Potential impacts of sea ice and ship traffic change to caribou sea ice crossing areas surrounding King William Island, Nunavut, Canada

by

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Abstract

Caribou (*Rangifer tarandus,* tuktuit in Inuktitut) use sea ice to facilitate movements that fulfill their ecological needs. Ship traffic is growing in the Kitikmeot region of Nunavut, and ice-strengthened ships can disrupt sea ice by breaking it apart. This project explored priorities identified by community members in Uqsuqtuuq (Gjoa Haven, NU) concerning changes in sea ice and ship traffic in caribou crossing areas surrounding King William Island. Using Canadian Ice Service ice charts and Canadian Coast Guard ship traffic data, the timing of freeze-up, break-up and ship transit was assessed for five caribou crossing areas. Preliminary results were discussed in workshops in Uqsuqtuuq in September 2018, and Inuit knowledge guided methods and analyses in this thesis. Despite a large interannual variability in sea ice conditions, the timing of ship movement was independent of local conditions. In the future, longer open water seasons and shifting freeze-up and break-up timing may intensify interactions between sea ice and ship transit creating challenges for caribou movement.

Acknowledgements

This project was accomplished thanks to the time, effort and expertise of many people, and groups. The thesis aimed to emphasize the importance of collaboration amongst researchers and Inuit community members, and I would like to acknowledge all of the effort and contributions from all involved.

I would first like to thank Simon Okpakok for his role in organizing, facilitating, and interpreting workshops held in Uqsuqtuuq in September 2018. His involvement enabled us to learn from Uqsuqtuurmiut (people of Uqsuqtuuq) knowledge and prioritize this knowledge whenever possible in our methods and analyses. I wish to thank the Uqsuqtuurmiut who contributed in community workshops, and who shared their knowledge and experience with sea ice and caribou around King William Island (KWI), including: Miriam Aglukkaq, Peter Akkikungnaq, Mary Aqilriaq, Saul Aqslaluq, Willie Aquptanguk, Simon Hiqniq Sr., Alissa Kammemalik, Paul Kammemalik, Jacob Keanik, Betty Kogvik, Sammy Kogvik, Simon Komangat, George Konana, Susie Konana, Ben Putuguq, Uriash Puqiqnak, Wayne Puqiqnak, David Siksik, Tommy Tavalok, Jimmy Qirqqut, Ruth Qirqqut, Salomie Qitsualik, and Adam Ukuqtunnuaq. I would also like to thank Shelly Elverum and Sarah Rosengard for allowing us to participate in their Ikaarvik: Barriers to Bridges meeting with Uqsuqtuurmiut youth researchers Gibson Porter and Nicole Kununaq.

I would like to thank Jackie Dawson and Melissa Weber, from the University of Ottawa, for sharing Canadian Coast Guard ship traffic data from their shipping database (reference additional specific source if possible) along with their expertise related to ship traffic in the Canadian Arctic Archipelago (CAA). This data enabled the exploration of the potential impact of ships on sea ice within caribou crossing areas around King William Island (KWI).

I am very appreciative of the funding and guidance provided by Environment and Climate Change Canada (ECCC). My co-supervisor Cheryl Johnson of Landscape Science and Technology in ECCC financially supported our 2018 trip to Uqsuqtuuq and assisted the facilitation of workshops alongside ECCC colleague Erin Neave. Cheryl's backing and expertise allowed us to explore caribou sea ice habitat guided by Inuit knowledge of sea ice conditions and relations with caribou. I would also like to thank Benoit Monpetit, also with ECCC, who provided an example of a Python code to analyze Canadian Ice Service regional ice charts. He provided vital guidance as I was adapting the code to suit project specifications.

Thank you to organizations who supported this project through various means. Thank you to the organizations within Uqsuqtuuq for the space and time they shared with us that enabled workshops in the community, including: the Nattilik Heritage Centre, Kitikmeot Inuit Association, Hamlet of Gjoa Haven, Gjoa Haven Hunters and Trappers Association, and Ikaarvik: Barriers to Bridges. I would like to thank those who provided financial support to this project that was vital for the execution of community workshops, including: the Ontario Ministry of Research and Innovation, the Northern Scientific Training Program, and ECCC.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

CAA	Canadian Arctic Archipelago
CIS	Canadian Ice Service
DU	Designated Units
ECCC	Environmental and Climate Change Canada
GN	Government of Nunavut
KWI	King William Island
NORDREG	Northern Canada Vessel Traffic Services Zone
NWP	Northwest Passage

Appendix List

Chapter 1: Introduction

Caribou (tuktuit in Inuktitut) are typically considered land mammals, but Peary caribou (*Rangifer tarandus pearyi*) are multi-island dwelling species in the Canadian Arctic Archipelago (CAA). In addition, Dolphin-Union (inconsistent scientific names in literature) and some Barren-ground (*Rangifer tarandus groenlandicus*) caribou move between the northern mainland and the southern islands of the CAA (Thorpe 2001; Miller et al. 2004; Ljubicic et al. 2018a; 2018b; Dumond et al. 2013). Seasonal sea ice connects the islands of the CAA, and caribou use the sea ice as a platform to cross between islands, and between islands and the mainland. Therefore, sea ice is part of caribou habitat in the High Arctic, facilitating the movement and behaviour that fulfills their reproductive requirements (Dumond et al. 2013; Miller et al 2014). Caribou primarily move across sea ice just prior to break-up, and just following freeze-up; therefore, the timing and conditions of sea ice during these seasonal transitions are important factors affecting caribou movement (Dumond et al. 2013; Ljubicic et al. 2018a). Climate change and human disturbance of the sea ice during seasonal movements could pose significant challenges for caribou when crossing through their sea ice habitat (Thorpe 2001; Miller et al. 2004; Poole et al. 2010; Dumond et al. 2013; Mallory and Boyce 2017).

Barren-ground and Peary caribou are important species for Inuit communities in terms of cultural practices, and dietary subsistence (Thorpe 2001; Hummell and Ray 2008; Johnson et al. 2016; Ljubicic et al 2018a). Climatic changes that impact the timing, extent, stability and thickness of sea ice also affects the safety of Inuit who use the sea ice for travel and hunting. Sea ice is a shared space, and changes to this space greatly impact the capacity of Inuit and caribou to use sea ice to meet their needs. While the impacts of sea ice change have mainly been documented in Inuit communities in relation to travel safety, marine mammal hunting, and physical and mental well-being (Aporta 2002; Nickels et al. 2005; Gearhead et al. 2006; Laidler et al. 2008; Laidler and Ikummaq 2008; Consolo-Willox et al. 2013; Durkalec et al. 2015) the importance of sea ice in relation to caribou habitat and hunting has received little attention.

Growing ship traffic in the CAA also poses risks to the use of sea ice by both Inuit and caribou. The movement of ice-strengthened ships can disrupt sea ice habitat by breaking apart or deforming sea ice, making it dangerous for caribou and people to cross the sea ice (Dumond et al. 2013; Carter et al. 2017; Dawson et al. 2020). Therefore, understanding the interplay between sea ice and ship traffic within the CAA is needed to assess potential impacts of these factors on caribou within their dynamic sea ice habitat.

This research project was motivated by community priorities in Uqsuqtuuq (Gjoa Haven, Nunavut), whose concerns for the space they share with caribou is intimately tied with cultural and subsistence practices facilitated by sea ice. Uqsuqtuuq is located on King William Island (KWI; Qikiqtaq in Inuktitut) in the Kitikmeot Region of Nunavut (Figure 1.1). Caribou and connections to community well-being were identified by Uqsuqtuurmiut (people of Uqsuqtuuq) as a local research priority through a previous project led by Dr. Gita Ljubicic and Elder Simon Okpakok (Laidler and Grimwood 2010; Ljubicic et al., 2016; 2018a) which ran from 2010 to 2016. Through this work, Uqsuqtuurmiut identified five important crossing areas that caribou use to move on and off of KWI. In follow-up discussions with Okpakok and the Gjoa Haven Hunters and Trappers Association, there was interest in building on the previous project to investigate the potential impacts of changing sea ice conditions and growing ship traffic on caribou sea ice crossing areas.

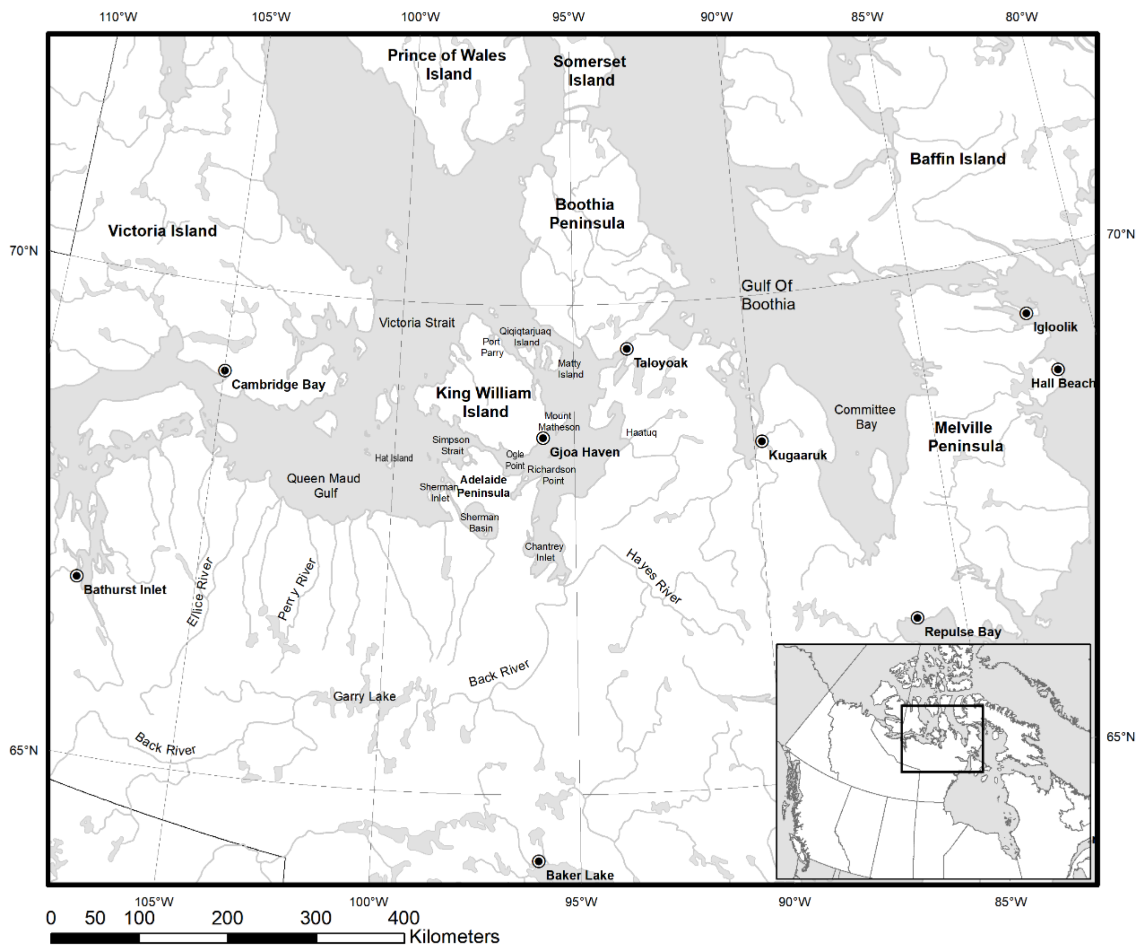

Figure 1.1 - Map showing King William Island, Gjoa Haven (Uqsuqtuuq), and key places referenced in the region

The broad question driving this research is: “What are the potential impacts of sea ice and ship traffic change to caribou crossing areas surrounding KWI?” To address this question, I explored the type of sea ice conditions around the island during the key transitional periods of freeze-up and break-up in the five caribou crossing areas according to Uqsuqtuurmiut knowledge and Canadian Ice Service data. I then investigated the timing and distance travelled by ships, according to Canadian Coast Guard shipping data, in these crossing areas over time to understand whether ships impact sea ice freeze-up and break-up conditions. Finally, I explored the potential of these combined factors on caribou habitat in each crossing area to estimate their relative importance for caribou use of sea ice. The following questions structured the analysis undertaken for each of the components contributing to the broader question:

1. What is the timing and prevailing sea ice stage at freeze-up and break-up in each caribou crossing area, and how have these conditions changed over time?
2. How does each caribou crossing area meet conditions of caribou sea ice habitat?
3. What is the timing and location of ship movement surrounding KWI?
4. How might dynamic sea ice conditions and changes in ship traffic impact the use of sea ice by caribou?

