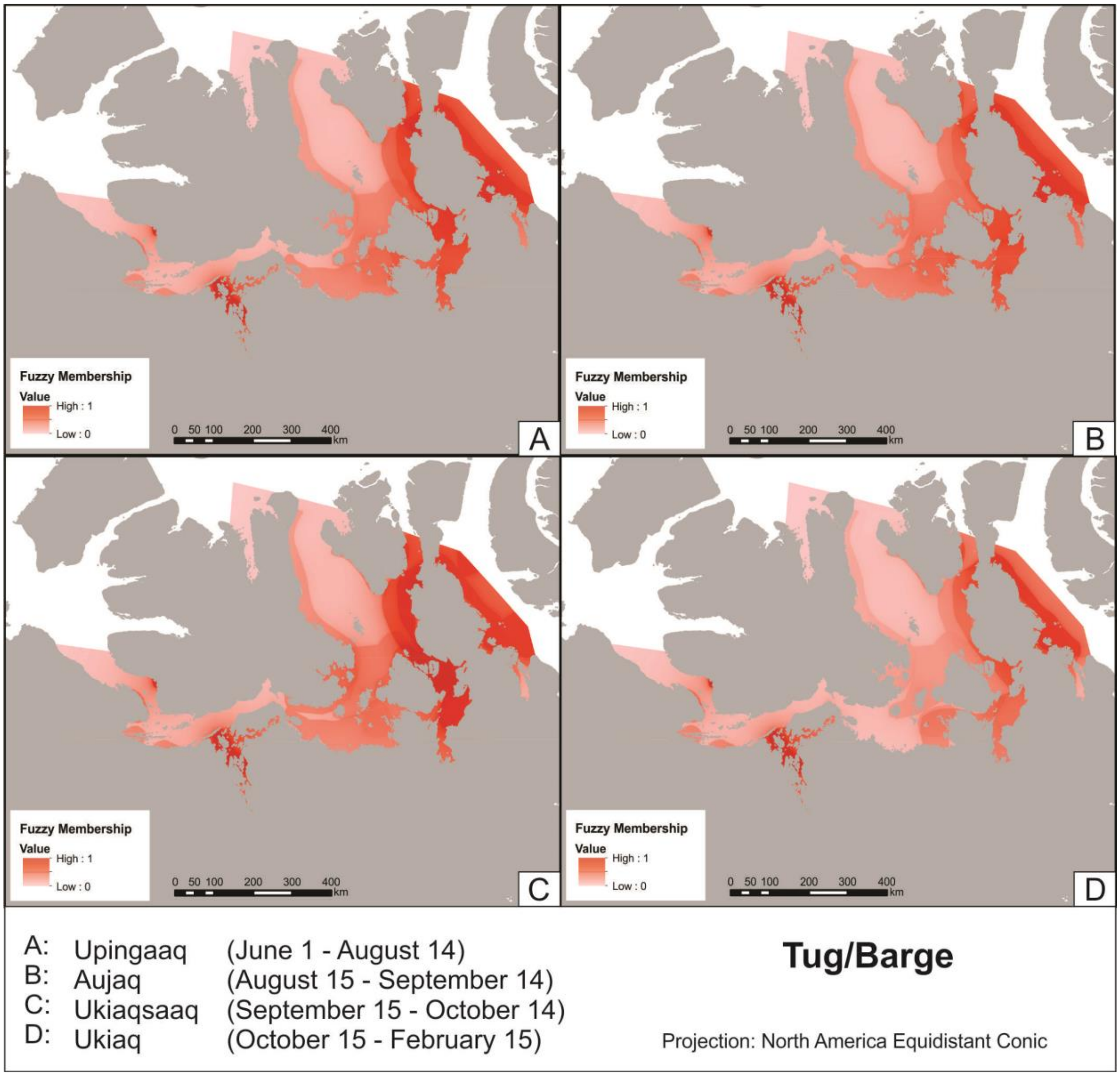

Figure 18. Areas of potential behavioural disturbance to marine mammals and fish from tug and barge vessel noise (source level = 170 ± 5 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

Tanker Ships

Tanker ships are vessels that transport liquids and compressed gases. From 1990-2015, there were 181 reporting records of cargo vessels in the Kitikmeot region from 22 unique vessels (Table 10). Halliday et al. (2017) identified a source level of 184 dB re 1 µPa at 1 m for tanker ships, which is the highest source level of vessel type transiting the Kitikmeot region. Halliday et al. (2017) determined this source level from the Awanuia, which is a medium-sized tanker and represents a vessel type that will likely use the Northwest Passage more frequently when it is ice free. Figure 19 shows the areas where vessel noise from tanker ships would likely cause behavioural disturbance in marine mammals and fish.

The likelihood of tanker ships causing behavioural disturbance in marine mammals and fish is the highest out of the vessel types discussed thus far. This is because tanker ships have the highest source level used in his study. The majority of the areas where tanker ships would transit the Corridors have a medium to high likelihood of causing behavioural disturbance. When transiting the Corridors through Coronation Gulf, tanker ships have a medium to low likelihood of causing behavioural disturbance. The only area where tanker ships may have a low likelihood of causing behavioural disturbance is the most western part of Dolphin and Union Strait.