These questions frame the investigation of changes in the Arctic marine environment in a way that addresses the concerns identified by Uqsuqtuurmiut about caribou sea ice crossings, and prioritizes Inuit knowledge in the production and interpretation of results. My approach to my Master's research acknowledges the complexity of relationships between non-Inuit researchers and Uqsuqtuurmiut, and the distinct knowledge systems represented within these relationships. Uqsuqtuurmiut knowledge guides the research questions identified collectively with research partners, and the application of both quantitative and qualitative analyses.

This dissertation is divided into six chapters. The general topic, research questions and objectives of this thesis are described here in Chapter 1. In Chapter 2, important context is provided according to available literature regarding caribou, sea ice and ship traffic in the CAA, as well as previous research in Uqsuqtuuq that led to the evolution of this project. Methods used in the project are described in Chapter 3, subdivided by approach, including: analyses of transcripts from community workshops, Canadian Ice Service sea ice chart data, and shipping data compiled from the Canadian Coast Guard archive for ship movements in the NORDREG zone (Arctic Canada Vessel Traffic Zone occurring north of 60 degrees in latitude in Canada). In Chapter 4, results are presented for all analyses, according to freeze-up, break-up, and open water seasons within each crossing area. Results are then interpreted in Chapter 5, focusing on the interplay of seasonal sea ice conditions, ship traffic, and potential impacts on caribou sea ice habitat in each crossing area. The project is summarized, and the potential significance of the work is considered in Chapter 6.

The narrative developed in this thesis is intended to respond to Inuit-identified concerns, and the desire for the enhanced consideration of Arctic wildlife and shipping management in concert. With this research I seek to address community priorities in Uqsuqtuuq, as well as to contribute to broader priorities identified in the Government of Nunavut (GN) Caribou Strategy (GN 2011). The GN emphasized the need to base decisions on the best available information (both western science and Inuit knowledge), to support the interests of Inuit, and to consider the cumulative effects of both human and natural impacts on caribou health and habitat. This research explores the complexities of putting the GN (2011) guiding principles into practice by investigating the interconnections between caribou, sea ice and ship traffic around KWI according to a combination of community workshops, analysis of sea ice chart data, and analysis of ship transit data. KWI has typically been overlooked in caribou research (Ljubicic et al. 2017), and Uqsuqtuurmiut want their knowledge to inform decisions in their region (Ljubicic et al. 2018a). This work expands on discussions in Uqsuqtuuq about important caribou crossing areas, and indicators of sea ice habitat surrounding KWI, contributing to Uqsuqtuurmiut knowledge-sharing goals within and beyond the community. Outcomes of this research emphasize the importance of sea ice as part of caribou habitat and highlight the potential risks of environmental and anthropogenic change to this habitat.

Chapter 2: Literature Review

Within Inuit Nunangat (Inuit homelands in the Canadian Arctic, including the Inuvialuit Settlement Region, Nunavut, Nunavik, and Nunatsiavut), it is recognized and required through land claim agreements, that Inuit must be included in decision-making in research, development, and management related to their homelands (Nickels et al. 2005; Ford et al 2007; Nichols et al 2014; ITK 2018; Andrew et al 2018). Social and environmental aspects of Inuit homelands cannot be separated, and thus assessments of change and their potential implications for lands and lives cannot be considered or examined without sincere inclusion of Inuit knowledge and well-being (Nickels et al. 2005, Ford et al 2007, ITK 2018). The National Inuit Strategy on Research (NISR) aims to facilitate actions to amplify the impact, relevance and usefulness of research within Inuit Nunangat (ITK, 2018). To achieve this, the NISR advocates for the advancement of Inuit priorities and governance in research, and the enhancement of ethical conduct in research that includes capacity building and responsible data ownership for Inuit involved in research (ITK 2018). Inuit rights are intimately tied to long term land use and occupancy (Aporta 2004; Gearhead et al. 2013; ITK 2018). The land (a general reference which refers to land, water, and ice and all aspects of the environment) continues to be integral to community life today, as it supports: eating and sharing country food, connecting with other communities, accessing hunting and fishing grounds, livelihoods, mental and physical health, and nurturing cultural and spiritual practices (Aporta 2004; Laidler et al. 2009; Krupnik et al. 2010; Gearheard et al. 2013; ICC 2015). Sea ice is an important travel and hunting platform, and also critical habitat for marine mammals (Laidler et al. 2009; Kovacs 2011; Pilfold et al. 2014; Laidre et al. 2015, Huntington et al.

2016). However, sea ice has not often been considered a part of caribou habitat (Poole et al. 2010; Ljubicic et al. 2018a; 2018b). As important context for this thesis, this literature review provides essential background on sea ice as caribou habitat, changing sea ice conditions, and changing ship traffic in the Arctic. The geographic focus of this literature review is the Canadian Arctic Archipelago (CAA) and the northern mainland, in particular the Kitikmeot region of Nunavut. The fourth section provides important regional and community context on Uqsuqtuuq, Nunavut, which is the focus of the remainder of this thesis.

2.1 – Sea ice as caribou habitat

2.1.2 – Arctic sea ice as a shared space for Inuit and caribou

Inuit use sea ice to facilitate travel outside their community for hunting, trapping, fishing, gathering, and/or recreational purposes. Sea ice acts as a seasonally available extension of the land that enables freedom of movement with smoother and shorter travel routes than many overland or open water options (Laidler et al. 2010, Durkalec et al. 2015; ICC, 2015). The ice is also a space that Inuit share with a diversity of Arctic wildlife species, supporting nutritional needs, emotional attachment, and opportunities to practice Inuit culture and language (Consolo-Willox et al. 2013, Durkalec et al. 2015). Because of the importance of sea ice in daily life, changes to ice conditions can impact individual and community well-being if they hinder people's ability to meet their needs (Aporta 2002, Nickels et al. 2005, Laidler et al. 2008, Laidler et al. 2009, Krupnik et al. 2010, Gearheard et al. 2013, Consolo-Willox et al 2013, ICC 2015). The depth of knowledge and experience Inuit have related to sea ice comes from the interconnected relations between people and the environment, and this has been documented in communities across Inuit Nunangat, including: Clyde River, Nunavut (Gearhead et al. 2006; 2013); Igloolik, Nunavut (Aporta 2002, Laidler and Ikummaq 2008, Laidler et al. 2009; 2010; 2011); Pangnirtung, Nunavut (Laidler et al. 2008; 2010; 2011); Kinngait, Nunavut (Laidler and Elee 2006; 2008; Laidler et al. 2010; 2011); Nain, Nunatsiavut (Durkalec et al 2015); Rigolet, Nunatsiavut (Consolo-Willcox et al. 2013); Sachs Harbour, Inuvialuit Settlement Region (Nichols et al. 2004); pan-Inuit Nunangat (Nickels et al. 2005); among others.

Sea ice is considered critical ecological habitat for a variety of Arctic marine mammals and migratory birds (Laidler et al. 2009, Kovacs 2011, Pilfold et al. 2014, Laidre et al. 2015, Huntington et al. 2016), whereby habitat comprises the predominant conditions used by a particular species for nourishment, survival, and reproduction (Franklin et al. 2002). The sea ice seasonally connects the islands of the CAA, and the CAA to the mainland, creating a platform that facilitates movement of caribou as it does for people and other animals. Caribou use sea ice to support their mobility, to complete reproductive cycles, to minimize predation, and to access areas with preferred climatic and vegetation conditions seasonally and/or sporadically (Miller et al. 2004, Poole et al. 2010, GN 2011, Dumond et al. 2013, Johnson et al. 2016). By using sea ice, caribou can effectively expand their range beyond the northern mainland into the CAA, or beyond a single island to multiple islands in the CAA, and thereby increase their adaptive capacity with spontaneous movement in response to changing environmental conditions (Miller et al. 2004, Jenkins et al. 2016). Therefore, sea ice can be considered an important part of Peary, Barren-ground and Dolphin-Union caribou habitat for herds whose ranges include the CAA and the northern mainland.

2.1.2 – Caribou in Nunavut

Caribou sub-species found in Nunavut include Peary (Designatable Unit [DU1]), Barren-ground (DU3) and Dolphin-Union (DU2) caribou, and their ranges extend across the CAA and northern mainland (COSEWIC 2011, GN 2011). Therefore, caribou are present in all three regions of Nunavut, including the Qikiqtani (Baffin), Kivalliq, and Kitikmeot regions, with some herd migrations that include parts of the Northwest Territories and northern Manitoba and Saskatchewan (TG 2008, Kendrick and Manseau 2018, GNWT 2011). These caribou are considered migratory due to their seasonal movements across wide ranges on the mainland, amongst the mainland and near-by islands, and/or amongst islands in the CAA relative to sedentary woodland and boreal caribou (Festa-Bianchet et al 2011). Indigenous knowledge of Barren-ground caribou in the Northwest Territories and Yukon is well recorded with work emphasizing primarily Indigenous (Inuit, First Nations and Metis) knowledge of caribou population health and distribution. Studies emphasized the importance of co-management of caribou population and the co-production of knowledge regarding caribou in Northwest Territories and Yukon (Gunn et al. 2001; Kendrick and Manseau 2008; Parlee et al. 2010; GNWT 2011; Beaulieu 2012; Lyver etal 2013). However, relatively little attention has been paid to caribou in the Kitikmeot region of Nunavut (with the exception of Thorpe et al. 2001, Poole et al. 2010, Dumond and Lee 2012, Dumond et al. 2013).

For biological research and wildlife management purposes, caribou sub-species are further delineated by herds or geographic populations. Caribou herds that may be found within the Kitikmeot region include the Ahiak, Bathurst, Beverly, Bluenose East, Dolphin and Union, Lorillard, Melville Peninsula, Qamanirjuaq, Peary, and Wager Bay herds (Figure 2.1) (GN 2011). Of these, the herds that seem most likely to move to/from King William Island (KWI), include Ahiak, Bathurst, Beverly, Lorillard, Melville and Wager Bay Barren-ground caribou herds that move to or through Adelaide Peninsula and Boothia Peninsula, and Peary caribou to the north or Dolphin-Union caribou to the west (WKSP 2018a,b,c,d; Miller et al. 2004, Miller et al. 2006, Nickels et al. 2005, Dumond et al. 2013, Johnson et al. 2016, Ljubicic et al. 2017). However, KWI has uncertain or unknown status in terms of caribou populations (COSEWIC 2011, GN 2011) and is often overlooked in caribou research (Ljubicic et al. 2017). Though Inuit hunters have reported Peary and Barren-ground-like caribou on KWI (Gunn et al 1981, Miller et al 1991, COSEWIC 2011, Johnson et al. 2016) no telemetry or aerial surveys have been conducted in the area. There is little consensus in the literature about the status – and relevant herds – of caribou on KWI (Carter et al 2017, Ljubicic et al. 2017; 2018b). However, research with Uqsuqtuurmiut over the last decade has shown that caribou are present on KWI year-round and there are up to four types of caribou distinguished locally (Laidler and Grimwood 2010, Ljubicic et al. 2018a).

Uqsuqtuurmiut tend to refer to caribou collectively, in general terms or in reference to specific placenames where caribou can be found (Ljubicic et al. 2018b). However, when they discuss different types of caribou, they use specific Inuktitut terminology rather than biological herd names. Uqsuqtuurmiut distinguish four groups of caribou (tuktuit) on KWI: Kingailaup tuktuit, Iluiliup tuktuit, Qungniit, and a potential hybrid of Kingailaup tuktuit and Iluiliup tuktuit (Ljubicic et al. 2018b) (Figure 2.2). Kingailaup tuktuit are typically translated into English as Peary caribou (*Rangifer tarandus pearyi*), and Illuiliup tukuit are typically translated into English as Barren-ground caribou (*Rangifer tarandus groenlandicus*) and are differentiated by their mainland/inland habitat. *Qungniit* are typically translated into English as North American reindeer, distinguished by their movements, and distinct physical traits (Figure 2.2). It is important to recognize that these names are specific to the cultural and geographical context of Uqsuqtuuq and families from traditional societies who now live in the community, and so local naming conventions do not necessarily directly translate or apply to other community contexts (Ljubicic et al. 2018b).

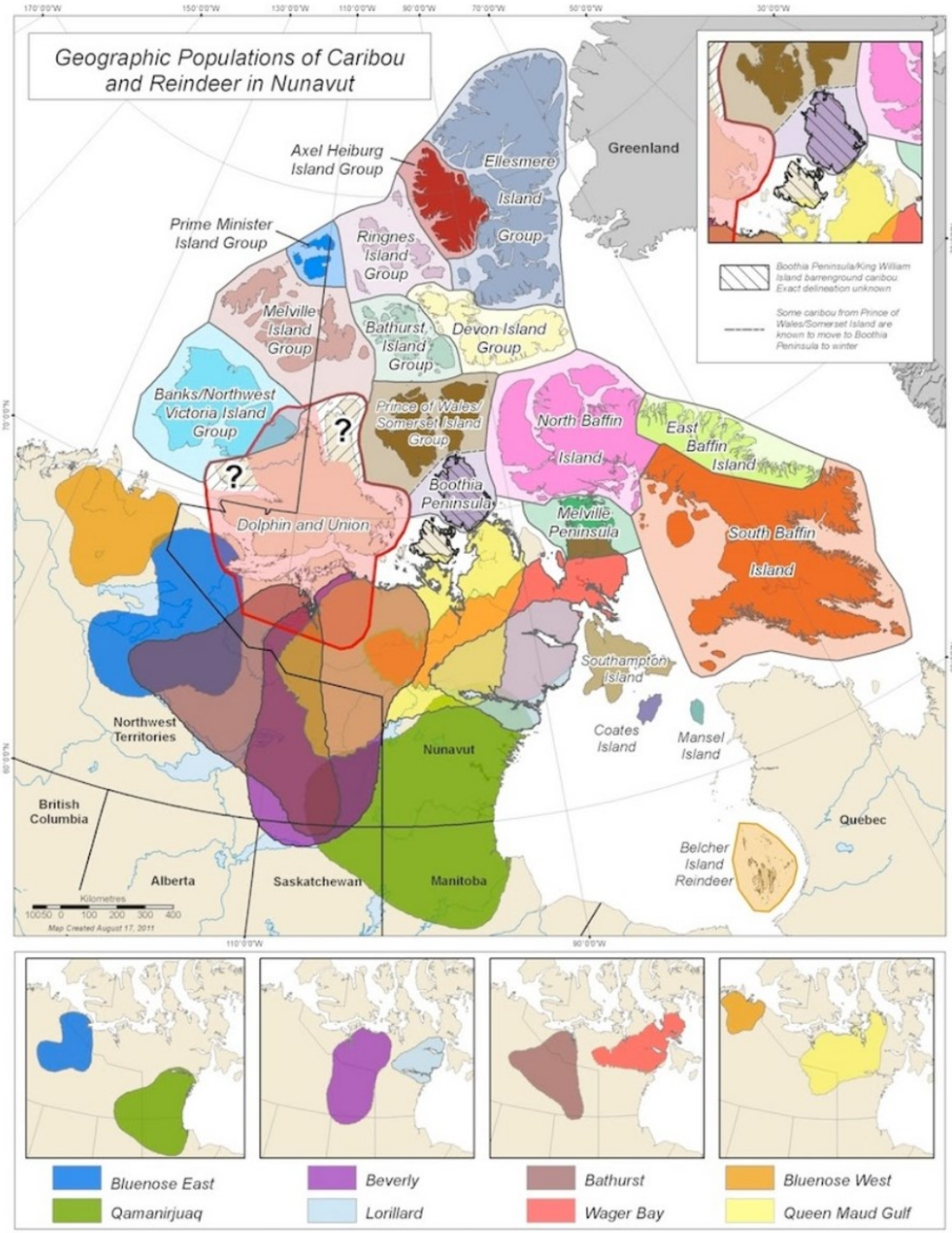

Figure 2.1 - Caribou herd ranges of within Nunavut (GN 2011, p. 6)

Inuktut name	Translated meaning	Source[1]	Closest biological reference	Notes
Tuktuit	General reference to caribou	All	Caribou	There may be slight spelling variations by dialect, but *tuktu* (*tuktuit* in plural) is a general reference to caribou across the Inuktut language.
Iluiliup tuktuit	Inland (mainland) caribou	Uqsuqtuurmiut	Barren-ground caribou	Most Uqsuqtuurmiut do not distinguish between types of *iluiliup tuktuit*.
Kingailaup tuktuit	Island caribou	Uqsuqtuurmiut	Peary caribou	The Inuktitut is a specific reference to Kingailaq (Prince of Wales Island) and is translated locally as Peary caribou, although it may potentially be a reference to Arctic-island caribou given geographic emphasis.
Qungniit	Reindeer	Uqsuqtuurmiut	Reindeer	Reindeer are known to escape reindeer herding operations at times, from around Tuktoyaktuk, Northwest Territories, and are also referred to as Alaskan caribou.
N/A	Mixed caribou (cross-breed)	Uqsuqtuurmiut	N/A	Caribou that are a mixture of *iluiliup tuktuit* and *kingailaup tuktuit* have been observed, but are uncommon and so there is no Inuktitut term.
Ahiarmiut	Mainland caribou	Qitirmiut	Barren-ground caribou	Most Qitirmiut do not distinguish between types of *Ahiarmiut*.
Kiilliniq	Island caribou	Qitirmiut	Dolphin and Union caribou	The Inuinnaqtun name specifically refers to Kiilliniq (Victoria Island), and Inuit consider this to be a mix of Bathurst and Peary caribou.
N/A	Heinz 57 (cross-breed)	Qitirmiut	Ahiak caribou herd	Caribou have been observed that are considered to be a mix of Kiilliniq and Bathurst herds and are associated with the Ahiak herd according to local interpretations, but these are uncommon and so there is no Inuinnaqtun term.

[1] Uqsuqtuurmiut refers to the specific contributors from Uqsuqtuuq who were interviewed as part of our project. Qitirmiut refers to

Figure 2.2 - Uqsuqtuurmiut ways of naming and distinguishing tuktuit (caribou) in the Kitikmeot region of Nunavut (Ljubicic et al. 2018b, p. 317).

Elders and hunters in Uqsuqtuuq describe hunting caribou year-round on KWI, as well as on the nearby the mainland (Laidler and Grimwood 2010, Carter et al. 2017, Ljubicic et al. 2018a). However, caribou have not always been close by. In interviews with Uqsuqtuurmiut, Ljubicic et al. (2018a) documented Inuit knowledge of long-term presence and absence of caribou around KWI (Figure 2.3). Prior to the 1930s caribou were abundant on the island and nearby mainland, during the childhood of today's Elders and early transitions to settlement life (1930s – 1970s) there were no caribou around. Caribou started coming back to KWI in the late 1970s, first Peary (Kingailaup tuktuit) and then Barren-ground (Iluiliuq tuktuit) caribou (Figure 2.3) (Ljubicic et al. 2018a). While some caribou remain on KWI year-round today, most caribou move seasonally on and off the island (Figure 2.4) (Ljubicic et al. 2018a). The most commonly described seasonal migration is of mainland Barren-ground caribou moving northwards in the spring to reach calving grounds on the shores of the Queen Maud Gulf or on KWI, and then moving back south in the fall to wintering grounds inland (Ljubicic et al. 2018a). Caribou movement to/from KWI is facilitated by sea ice, and so the timing of their crossing tends to be before break-up (June/July) and after freeze-up (September) (Figure 2.4) (Ljubicic et al. 2018a).

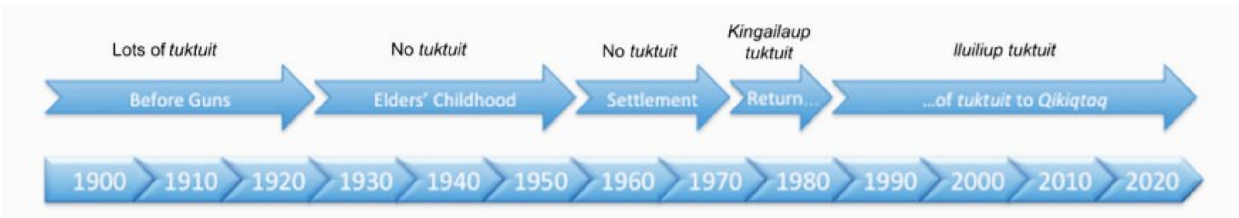

Figure 2.3 - Uqsuqtuurmiut knowledge of long-term presence/absence of caribou (tuktuit) on King William Island (Ljubicic et al. 2018a, p. 219).

2.1.3 - Caribou movements and use of sea ice habitat

Caribou migrate for various reasons, and their motivations for movement are not uniform across populations, seasons, habitats or even individuals. Caribou do not necessarily move across the sea ice in one large group; a few individuals or a small group may travel across the sea ice at different times. Therefore, migration does not represent a single instance in time, but rather an event that can occur over weeks, with variability in defining the beginning and end of the timeframe.

Sightings of Peary caribou on sea ice have been reported in studies since 1974 in the CAA amongst the majority of islands (Figure 2.5) (Johnson et al. 2016). Caribou moving on sea ice were initially observed and described within Prince Patrick and Melville caribou sub-populations (Gunn et al. 1981). Caribou use of sea ice crossing areas are not linear, and the caribou may move in dispersed groups across several kilometers, as was described by Inuit hunters in Resolute Bay and Uqsuqtuuq (Miller et al. 2004, Ljubicic et al. 2018a). Caribou have also been observed swimming across open water between islands (Miller 1995, Dumond et al. 2013). These movements of caribou over sea ice or in open water may be necessary for completion of reproductive cycles or responding to changing resource availability (Dumond et al. 2013).

Figure 2.4 - Uqsuqtuurmiut knowledge of caribou seasonal rounds on King William Island (Ljubicic et al. 2017, p. 221).