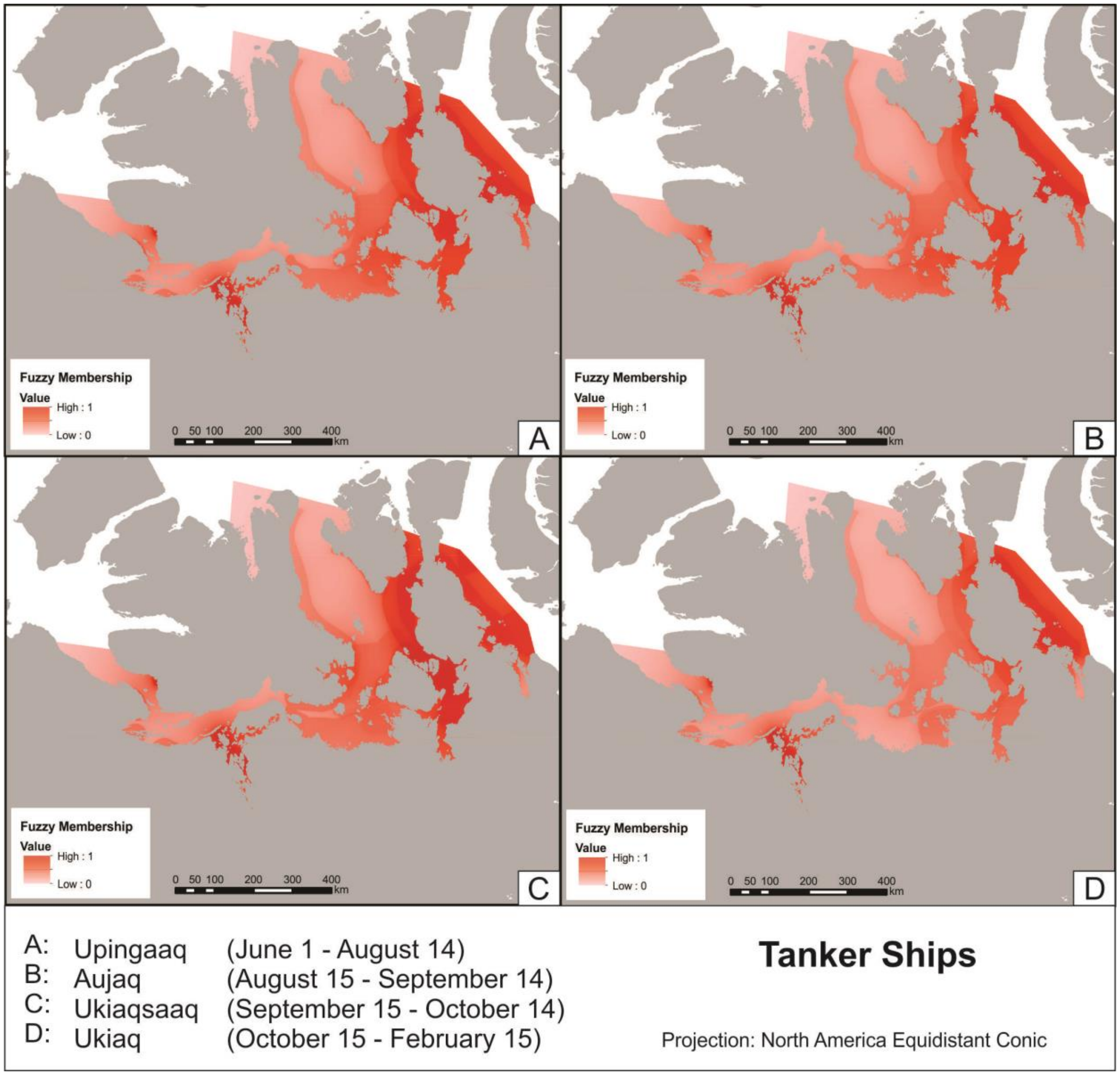

Figure 19. Areas of potential behavioural disturbance to marine mammals and fish from tanker vessel noise (source level = 184 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

3.7 Discussion

3.7.1 Congruence Between the Corridors and Important areas for marine mammals and fish

Study results indicate that the current Corridors have a high degree of congruence between important areas for marine mammals and fish in the Kitikmeot region of Nunavut. This is the case in particular for Corridors located in the Gulf of Boothia, Peel Sound, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet. The community of Gjoa Haven indicated concern over shipping through Peel Sound and Franklin Strait, as beluga whales congregate in this area (Nunavut Planning Commission, 2014a). Bowhead whales and narwhal are also found in Peel Sound and Franklin Strait, making these areas important for all three species. Seal species (mainly ringed and bearded seals) and fish can be found around King William Island through Larsen Sound, Queen Maude Gulf and through Rae Strait – areas where the Corridors overlap.