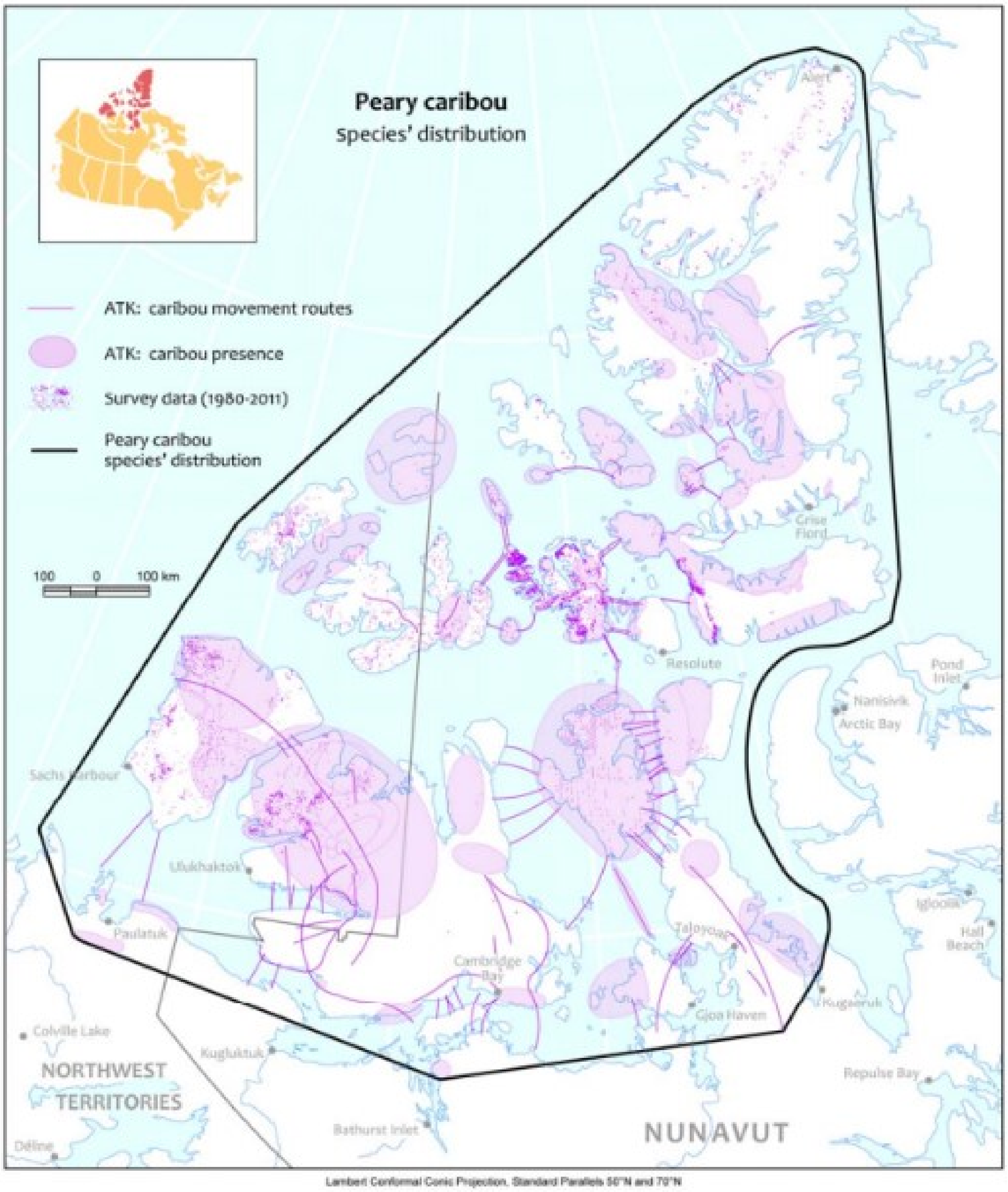

Figure 2.5 - Peary caribou distribution in the CAA and movement routes survey and telemetry data, as well as workshops in Inuvialuit (Ulukhaktok, Sachs Harbour, Paulatuk) and Nunavut (Resolute Bay, Grise Fiord, Taloyoak, Cambridge Bay, Kugaaruk and Gjoa Haven) communities (Johnson et al. 2016, p. 10).

Caribou may rely on collective behaviours to revisit crossing areas used in previous years, meaning that a successful sea ice crossing area can be used year after year

(Nicholson et al. 2015, Klein 2018). Miller et al. (2002) observed female Peary caribou moving between several near-by/adjacent islands during the spring and summer seasons, suggesting that caribou also act as individuals and may choose to cross sea ice repeatedly over a given winter (Miller et al. 2002). This challenges the perception of caribou as single island-dwelling by emphasizing the seasonal movements of caribou on sea ice to one or more near-by islands. Single island-dwelling behaviour is distinct from considerations of sedentary vs migratory caribou. All Peary and Barren-ground caribou are defined as migratory; this is regardless of whether they use sea ice or terrestrial habitats to move across (Miller et al. 2002, Millet et al. 2004, Festa-Bianchet et al. 2011).

There is little information in the literature on collective caribou memory and their recurring use of key sea ice and territorial habitat and associated migratory routes (Miller et al. 2004, Poole et al. 2010, GN 2011, Dumond et al. 2013, Ljubicic et al. 2017, Ljubicic et al. 2018b). Miller et al (2004) found that caribou do not tend to use land features or elevation in selecting sea ice crossing areas, suggesting that Peary caribou rely on other means to assess sea ice quality and for historical recall of previously used crossing areas. Peary caribou add urine and feces to their scent trail, which may be collective and social indicators of caribou moving on the sea ice to signal other caribou that the sea ice is adequate for travel (Miller et al. 2004). Interannual variability in sea ice habitat and caribou crossings are possible, however site fidelity has been observed in Peary caribou (Miller et al. 2004, Nicholson et al. 2005, Dumond et al. 2013). Reliance on collective behaviour and movements may impact the capacity of caribou to adapt to the dynamic sea ice and coastal environments within the CAA (Miller et al. 2004, Nicholson et al. 2005). Environmental changes can impact caribou by motivating caribou to redistribute within or outside of their range. Once a historically used sea ice habitat is no longer suitable for caribou movement, caribou need to reassess their environment and select a new habitat as opposed to relying on their collective memory of the previously used area (Nicholson et al. 2015).

Barren-ground caribou may move into new or historic areas to avoid predators either on the tundra, or south of the tree-line (Nicholson et al. 2015). If caribou were motivated by foraging alone it is unlikely the fall movement on sea ice returning to the wintering range used in the year prior would occur, as this movement uses much of the energy from food-resources obtained within the summer range on the CAA islands (Bergerud 1996). Thus, additional influences, such as avoiding predator abundance, may impact the decision to move across sea ice towards their winter ranges. Inuit in Cambridge Bay described that an increase in predators on Victoria Island may impact year-round ranges of caribou (Dumond and Lee 2012). The lack of insects in the CAA may also motivate Barren-ground caribou to move to the islands during the summer season to avoid potential blood loss and infection (Gunn et al. 1981).

Calving ground fidelity amongst one or more sites between years has been observed in several Barren-ground and Peary caribou herds/sub-species (Miller 1995); including Dolphin-Union (Dumond and Lee 2012; Dumond et al. 2013), Bathurst (Gunn et al. 2008; Taillon et al. 2012), and Somerset/Prince of Wales/Boothia (Gunn et al. 1981; Miller et al. 2004) caribou. Two caribou sub-species have been observed congregating in the coastal areas of the CAA prior to moving onto sea ice or into open water, including: Dolphin-Union caribou between Victoria Island and the mainland (Dumond and Lee

2012; Klein 2018) (Figure 2.6); and, Peary caribou within the Prince of Wales, Somerset island and Boothia Peninsula complex (Miller et al. 2004).

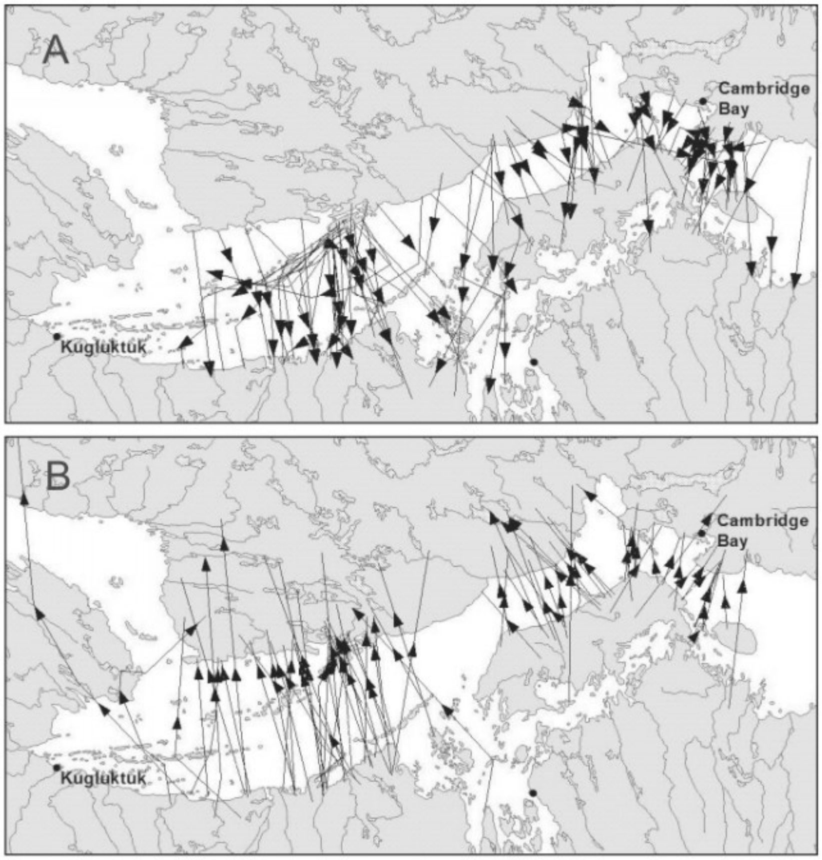

Figure 2.6 - Crossing locations of Dolphin and Union caribou in (A) fall-early winter and (B) late winter-spring between 1987-2006 (Poole et al. 2010, p. 423).

Dolphin-Union caribou demonstrate individual and collective behaviour within 6 seasons; fall–early winter migration, staging, mid-winter, late winter–spring migration, calving, summer (Poole et al. 2010). In the early fall, caribou gather on the southern shore of Victoria Island and begin staging, waiting for adequate conditions for movement south towards mainland wintering habitat (Dumond and Lee 2012; Dumond et al. 2013; Klein 2018) (Figure 2.6). Poole et al. (2010) observed Dolphin-Union caribou concentrating in relatively small areas of Victoria Island, following a period of staging, and prior to crossing towards their winter range on the mainland using the newly formed sea ice (Poole et al. 2010; Dumond and Lee 2012; Klein 2018). These areas have a high concentration of caribou moving across the ice for several days or weeks following sea-ice freeze-up (Poole et al 2010). Thorpe (2001) led a large project highlighting Qitirmiut (people of the Kitikmeot region) knowledge (specifically people of Umingmaktuuk and Kingauk) regarding caribou and their calving grounds in Bathurst Inlet and surrounding areas (including Bathurst and Dolphin-Union caribou). Qitirmiut emphasized the seasonal relationship between Qitirmiut and caribou, focusing on caribou related activities and events that frame Qitirmiut livelihood in each season. Qitirmiut explained seasonal crossings of caribou on sea ice and freshwater ice. These occurred during the fall close to the timing of freeze-up to reach more northern areas or islands, and in the spring around break-up time to move towards the mainland from Victoria Island. Contributors shared with Thorpe (2001) that caribou can swim to make these crossings, but they have also observed caribou drowning when they attempt this.

Similar behaviour of pausing prior to crossing sea ice was observed in caribou within the Prince of Wales, Somerset, and Boothia complex. Peary caribou move off the islands/peninsula towards the mainland as ice forms in Oct-Nov, returning to the complex during in May-June (Miller et al 2004). Miller et al. (2004) observed caribou moving as much as 109 km on continuous sea ice. In the late summer of 1993, Miller (1995) observed 19 caribou swimming between south-central Queen Elizabeth islands, suggesting that caribou can swim across narrow (>10 km) straits. Similar behaviour has also been observed in Barren-ground caribou of the Rivière-aux-Feuilles herd in northern Québec prior to crossing frozen lakes and rivers (Leblond et al. 2016). Leblond suggested that these pauses may represent caribou assessing ice quality prior to beginning their crossings, and/or increasing their intake of vegetation prior to the large expenditure of energy needed to traverse ice or open water (Leblond et al. 2016). Although freshwater ice conditions differ significantly from sea ice conditions, caribou behaviour on freshwater ice may inform potential ways that caribou may assess sea ice.

Little information is available on the types or quality of ice used by caribou during their movement across sea ice. Joly (2012) observed caribou avoiding areas of dark coloured ice in Kotzebue Sound, Alaska. Dumond and Lee (2012) observed Dolphin-Union caribou avoiding areas of open water within Victoria Strait. This avoidance suggests caribou can assess sea ice conditions and respond by making decisions on the direction of their movement on the sea ice. With sea ice being important habitat for caribou in and near the CAA, it is important to consider sea ice conditions and trends in change for their potential impact on caribou movement and health.

2.2 – Changing sea ice conditions

Changes in sea ice conditions, reduced ice thickness, and reduced extent are commonly identified as indicators of Arctic warming (Gagnon and Gough 2005; Post et al. 2013; Pistone et al. 2013). However, changing sea ice conditions also play a role in amplifying such warming with the associated decline in surface albedo as the reflective sea ice surface reduces (Gagnon and Gough 2005; Post et al. 2013; Pistone et al. 2013). The Budyko–Sellers hypothesis describes that a warming of the Arctic leads to decreased ice cover which exposes more of the underlying darker ocean and amplifies the absorption of solar radiation thus warming the Arctic (Pistone et al. 2013). Pistone et al.

(2013) observed a correlation between planetary albedo and sea ice cover supporting this hypothesis. The longer open water season also impacts the type of ice that is present in the spring, resulting in waters dominated by newly formed first-year ice (Stroeve et al. 2011). First-year ice melts quickly, expanding open water areas and further intensifying the cyclical impacts of changing sea ice (Stroeve et al. 2011). This demonstrates that sea ice has a role in a changing climate and is both a consequence of, and causal factor contributing to, the progression of climate change.

Trends of sea ice decline are complex with significant interannual variation. For example, in 2008 and 2009 there was a high sea ice extent in May within the Arctic Ocean followed by a summer of low ice concentration in 2010 (Stroeve et al. 2011; ICC 2015). Extreme lows in sea ice extent were also observed in the CAA in 1998 and 2007 by Howell et al. (2010), although distinct conditions, timing of sea ice minimums and preconditions factors were influential in each of years. The differences in ice conditions in these two years, challenges ideas of predictable sea ice behaviour in the CAA (Howell et al. 2010).

Increased advection of multi-year ice from the high north Arctic Ocean to the CAA was observed in the 1990s (Nichols et al. 2004, Stroeve et al. 2011, Bourbonnais and Laserre 2015, Howell and Brady 2019). The infiltration of mobile multi-year ice may complicate the assessment and interpretation of sea ice extent. Howell and Brady (2019), and Howell et al. (2009) described a trend towards larger influx of multi-year sea ice from the Arctic Ocean basin to lower latitude waters (Figure 2.7). Haas and Howell (2015) described thick sea ice observed in 2014 and 2015 remaining during the summer season (Haas and Howell 2015).

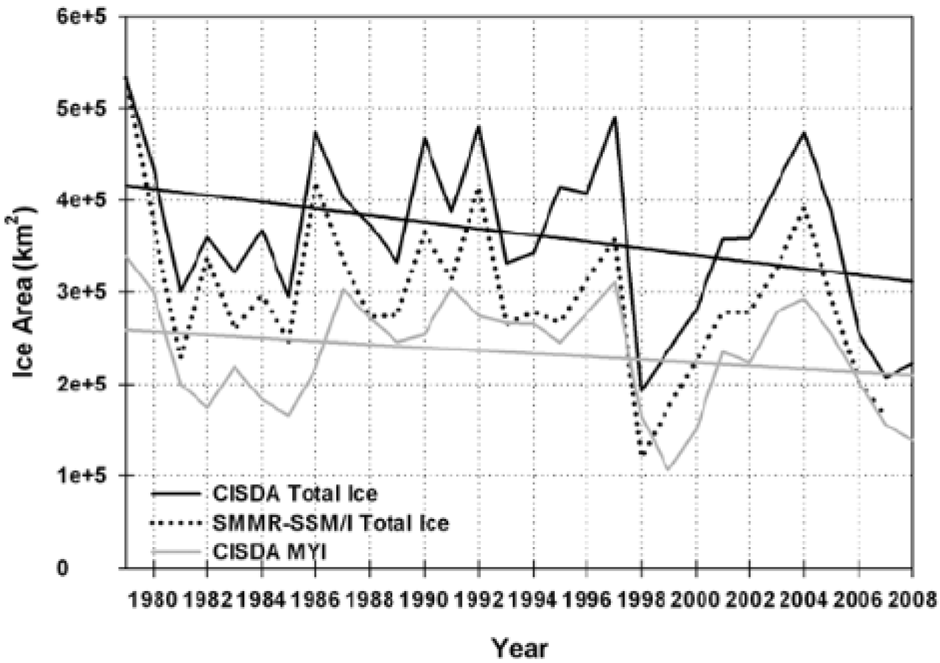

Figure 2.7 - Time series of average monthly September total ice and multi-year ice area as determined from the CISDA within the Canadian Arctic Archipelago, 1979–2008. Time series of average monthly September total ice area as determined from the SMMR-SMM/I sea ice dataset within the Canadian Arctic Archipelago, 1979 –2007 (Howell et al. 2009, p. 3).

Ice age typically describes ice thickness, with older ice being up to 3-4 m thick (excluding ridges, Meier et al. 2014). However, prior to the current decade, sea ice thickness has been difficult to distinguish with available satellite imagery. The development of data from cryospheric-focused altimeters such as the Ice, Cloud, and land Elevation Satellite (ICESat) and CryoSat-2 improved sea ice thickness observations in the Arctic (Meier et al. 2014). Markus et al. (2009) reported statistically significant changes from 1979 to 2009 in the distribution and types of sea ice in the Arctic basin, with the majority of ice being thin, first-year ice with little to no evidence of ice older than 7 years. It should be noted that ice thickness and approximate ice age also exhibits substantial interannual variation (Howell et al. 2010, Meier et al. 2015).

Inuit knowledge can play an important role in understanding local and regional ice conditions during periods of inadequate or developing satellite technologies. For example, Inuit from Igloolik, NU and Sachs Harbour, NT reported changes in the general thickness of sea ice used for travel (Nichols et al. 2004, Laidler et al. 2009, Markus et al. 2009). Sachs Harbour residents described reductions in the extent of multi-year ice (Nichols et al. 2004). Similar findings were reported by Igloolik residents, who described observing less multi-year ice than in the recent past (Laidler et al. 2009). Inuit from Clyde River, NU also described recent changes in the patterns and timing of break-up, with break-up occurring simultaneously across large areas (Gearheard et al 2006). This contrasted with previously observed break-up timing which typically started at the head of fjords surrounding Baffin Island. Residents of Clyde River also described predominantly first-year ice in the region and highlighted significant local variation in sea ice thickness and features (Gearhead et al. 2006). Many of the sea ice conditions that are important for Inuit travel safety and hunting success are observed at a much finer scale that is observable with satellite imagery (Laidler et al. 2011), so the relatively coarse resolution of satellite imagery is often inadequate to support community needs (Meier et al. 2014). Although literature that documents Inuit knowledge of sea ice has grown considerably over the last two decades (e.g. Nickels et al. 2005; Gearhead et al. 2006; Laidler et al. 2007; Laidler and Ikummaq 2008; Laidler et al. 2008; Cunsolo et al. 2013; ICC 2015; Durkalec et al. 2015) very little of this focuses on the Kitikmeot region of Nunavut. Therefore, literature in the following sections relies predominantly on scientific assessments of sea ice trends as relevant context for ice conditions around KWI.

2.2.1 - Sea ice break-up and freeze-up trends in the CAA

Transitional sea ice stages of freeze-up and break-up are pulses of productivity within the Arctic marine ecosystem, denoting important periods of seasonal change (Post et al. 2013). Dates of break-up represent a length of time in which ice disappears in a given area (1 to 2 weeks) and does not always represent a melt of ice, but can also indicate a movement of ice out of the given area (Government of Canada 2016). Likewise, freeze-up represents a length of time in which ice appears in given area (generally 1 to 2 weeks) (Government of Canada 2016). Climatic warming is contributing to earlier break-up and later freeze-up timing, facilitating the movement of sea ice into lower regions of the Northwest Passage (NWP) (Howell et al. 2009). Changes in the timing of freeze-up are more often more pronounced than those of break-up across the Arctic due to delayed ice formation resulting from the temperature albedo feedback (i.e. when solar radiation in the summer is stored, increasing water temperatures and thereby affecting autumn freeze-up) (Smith 1998; Markus et al. 2009; Lei et al. 2015).

Substantial interannual variation was reported in both freeze-up and break-up timing in the CAA (Smith 1998; Markus et al. 2008; Stroeve et al 2011; 2014; Pannikar et al. 2018). Climate factors like air temperature, wind conditions, snow and ice thickness, and ocean heat flux can impact the timing of freeze-up and break-up. The latitude of a given area impacts the timing of freeze-up and break-up, with earlier melt onset and later freeze onset detected in more southern areas of the CAA (Stroeve et al. 2014). Howell et al. (2009) observed a lengthening of ice melt from 1979-2008 within the CAA (Figure 2.8).

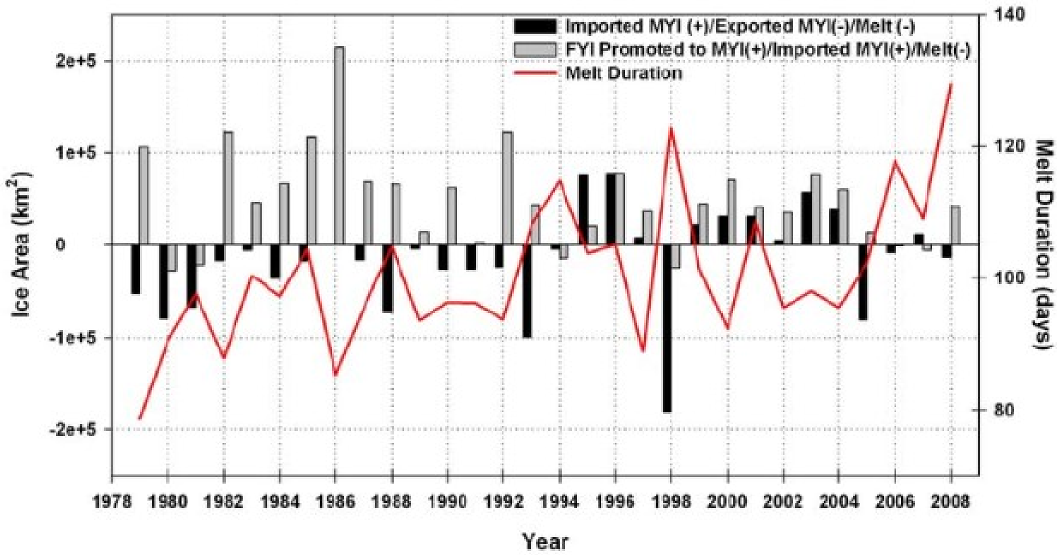

Figure 2.8 - Time series of changes in the amount of first-year ice promoted to multi-year ice, dynamically imported multi-year ice, and the melt duration within the Canadian Arctic Archipelago, 1979–2008 (Howell et al. 2009, p. 5)

A trend towards later freeze-up was detected in eastern Dolphin and Union Strait, western Coronation Gulf, Dease Strait, and western Queen Maud Gulf (i.e. 8-10 days later in 2006 than 1982) (Poole et al. 2010). To the north, break-up timing within the Bathurst Island complex demonstrated high interannual variation, with select areas more likely to be ice free first due to localized water currents (Miller 1995).