Community members from Gjoa Haven and Taloyoak identified the Gulf of Boothia as being an area where beluga whales, bowhead whales, and narwhal congregate (NPC, 2014a, 2014d, respectively). Fisheries and Oceans Canada (2011; 2015) developed an EBSA in the Gulf of Boothia, which acts as a bowhead whale migration corridor and an area of feeding, rearing of young, and refugium from killer whales. The Corridors overlap with these areas of marine mammal congregation. Additionally, Fisheries and Oceans Canada (2011; 2015) developed an EBSA in the Gulf of Boothia, which is an area of aggregation for bowhead whales and narwhals. North of the Gulf of Boothia, Prince Regent Inlet is an EBSA where bowhead whales and narwhal congregate from July to mid-November to feed and rear their young (Fisheries and Oceans Canada, 2011; 2015). The Corridors currently overlap with these important areas for marine mammal in the Gulf of Boothia and Prince Regent.

Bathurst Inlet is an EBSA and an area where all species in this study can be found during the lengthened shipping season. There are a number of Corridors through Bathurst Inlet for vessels navigating through Melville Sound towards a number of resource extraction sites and to the community of Bathurst Inlet, all which overlap with important areas for marine mammal and fish. Fish are widely dispersed across the Kitikmeot region and often overlap with the Corridors. The high level of overlap between these important areas and Corridors reiterates the need for policymakers to develop shipping legislation to mitigate the impacts of vessel noise on marine mammals and fish.

3.7.2 Likelihood of vessels causing behavioural disturbance

This study found that vessels transiting the Corridors have the potential to cause behavioural disturbance in marine mammals and fish from vessel noise. Additionally, vessels with higher source levels (louder vessels) will affect larger areas in comparison to vessels with lower source levels (quieter vessels). In this case, tanker ships have the highest likelihood of causing behavioural disturbance in marine mammals and fish and pleasure crafts have the smallest likelihood.

Vessels transiting the Corridors have a higher or lower likelihood of causing behavioural disturbance depending on the seasonal presence of marine mammals and fish. Overall, our results indicate that vessels transiting the Corridors in Ukiaqsaaq have the highest likelihood of vessel noise impacting marine mammals and fish, and vessels transiting the Corridors in Ukiaq have the lowest likelihood of vessel noise impacting these species. However, vessels transiting the Corridors in areas including Bathurst Inlet and Gulf of Boothia have a high likelihood of causing behavioural disturbance during the full shipping season because multiple species reside in these areas during Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq. It is also important to highlight Upingaaq, which begins in the shoulder month of June of the shipping season, as the likelihood of vessels causing behavioural disturbance in Upingaaq are higher than in Aujaq and Ukiuq.

This implies that many marine mammals and fish species are present in the Kitikmeot region during the shoulder month of June.

It is important to note that as sea ice continues to decline, species ranges may change, and the seasonal presence of species may extend. Therefore, while Ukiaq is currently the season with the lowest likelihood of vessel noise disturbing wildlife, this could change if species begin to extend their seasonal presence in the Kitikmeot region.

3.7.3 Management and Mitigation Measures

The high degree of congruence between the Corridors and important marine mammal and fish areas along with the results that vessel noise in the Corridors can cause behavioural disturbance in these species gives strong indication that vessel management plans and mitigation measures are needed for vessels transiting the Kitikmeot. In particular, guidelines for vessels transiting the Corridors should be developed to reduce the impact of vessel noise on marine mammals and fish. In the Kitikmeot region, guidelines should be focused on areas important to marine mammals and fish, including Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, Larsen Sound, and Bathurst Inlet.

McWhinnie et al. (2018) evaluated management tools for vessels that are in line with MPA management schemes, and separated these tools into four categories: Spatial, Vessel based, Monitoring, and Outreach. Spatial management tools included mandatory exclusion zones, restricted access, voluntary exclusion zones, and vessel re-routing. Vessel based tools included pilotage, code of conduct, reporting, and speed reductions. Monitoring included acoustic monitoring of marine mammals and vessel source levels, visual monitoring of marine mammals, and spatial monitoring of vessels using AIS. Outreach tools included training and information provided for pilots and captains, industry and stakeholders, and the general public related to the impacts of vessels on marine mammals and how to mitigate these impacts. McWhinnie et al. (2018) recommended that at least one tool from each of the four categories should be implemented in conjunction with one another to effectively establish a management scheme for vessels transiting the Arctic. Notably, they found that implementing speed restrictions for vessel traffic would be a practical management tool for wide-spread application across the Arctic, and can also reduce noise emitted from vessels, as propeller cavitation is reduced when vessels slow down (McWhinnie, Halliday, Insley, Hillard, & Canessa, 2018). Therefore, implementing speed restrictions for vessels transiting the Corridors through important areas for marine mammal and fish in the Kitikmeot region could reduce the potential for vessel noise to disrupt these species.