Inuit communities are also observing earlier break-up and later freeze-up timing, that varies according to their geographic location and context (Nickels et al. 2005; Laidler et al. 2010; Carter et al. 2017) (Figure 2.9). In the Kitikmeot region, residents of Kugaaruk reported thinner sea ice, earlier break-up and later freeze-up relative to previous decades (Nickels et al. 2005). Later freeze-up timing was also the most common response from residents of Kugluktuk and Cambridge Bay when asked about changing environmental characteristics around their communities (Panikkar et al. 2018) (Figure

2.10). Earlier break-up was the fourth most frequent response, along with various associated indicators of sea ice change including more difficult ice conditions and thinner ice (Panikkar et al. 2018) (Figure 2.10). However, in Cambridge Bay there are also contradictory observations of later break-up, suggesting that there is significant interannual variation and trends of change are likely to be complex and non-linear (Panikkar et al. 2018).

Region	Inuvialuit Settlement Region					Nunavut			Nunavik			Nunatsiavut
Community	Paulatuk	Holman Island	Aklavik	Tuktoyaktuk	Inuvik	Repulse Bay	Kugaaruk	Arctic Bay	Puvirnituq	Kangiqsujuaq	Ivujivik	Nunatsiavut
OBSERVATIONS												
ICE												
Ice is thinner now.	●	●	●	●	●	●	●	●	●	●	●	●
Earlier break up of ice.	●	●	●	●	●	●	●	●	●	●	●	●
Later freeze up of ice.	●	●	●	●	●		●	●	●	●	●	●
Permanent snowpacks/ icepacks are melting/ glaciers are melting.					●	●	●	●		●	●	

Figure 2.9 - Summary of observations of environment in the CAA as discussed in community workshops (Nickels et al. 2005, p. 69)

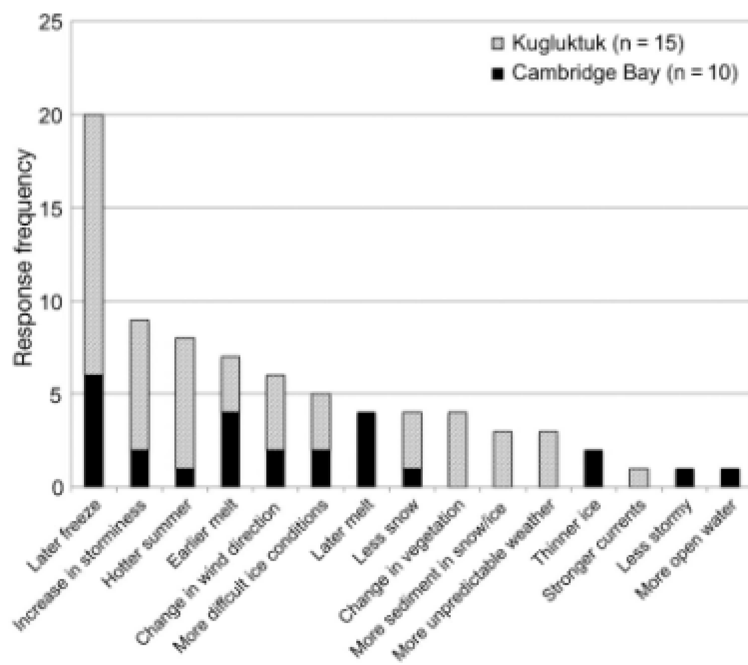

Figure 2.10 - Summary of interview responses by residents of Kugluktuk and Cambridge Bay concerning changing environmental characteristics (Panikkar et al. 2018, p. 10).

2.2.2 - Potential impacts of sea ice change on Arctic caribou

For Arctic caribou that rely on sea ice as part of their habitat, they will be directly impacted by changes in sea ice conditions, and timing of break-up/freeze-up, due to their use of sea ice mobility and to complete their reproductive cycles (Poole et al. 2010; Johnson et al 2016; Jenkins et al. 2016). Dolphin-Union caribou were listed as being of "Special Concern" under the Species at Risk Act due to changing sea ice conditions and predicted growth in Arctic ship traffic (Dumond and Lee 2012). Environment and Climate Change Canada's (ECCC) knowledge assessment of critical habitat for Peary caribou in the Canadian Arctic identified multiple threats that could impact population health and habitat (Figure 2.11). Mechanisms affecting Peary caribou included changes in the extent, duration, and thickness of sea ice that could delay or prevent caribou movements between seasonal habitats, as well as ice-breaking caused by increasing ship traffic. These mechanisms may threaten Peary caribou population health and habitat use, including: habitat loss, changes in hunting/harvesting practices, potential contaminants and disturbance to nearby species (Johnson et al. 2016) (Figure 2.11).

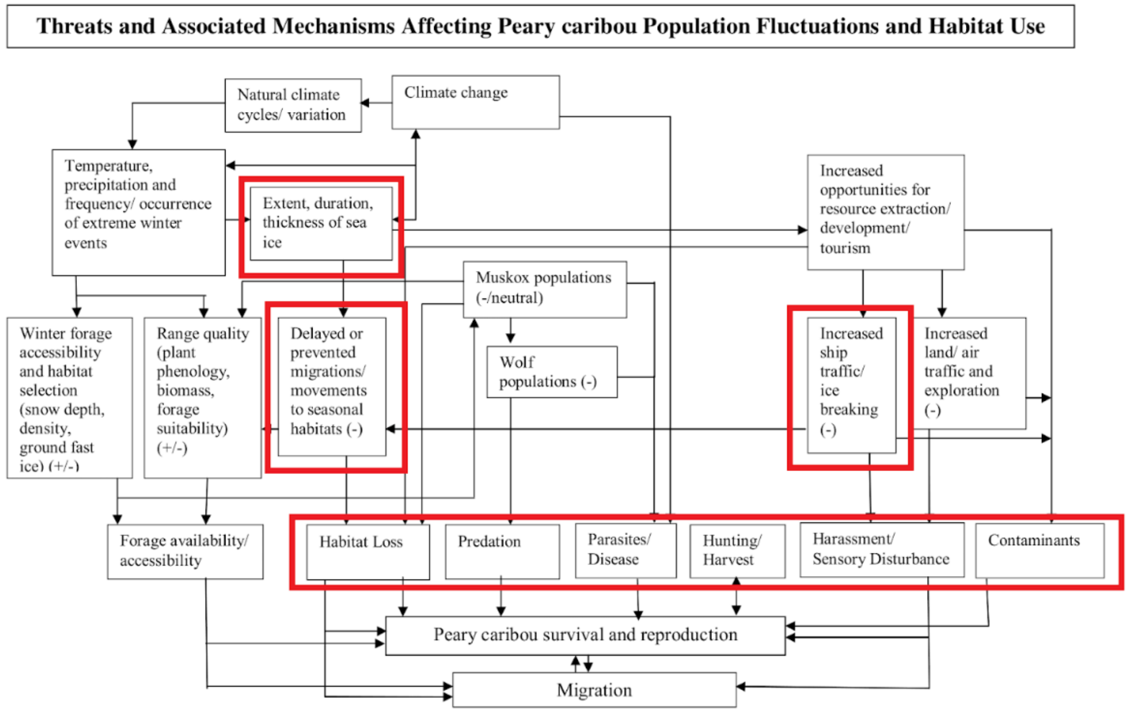

Figure 2.11 - Threats and associated mechanisms affecting Peary caribou population fluctuations and habitat use according; threats and mechanisms relevant to our project are outlined in red (Johnson et al 2016, p. 20).

Peary caribou are constantly moving within their habitat, and therefore challenges and barriers to their range distribution restricts their ability to move across sea ice and disrupts potential coping mechanisms to buffer habitat change (Robert and Forbes 2011; Taillon et al 2012). Changes in sea ice conditions and break-up/freeze-up timing may also lead to caribou falling into open water in areas during sea ice crossings. In 2010, a few dozen caribou carcasses were found frozen in the ice and on near-by islands surrounding Victoria Island indicating that they had fallen into the water and froze to death after recovery onto the ice (Dumond and Lee 2012). The trend towards later freeze-up could mean that caribou start moving onto sea ice prior to it being fully formed, leading to an increased amount of caribou drowning or freezing after recovering from falling (Poole et al 2010). Additionally, the shifting or prevention of seasonal caribou movement may expose the species to additional pathogens, insects and predators they are unfamiliar with, as they move away from their traditional habitat (Post et al. 2013).

2.3 - Changing ship traffic in the CAA

2.3.1 - Potential influences of changing sea ice on Arctic ship traffic

As changes in sea ice affect movement of people and caribou across the sea ice, they also influence the movement of ships through sea ice and ice-filled waters. It is commonly predicted and reported that melting of Arctic sea ice will lead to increased ship traffic across longer shipping seasons (Lei et al 2015, Bourbonnais and Laserre 2015, Guy and Laserre 2016). Sea ice conditions are discussed as determining factors for Arctic shipping, influencing the size, breadth and navigation conditions of Arctic vessels (Bourbonnais and Laserre 2015). Therefore, the consequences of changing sea ice on Arctic ship traffic must take into account the different types and sizes of vessels, as they can be uniquely impacted by sea ice dynamism (Guy and Laserre 2016, Dawson et al 2018).

Pizzolato et al. (2014) examined the relationship between sea ice melt and the number of ships in the NORDREG zone (i.e. the Vessel Traffic Reporting Arctic Canada Traffic Zone) (Figure 2.12). Ships within this zone are required to comply with Government of Canada regulations, they can receive support from government vessels and icebreakers, and they are requested to report their movements to the Canadian Coast Guard (Pizzolato et al. 2014). Despite increasing trends in fall and spring shipping activity (i.e. vessel count) between 1992-2012, there were no significant correlations between vessel count and the timing of freeze-up or break-up (Pizzolato. 2014). However, Pizzolato et al. (2014) found some correlation between vessel count and mean total ice, percentage of multi-year, and first-year ice for select ship types (i.e. government vessels and icebreakers [-0.34], passenger ships [-0.30], and general cargo [-0.30]). This suggests that the relationship between growing ship traffic and changing sea ice is complex, and correlations may not be present across all sea ice variables.

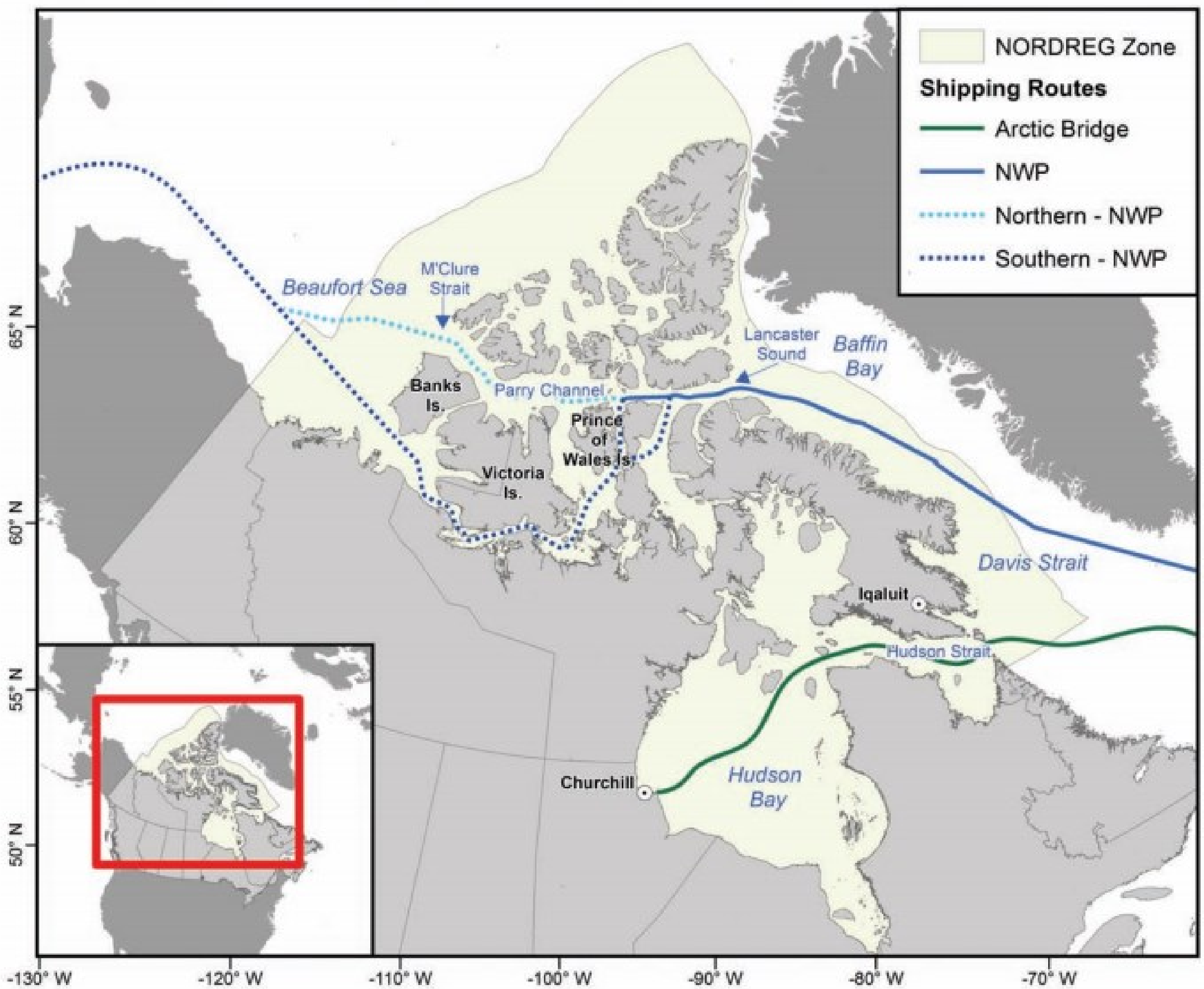

Figure 2.12 - Outline of major shipping routes within the NORDREG zone (the Vessel Traffic Reporting Arctic Canada Traffic Zone; Dawson et al. 2018 p. 18).

Ships that typically travel in the early stages of sea ice freeze-up or break-up pose the greatest risks to altering the timing and conditions in these seasonal transition periods. Government vessels and icebreakers (considered together as one ship type) operate throughout the shipping season, facilitating the planning and travel of other ships. Icebreakers are most common in Arctic waters (Pizzolato et al. 2014; Dawson et al. 2018), and their ice-breaking capacity may disrupt sea ice freeze-up, and/or may disrupt break-up by breaking apart landfast or consolidated pack ice earlier than would be naturally occurring (Pizzolato et al. 2014; Pizzolato et al. 2016; Dawson et al. 2018; Dawson et al. 2020). Long-term trends in Arctic ship traffic are important considerations in Arctic wildlife management plans, the development of emergency response systems, and for interdisciplinary research examining cumulative impacts on Arctic species and Inuit well-being (Dawson et al. 2018).

The shipping industry has the motivation to lengthen their operational season in the Arctic, however, sea ice conditions remain highly variable and pose ongoing risks for ship traffic (Stroeve et al. 2014). Pizzolato et al. (2014; 2016) observed that multi-year ice is the most significant variable impacting ship navigation because of its mechanical strength which may damage ships. Minimal ship traffic was observed in the following areas where high amounts of multi-year ice observed: northern Beaufort Sea, Queen Elizabeth Islands, Western Parry Channel, Mˈ Clintock Channel, and Victoria Strait regions (Haas and Howell 2015). Haas and Howell (2015) observed thick sea ice (3-4 m) in M'Clintock Channel during the summer season, with high volumes of thick deformed ice. The presence and unpredictability of movement of thick multi-year ice presents hazards to ship traffic (Haas and Howell 2015).

Other sea ice and open water conditions can impact ship movement and vessel count. Increased amounts of pressured ice and ridges create barriers, and may force ship captains to move slower when navigating waters and to prepare for emergency situations if they become stuck (Bourbonnais and Laserre 2015; Pizzolato et al. 2016; Mussels et al. 2016). The distribution of open water can also impact ship navigation and safety, as ships interacting with open water during the winter seasons in the CAA have led to increased instances of icings reported on ships (Bourbonnais and Laserre 2015). Furthermore, passages within CAA can be both shallow and narrow (Bourbonnais and Laserre 2015; Guy and Laserre 2016). Inadequate charting of Arctic waters is a concern for larger ships that may become grounded while seeking alternative travel routes when avoiding ice (Bourbonnais and Laserre 2015; Guy and Laserre 2016). These conditions pose challenges to the perceived rapid intensification of Arctic shipping (Pizzolato et al. 2016; Guy and Laserre 2016; Mussels et al. 2016; Howell and Brady 2019; Dawson et al. 2020). Potential risks associated with growing Arctic ship traffic are further exacerbated by: the lack of shipping infrastructure in Arctic waters, lack of monitoring of vessel support and traffic, limited emergency response capacity, limited availability of experienced Arctic ship workers, and potentially inaccurate charting and monitoring of sea ice information (Ho 2010; Andrews et al 2018).

2.3.2 - Historic and recent trends in Arctic ship traffic

Arctic ship traffic moves through the NWP in the CAA to access growing communities, tourism destination sites (which includes Inuit communities), small-scale fish operations, and mining/resource extraction sites (Dawson et al. 2018; 2020). These are all are expected to increase in their demand of shipped goods and/or the number of vessels. Additionally, the presence of government and military vessels have increased in response to the Royal Canadian Navy's recent (2017) operationalization of a fleet of Arctic Offshore Patrol Ships (Dawson et al. 2018; 2020).

Significant increases in Arctic ship traffic have been observed in several studies (Lei et al. 2015; Dawson et al. 2018; 2020; Andrews et al. 2018), with Dawson et al. (2018) reporting a tripling of total distance travelled by all ships in 2015 (918 266 km) relative to 1990 (364 179 km). The majority of this ship traffic was attributed to general cargo, government vessels and icebreakers, with pleasure crafts increasing rapidly in the last five years (Figure 2.13).

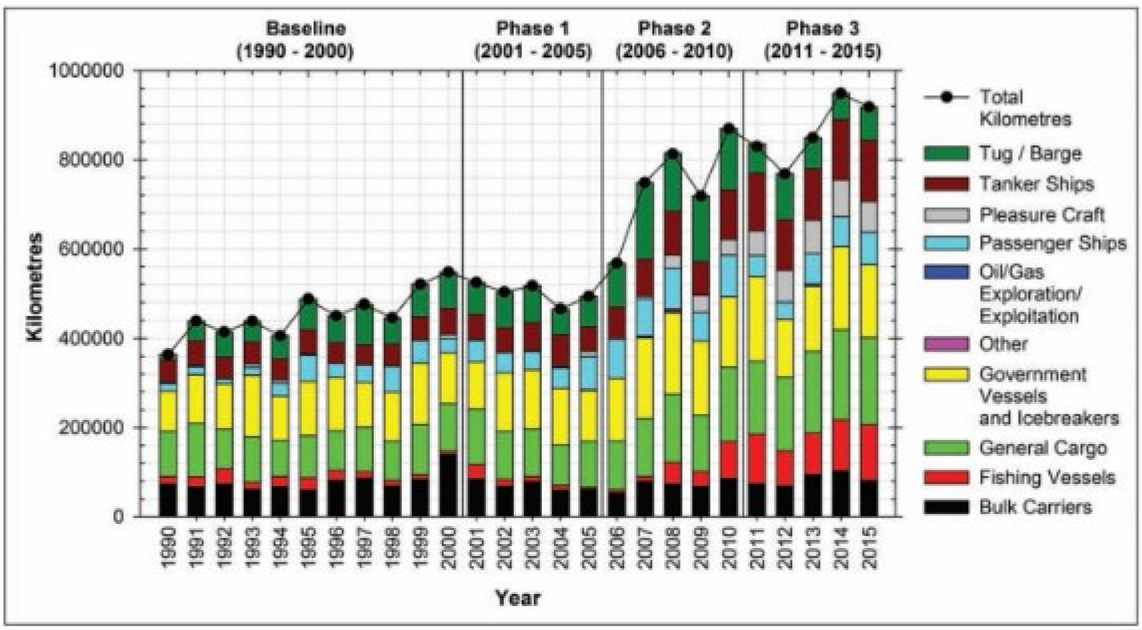

Figure 2.13 - Total kilometers travelled annually by all vessels types in the Canadian Arctic (Dawson et. al. 2018, p. 19).

The Kitikmeot region has experienced significant growth in the total distance travelled by ships between1990 to 2016, with substantial growth starting around 2005. Ship traffic is concentrated in the NWP within the Kitikmeot Region (Figure 2.14). Our analysis includes this period of growth in ship traffic surrounding KWI.

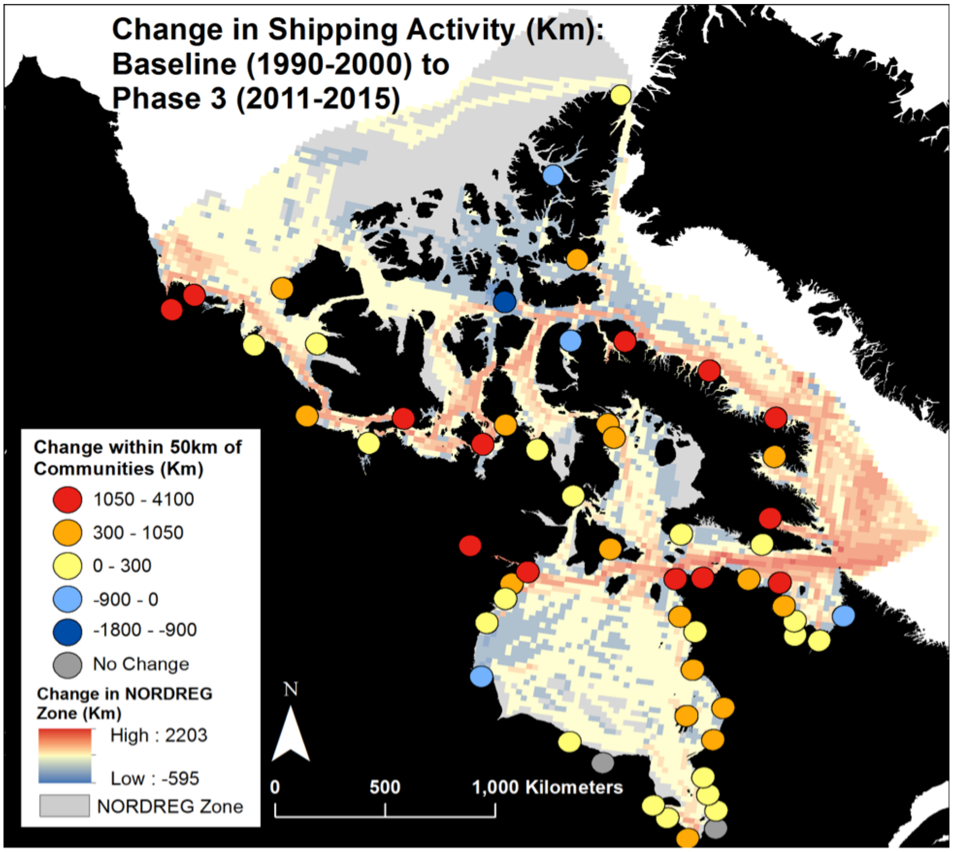

Figure 2.14 - Change in vessel traffic (km travelled per year) between the baseline period (1990-2000) and Phase 3 (2011-1015) (Dawson et al. 2018, p. 24).