In 2014, the IMO adopted guidelines for the reduction of underwater noise (International Maritime Organization, 2014). These guidelines include design considerations, onboard machinery considerations, additional technology, and operational and maintenance considerations for reducing underwater noise (International Maritime Organization, 2014). The design of the ship poses the greatest opportunity for reducing underwater noise, especially the design of propellers (the dominant source of underwater noise in vessels), which can be designed to reduce cavitation (International Maritime Organization, 2014; World Wildlife Fund, 2017). A homogeneous structural design of the hull can also decrease cavitation (International Maritime Organization, 2014). Installing vibration control measures to onboard machinery can also reduce underwater radiated noise, including insulating the ship engine and using resilient mountains for onboard machinery (International Maritime Organization, 2014). There are also additional technologies that can be installed on existing ships to reduce noise, including new propellers, wake conditioning devices, and air injection into propellers (International Maritime Organization, 2014). Noise from existing and new vessels can be reduced through operational and maintenance considerations, including propeller cleaning to help reduce propeller cavitation, maintaining a smooth underwater hull surface to reduce the vessels resistance, reducing vessel speed, and rerouting vessels to avoid sensitive marine areas (International Maritime Organization, 2014). These are guidelines that should be considered for vessels transiting the Corridors in the Kitikmeot. In addition to the guidelines adopted by the IMO, vessels transiting the Corridors should also be equipped with marine mammal and fish observers, so they can reroute and/or reduce speed.

3.7.4 Challenges

A challenge of this study in terms of approach is the equation used in the methods section does not take into account certain factors that can add to, or change, the Arctic soundscape, including the presence of sea ice (ice cracking), wind and wave noise, and salinity. In addition, this study does not take into account bathymetric data, and only considers the noise from one vessel; however, noise levels can very significantly depending on the number of ships present. Also, the equation in this study does not take into account the different size, weight and speed that vessels are travelling at, which can influence the vessel source level. Furthermore, the equation does not take into account the noise produced from vessel during different shipping activities, including icebreaking, which can generate higher and more variable noise levels from an icebreaker backing up and ramming into ice (World Wildlife Fund, 2017). These data are important considerations and because they were not included in the study, this study does not provide specific recommendations on where ships should navigate in the Kitikmeot region. Further research is required in order to make such recommendations.

3.8 Conclusions

This study demonstrates how GIS can be used to spatially and temporally display areas where vessel noise has the potential to disturb marine mammals and fish in the Kitikmeot region of Nunavut. Also, the importance of using both Traditional Knowledge and western science to gain insights on where marine wildlife can be found and when is highlighted in this study. Based on historic ship tracks through the study region from NORDREG data during the period of 1990-2015, this study was able to identify which vessel types have transited the Kitikmeot and when. These two sets of spatial and temporal data (i.e. for marine mammals and fish and for vessels) allowed for the identification of the areas within the Corridors where a vessel would have the highest potential of causing behavioural disturbance in marine mammals and fish, including Corridors through the Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet. It is important to consider that vessels with higher source levels (louder vessels) will affect larger areas in comparison to vessels with lower source levels (quieter vessels). Additionally, the current shipping season overlaps with the period of time where marine mammals and fish are present in the Kitikmeot region – especially during the season of Ukiaqsaaq.

The maps of behavioural disturbance in marine mammals and fish produced in this study can act as a tool to help answer important policy questions regarding the impacts of different vessel types transiting the Corridors in the Kitikmeot region of Nunavut. These can be used to determine which sections of the Corridors overlap with important marine mammal and fish areas, and subsequent guidelines or legislation can be put in place to reduce the impacts vessels may have when transiting through these areas. For instance, implementing speed restrictions for vessels in important areas for marine mammals and fish.

Chapter 4: Conclusion

As shipping trends in the Kitikmeot region of Nunavut continue to increase, it is becoming especially important to consider the ecological impacts that vessels could have, including the potential for vessel noise to disturb marine mammals and fish. The current location of the Corridors overlaps with a number of important areas for marine mammals and fish, and results from Chapter 3 indicate that vessels transiting the Corridors have the potential to cause behavioural disturbance in these marine species, especially through the Gulf of Boothia, Franklin Strait, Rae Strait, Rasmussen Basin, and Bathurst Inlet. Furthermore, the current shipping season in the Kitikmeot region overlaps with the presence of many marine mammals that are seasonal residence of the region, including beluga whales, narwhals and bowhead whales, especially during the season of Ukiaqsaaq.

Importantly, vessels with higher source levels, or louder vessels (i.e. Tanker ships), have a higher potential to disturb marine mammals and fish in comparison to vessels with lower source levels, or quieter vessels (i.e. pleasure crafts). In the 90's and early 2000's, the Kitikmeot region mainly saw government vessels and icebreakers, tugs and barges, and a limited amount of passenger ships. Furthermore, ship traffic was concentrated mainly through Union and Dolphin Strait, and into Coronation Gulf. Ten to fifteen years later, government vessels and icebreakers and tugs and barges are still present, but the variety of vessel types in the Kitikmeot region has increased, with many more pleasure crafts, general cargo ships, passenger ships, and tanker ships. Moreover, ship traffic now extends throughout the entire Northwest Passage in the Kitikmeot region. These changes in shipping trends are important because vessel types with higher noise source levels (i.e. tanker ships, government vessels and icebreakers, and general cargo ships) are now navigating through important areas for marine mammals and fish, whereas in the 90's and early 2000's, these areas experienced very little ship traffic.

In addition to vessel noise pollution, there are other impacts of increased shipping in the Arctic that need to be considered, as discussed in Chapter 2, such as the impacts associated with icebreaking operations, ship strikes, accidental and regular discharges, invasive species, and light disturbance. For example, despite the fact that pleasure crafts and passenger ships have relatively low vessel broadband source levels, these vessels are used for exploration tourism (Dawson, Copland, Mussells, & Carter, 2017) and will navigate through areas known to have high concentrations of wildlife. These tourism vessels mainly navigated more southerly waters in the past but recently have been concentrated through the Northwest Passage. Another example is the serious threat that accidental discharges of oil or toxic chemicals pose to the Arctic marine environment (Arctic Council, 2009; Hodgson, Russel, & Megganety, 2013; Huntington, et al., 2015; Reeves, Rosa, George, Sheffield, & Moore, 2012). Oil spills can be detrimental to marine species, especially in important areas of high aggregation (Arctic Council, 2009; Huntington, et al., 2015). A last example is the potential for invasive species to impact the Arctic environment, which will become especially important as climate change continues and results in more suitable habitats for invasive species to survive in the Arctic (Goldsmit, et al., 2018).

The potential impacts of shipping in the Arctic are clear indicators of the need for policy and management tools and the implementation of mitigation measures for ships transiting the Corridors in the Kitikmeot region – especially during this time of rapid change in shipping trends. Moreover, it is crucial that further development of the Corridors initiative fully considers important areas for marine wildlife to ensure the potential impacts from vessels are reduced. McWhinnie et al. (2018) conducted a comprehensive review of management tools for vessels navigating through MPAs in the Beaufort Sea to mitigate negative impacts on important species, such as bowhead and beluga whales. The management tools identified, including Spatial, Vessel Specific, Monitoring, and Outreach tools, could be implemented in other regions of the Arctic, such as the Kitikmeot region (McWhinnie, Halliday, Insley, Hillard, & Canessa, 2018). They concluded that implementing at least one management tool from each of the four categories in conjunction with another will result in the most effective management schemes for vessels (McWhinnie, Halliday, Insley, Hillard, & Canessa, 2018). They also found that voluntary management options had fast and successful uptake in the Arctic – especially if local people were engaged in the process from the start (McWhinnie, Halliday, Insley, Hillard, & Canessa, 2018). In the Kitikmeot region, a management plan should be developed specific to the region for vessels transiting the Corridors using the management tools identified by McWhinnie et al. (2018). The goal of this management plan should be to reduce the potential impacts of shipping on important areas for marine mammals and fish.

4.1 Study Contributions

The development of management plans and the implementation of mitigation measures for vessels are important steps to reducing the potential impacts of increased shipping in the Kitikmeot region of Nunavut. The maps developed in Chapter 3 of this thesis can be used as a spatial and temporal tool to inform decision makers on the locations where different vessel types can cause behavioural disturbance in marine mammals and fish and during which season in the Kitikmeot region. Stakeholders such as Transport Canada can take into account these disturbance areas when further developing Arctic shipping policies like shipping safety control zones. Furthermore, Fisheries and Oceans Canada can use this tool to assist with the development of MPAs in the Canadian Arctic. Additionally, this research contributes to frameworks like the Polar Code, which requires that measures be taken by vessels when marine mammals are encountered in areas of high congregation or seasonal migration areas, but does not indicate where these areas are, when marine mammals are present, or what ships should do if they encounter these species (International Maritime Organization, 2016). Therefore, the spatial and temporal information regarding marine mammals and fish in this study contributes to this requirement in the Polar Code. Importantly, this research will contribute to the Corridors initiative by providing spatial and temporal information on marine mammals and fish in the Kitikmeot region, and on areas of potential behavioural disturbance for marine mammals and fish from vessel noise. Implementation measures discussed in Chapter 3, such as speed reductions and vessel rerouting, can then be implemented in areas with high potential for behavioural disturbance in marine mammals and fish. Moreover, this research contributes to the AMSA recommendations to identify areas of heightened ecological significance and implement measures to protect these areas, and further assess the effects on marine mammals due to ship noise in Arctic waters.

4.2 Limitations and Uncertainty

There are limitations to this study in addition to the challenges to the methods discussed in section 3.7.4. First, one limitation was completing an exhaustive review of spatial and temporal marine mammal and fish datasets in the Kitikmeot region, as little date of this nature exists, or is publicly available. While the data used in this study is not exhaustive, it is comprehensive and provides a snapshot of marine mammals and fish present and during which season in the Kitikmeot region. Additionally, it is important to note that several of the marine mammals and fish spatial and temporal datasets were collected manually through participatory mapping workshops and were then digitized using ArcGIS (see Carter, Dawson and Joyce, et al., 2017b, Carter, Dawson and Knopp, et al. 2018, Nunavut Planning Commission 2014a, Nunavut Planning Commission 2014b, Nunavut Planning Commission 2014c, Nunavut Planning Commission 2014d). Therefore, the spatial uncertainty that exists when digitizing maps that were drawn manually into feature layers must be considered. The total location uncertainty (δ) of a digitized map was calculated for the basemaps used in the studies mentioned above using an error propagation formula (Table 11). This formula assumed a 1 mm width marker was used when features were drawn on the basemaps.

$$Base\ scale\ \delta = 0.5\ mm\ \times Scale\ denominator$$

$$Digitial\ \delta = 0.5 \times Base\ scale\ denominator$$

$$Total\ \delta = \sqrt{base\ scale\ error^2} + digital\ error^2$$

Table 11. Total location uncertainty for digital maps used in this study.

Source	Scale of Basemap	Total Uncertainty (m)
NPC 2014a, 2014b, 2014c, 2014d basemap	1:1000000	707
Carter, Dawson and Joyce, et al. 2017b basemap	1:500000	354
Carter, Dawson and Knopp, et al. 2018 basemap	1:250000	177

Moreover, there is a presumption of placement validity when using the method of participatory mapping, meaning that there is no specific evidence to indicate that a manually drawn area isn't an important area for marine mammals and fish. Another issue with using data from participatory mapping workshops in this study is that only select people from a community with knowledge of wildlife areas were chosen to sample. Therefore, data recorded from participatory mapping workshops only include areas where these participants travel; however, there are areas in the Kitikmeot region, such as in northern M'Clintock Channel, that participants don't travel as often. Therefore, there may be important areas to marine mammals and fish that are not recorded in these participatory mapping workshops.

With respect to the vessel data used in this study, vessel types were noted from the NORDREG dataset of vessels transiting the region from 1990-2015. Therefore, this historic record provides evidence on what vessel types have previously transited the Kitikmeot region and when but may not be representative of vessel types transiting the region in the future. Additionally, the vessel source levels used in this study were not estimated based on acoustic data from the Kitikmeot region, and therefore may not be representative of vessel noise in the study region. However, source levels for tanker ships and government vessels and icebreakers were based on acoustic data from the Beaufort Sea (Halliday, Insley, Hilliard, de Jong, & Pine, 2017) and were found to be similar but slightly more conservative than source levels estimated by Veirs, Veirs and Wood (2016).

4.3 Future Research Needs

This study established that a geospatial approach coupled with Fuzzy Logic can be used to map behavioural disturbance potential in marine mammals and fish based on broadband source levels from different vessel types. Future research should focus on monitoring, tracking and observing marine mammals and fish in the Kitikmeot region of Nunavut using both western science and Traditional Knowledge. This will provide a comprehensive understanding of important areas for marine mammals and fish, migratory routes, and temporal data on when species are present in the Kitikmeot region. Future research should also focus on recording acoustic data in the Kitikmeot region to better estimate the broadband source levels of different vessel types transiting the Corridors. This data will be especially important as the navigation season lengthens and a variety of vessel types begin to transit through the Kitikmeot region. Spatial and temporal data on marine wildlife and vessels transiting the Kitikmeot should then be used in future research to model the behavioural disturbance potential caused by vessels in other marine areas of the Canadian Arctic outside of the Kitikmeot region.

It is important to collect spatial and temporal data on marine wildlife and vessels through the Kitikmeot so that decision-makers can make informed and evidence-based decisions in terms of the management of shipping activities, and the mitigation measure that need to be put in place to reduce the impacts of shipping. Future analysis should focus on identifying effective mitigation measures for reducing the impacts of shipping on marine mammals and fish and developing a management plan specific to the Kitikmeot region for vessels transiting the Corridors. This management plan should use tools identified in the study by McWhinnie et al. (2018) as a starting point. Future work should aim to provide outreach for decision-makers, stakeholders, and the general public on the impacts shipping activities can have, not only on marine wildlife, but on the Arctic as a whole.

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Appendix

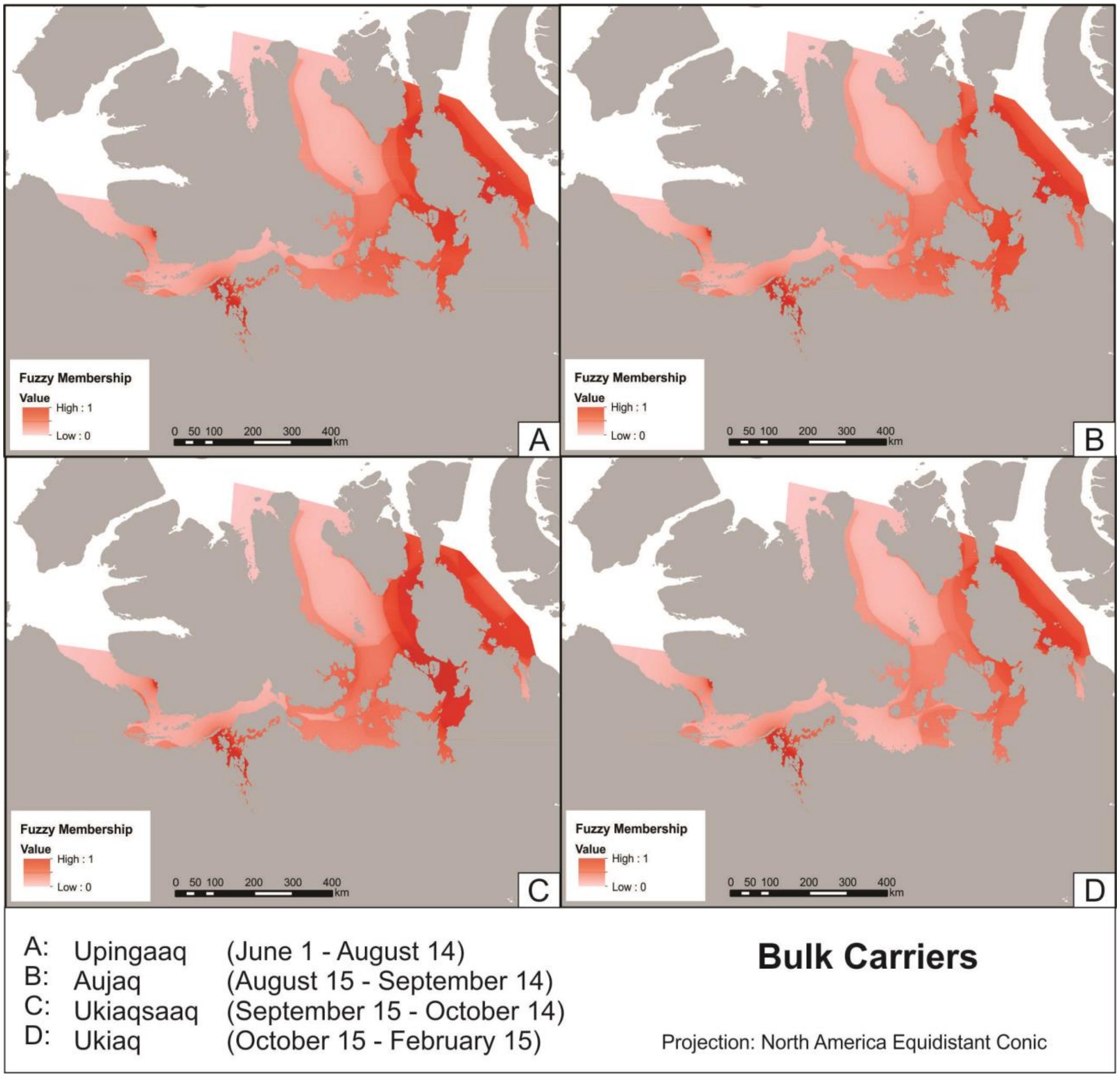

Figure 20. Areas of potential behavioural disturbance to marine mammals and fish from bulk carrier vessel noise (source level = 173 ± 5 dB re 1 µPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

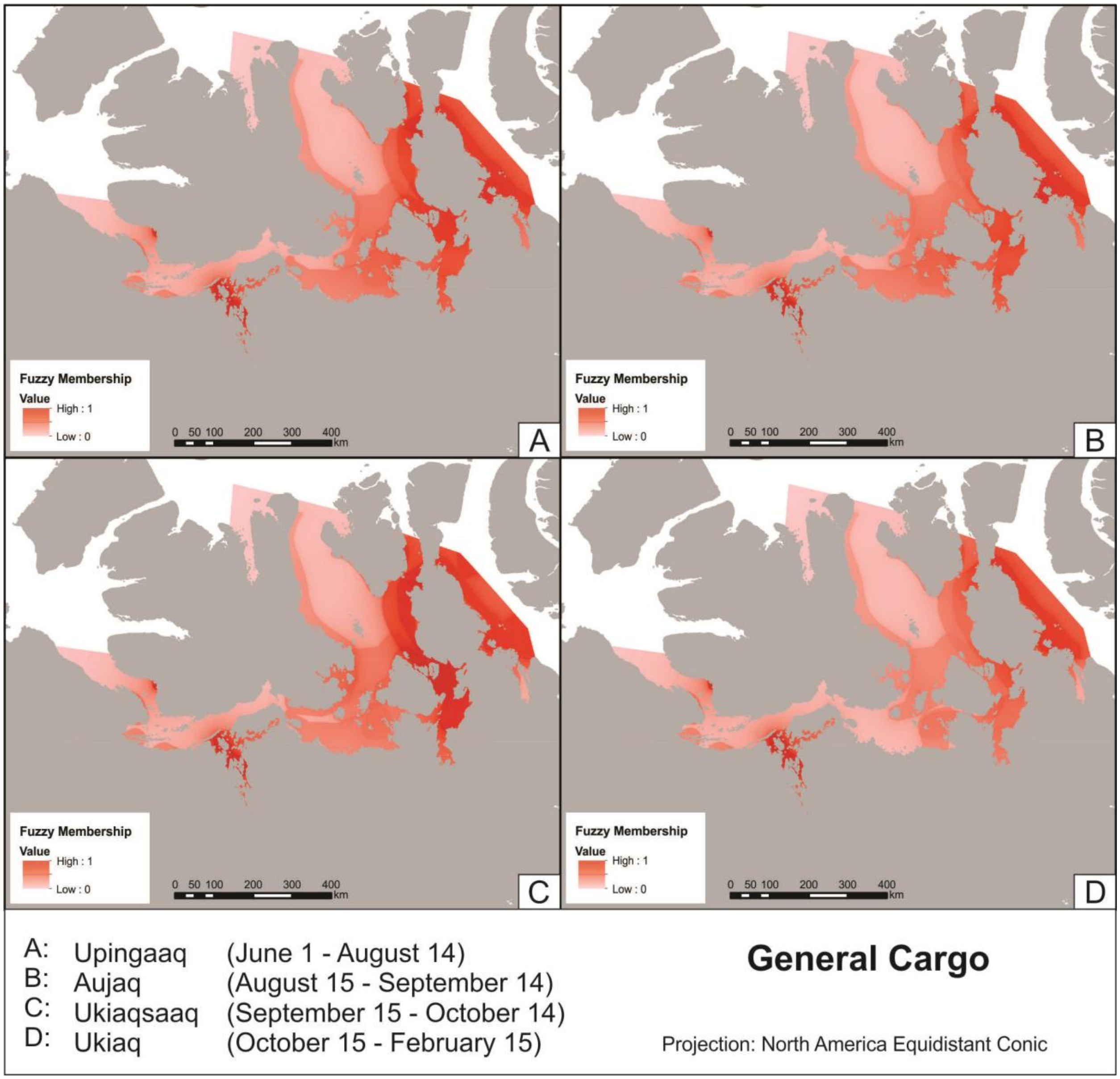

Figure 21. Areas of potential behavioural disturbance to marine mammals and fish from general cargo vessel noise (source level = 175 ± 5 dB re 1 μPa @ 1 m) for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.

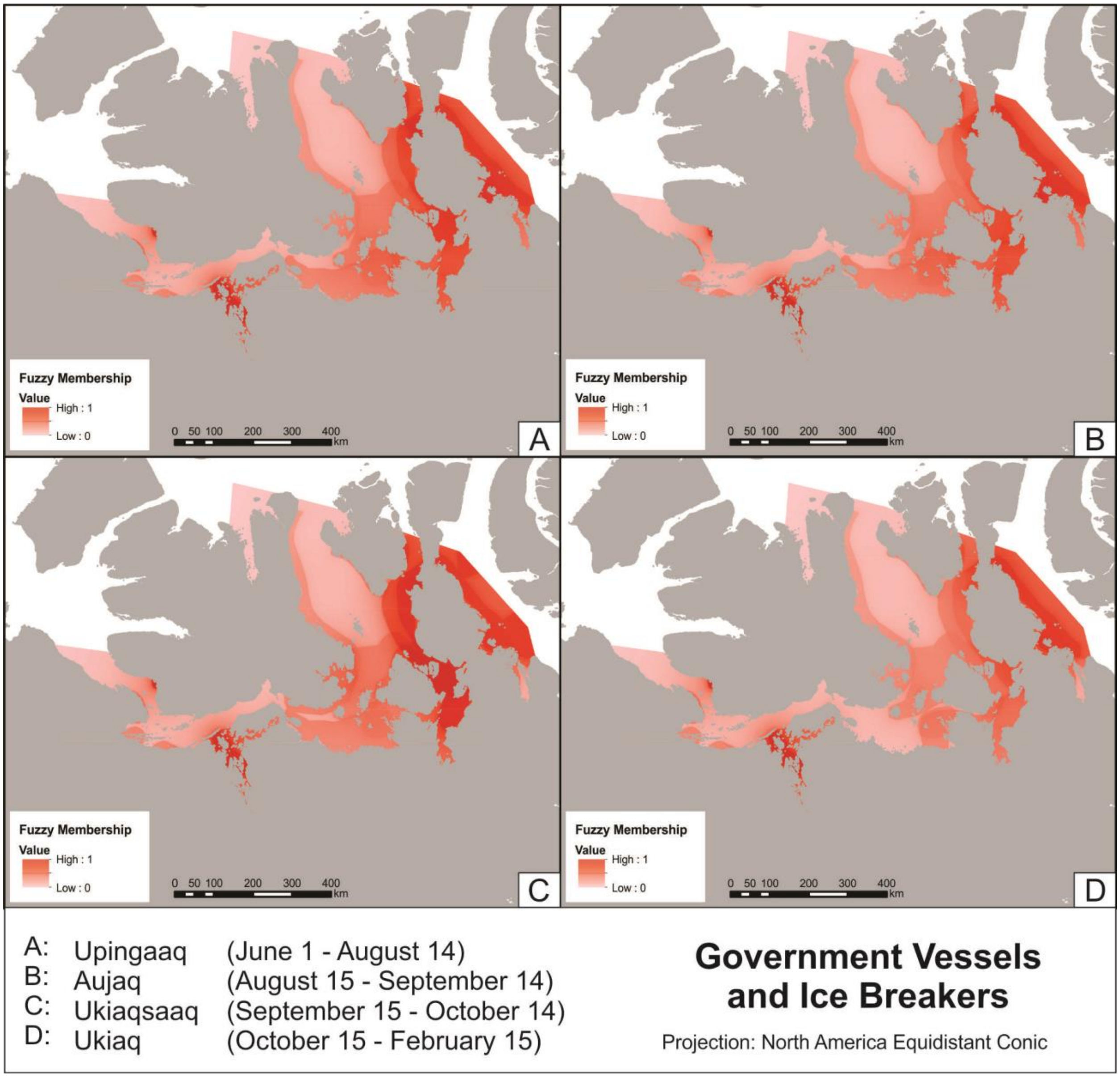

Figure 22. Areas of potential behavioural disturbance to marine mammals and fish from government vessel and icebreaker noise (source level = 176 dB re 1 µPa @ 1 m) while transiting through open water for the seasons of Upingaaq, Aujaq, Ukiaqsaaq and Ukiaq in the Kitikmeot region, Nunavut.