2.3.3 - Potential impacts of ship traffic on Inuit and caribou

The majority of research concerning changes of sea ice and/or ship traffic that focuses on potential wildlife impacts, relates mainly to marine mammals with little consideration of caribou habitat and movement (Laidler et al. 2009; Kovacs 2011; Pilfold et al. 2014; Laidre et al. 2015, Huntington et al. 2016). The Kitikmeot Regional Land Use Plan reports community concerns about the impacts of ship traffic on both wildlife and Inuit use of sea ice (GN 2004). The plan supports shipping during the typical open water season between from 1 July to 15 - 30 October (GN 2004). Specific concerns for wildlife and Inuit use of sea ice varies amongst communities based on their experiences and use of their surrounding environment (Olsen et al. 2020).

Ice-breaking by larger vessels can create barriers that caribou movement by creating channels of open water in the sea ice (Johnson et al 2016, Carter et al. 2017). These channels can disrupt caribou sea ice habitat because caribou will generally not cross these channels, or use strips of ice that may cross open water. As was observed in Dolphin-Union caribou, a channel created by ship traffic delayed movement of caribou by several days (Poole et al. 2010; Dumond and Lee 2012; Dumond et al. 2013) (Figure 2.15).

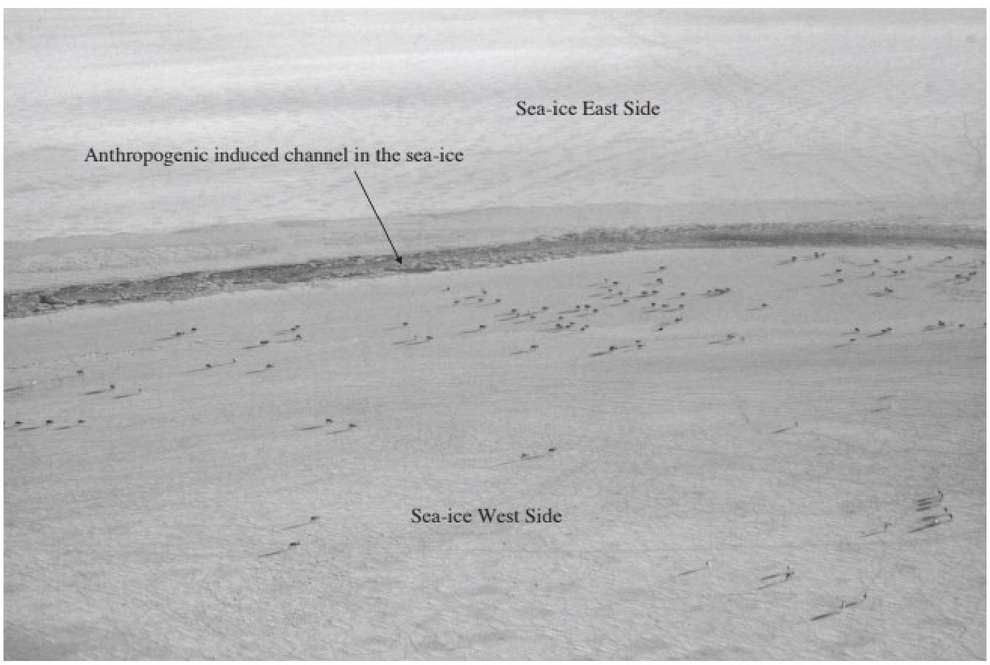

Figure 2.15 - Dolphin-Union caribou congregating on the edge of a channel created by an icebreaker near Cambridge Bay, NU (Dumond et al. 2013, p. 117).

These disruptions are considered dangerous to caribou in the winter as they move across the sea ice (Poole et al. 2010; Dumond and Lee 2012; Dumond et al. 2013; Carter et al 2017). Though gaps created by ice-breaking ships may quickly refreeze, the surface is no longer smooth, and the resultant rubble impedes surface travel (GN 2004, GN 2011, Pizzolato et al. 2014; ICC 2015). In addition, icebreaking can isolate areas potentially used by caribou, and can delay freeze-up and accelerate break-up processes (Johnson et al 2016, Carter et al. 2017).

Wildlife can be impacted by the noise disturbance caused by ship traffic (McKenna et al. 2011; Carter et al. 2017; Hauser et al. 2018; Erbe et al. 2019), and studies have largely focused on repercussions of shipping noise on marine mammals (McKenna et al. 2011; Hauser et al. 2018; Erbe et al. 2019). However, communities involved in the Arctic Corridors-Northern Voices project led by Jackie Dawson at the University of Ottawa (which included Uqsuqtuuq), discussed that caribou on the land may move away from ship traffic to avoid noise (Carter et al. 2017; Dawson et al. 2018; Dawson et al. 2020). Furthermore, caribou calving sites have changed in response to noise (and other factors) from mining exploration, and more studies are needed to assess the potential impact of noise disturbance from ships on caribou (Boulanger et al. 2012; Carter et al. 2017), among other animals.

Available literature on changes in ship traffic and sea ice conditions in the CAA provides context to our project objectives and identifies a gap in literature about conditions within the lower NWP and Kitikmeot region. Due to the ambiguous status of caribou on KWI in scientific literature, our project relies on Uqsuqtuurmiut knowledge of caribou to explore our central and secondary research questions (Chapter 1).

Chapter 3: Methods

Prior to outlining the mixed research methods used in this thesis, it is important to provide some background on how this project evolved, and how Uqsuqtuurmiut knowledge guides the way that sea ice and ship traffic analysis is undertaken. After this contextual overview, I will outline how caribou sea ice crossing areas around KWI were defined, how we visited Uqsuqtuuq and held workshops in 2018, and methods employed in sea ice and shipping analysis. I then summarize the approach to statistical and integrative analysis taken to bring Uqsuqtuurmiut knowledge, CIS data, and CCG data together to learn about the interplay between caribou sea ice habitat, and sea ice and shipping change. Throughout this chapter, and in the remainder of the thesis, I will write in first person when I (Emmelie Paquette) was primarily responsible for specific methods, analysis, and interpretations. However, this research is a collective process supported by community contributors and my co-supervisors. Therefore, at times the collective pronouns of "we" or “our” are most appropriate to describe processes, outcomes and interpretations that were shaped by the collective.

3.1 – Research Context

3.1.1 – Community Context

The Hamlet of Gjoa Haven (Uqsuqtuuq in Inuktitut) is located on the southeastern coast of KWI (12,516 km^2), the southernmost island in the CAA. The name Uqsuqtuuq refers to the abundance of fatty fish in the near-by lake of the same name (Figure 1.1) (Swan Lake in English; Ljubicic et al. 2018b). A Hudson Bay Company trading post was established in Uqsuqtuuq in 1927. Families from diverse traditional homelands -

including Nattiligmiut, Iluilirmiut, Utkuhigsaligmiut, Ahiarmiut, Haningarurmiut, Kiluhigturmiut and Ki'linirmiut - transitioned to the settlement between the 1950s and 1970s for access to government support services (Ljubicic et al. 2018b). Because of this diversity in homelands, both Inuktitut and Inuinnaqtun are spoken in the community. Uqsuqtuuq now has a population of 1,324 (Statistics Canada 2016) and has a number of community and government services including: select departments of the decentralized Government of Nunavut, the Nunavut Water Board, Gjoa Haven Continuing Care Centre, Nattilik Heritage Centre, Qiqirtaq High School, Quqshuun Elementary School, and a small campus of the Nunavut Arctic College (Ljubicic et al. 2018a). Among other land-based and cultural activities, caribou hunting on KWI – as well as on Adelaide and Boothia Peninsula, and further south on the mainland – is a vital part of community well-being in Uqsuqtuuq (Grimwood and Laidler 2010, Ljubicic et al. 2016, Ljubicic et al. 2018a).

3.1.2 – Project evolution

This thesis research is an extension of a previous collaborative research project led by Gita Ljubicic and Simon Okpakok to learn about the connections between caribou, community, and well-being in Uqsuqtuuq (Ljubicic et al. 2016, 2018a). In February 2010, Ljubicic and Okpakok facilitated a 3-day research planning meeting with a range of community representatives in Uqsuqtuuq. During these planning meetings, caribou came up as an important research priority, including the connections between caribou and local diet, cultural practices, and community well-being (Laidler and Grimwood, 2010). Working with local and regional representatives of Kitikmeot Inuit Association (KIA), Ljubicic secured SSHRC funding to develop a follow-up project to address priorities identified in the planning meetings (Ljubicic et al. 2018a). Over three summers (2011 - 2013), interviews, participatory mapping, and Elder-youth land camps were facilitated to document and share Uqsuqtuurmiut knowledge of caribou. Verification workshops were held in 2013 and 2016, and results are shared in several reports and publications (Ljubicic et al. 2016, Mearns 2017; Ljubicic et al. 2018a; 2018b, Robertson and Ljubicic 2019).

I started my MSc in the fall of 2017, under the supervision of Gita Ljubicic and Cheryl Johnson. I expressed my broad interests in interdisciplinary research, Arctic environments and working with Indigenous communities. Ljubicic suggested that my interests were complementary to the caribou research wrapping up in Uqsuqtuuq, and that perhaps I could explore opportunities for follow-up research. In January 2018 Ljubicic had a phone conversation with James Qitsualik (Chair of the Gjoa Haven Hunters and Trappers Association, HTA) in which he talked about his concern for potential impacts of changing sea ice conditions and ship traffic on caribou movements to/from KWI. With the previously documented caribou crossings (Ljubicic et al. 2018a) and recent shipping research that had been conducted in Uqsuqtuuq (Carter et al. 2017), Qitsualik's interests provided the motivation to explore the connections between caribou, sea ice, and Arctic ship traffic around KWI.

This research would not have been possible without the long-term relationships developed by Ljubicic, guided by principles of community-based participatory research and Indigenous research methodologies (see Ljubicic et al. 2018a for details). I strived to follow a similar approach in my own research, seeking guidance from Ljubicic and Okpakok along the way. The GN (2011) caribou management strategy emphasizes the important of considering Inuit knowledge equally with scientific knowledge in policy-and decision-making. The strategy states that information must be recorded through valid and widely accepted methods. However, what qualifies as valid, widely accepted – and ultimately respectful research – must be decided in discussion and collaboration with community members and local organizations (Ljubicic et al. 2018a). Therefore, as in the previous work undertaken by Ljubicic, I considered it essential to be guided by Uqsuqtuurmiut knowledge in undertaking research on the potential impacts of sea ice and shipping change for caribou around KWI.

3.1.3 – Uqsuqtuurmiut knowledge guiding mixed methods research

Previous research conducted by Ljubicic et al. (2018a) documented caribou crossings to/from KWI according to Uqsuqtuurmiut knowledge. Participatory mapping was used to learn about caribou movements in the region and, despite not being a primary focus of mapping exercises, most contributors indicated important locations where caribou use sea ice to reach KWI (Figure 3.1). Five main crossing areas were identified by Uqsuqtuurmiut, and these became the basis for the spatial delineation of sea ice and shipping analyses (Section 3.2). As mentioned in section 2.1.2, caribou move onto and off KWI seasonally, in the spring and fall, respectively.

There are six seasons identified in Uqsuqtuuq based on marine conditions (Figure 3.2) (Carter et al. 2017), where transitional stages of sea ice break-up and freeze-up are most critical to caribou movement. This is reflected in the seasonal rounds of caribou described by Uqsuqtuurmiut in Ljubicic et al. (2018a) (section 2.1.2), highlighting spring to early summer, and early fall as most important seasons for caribou movement through sea ice habitat.

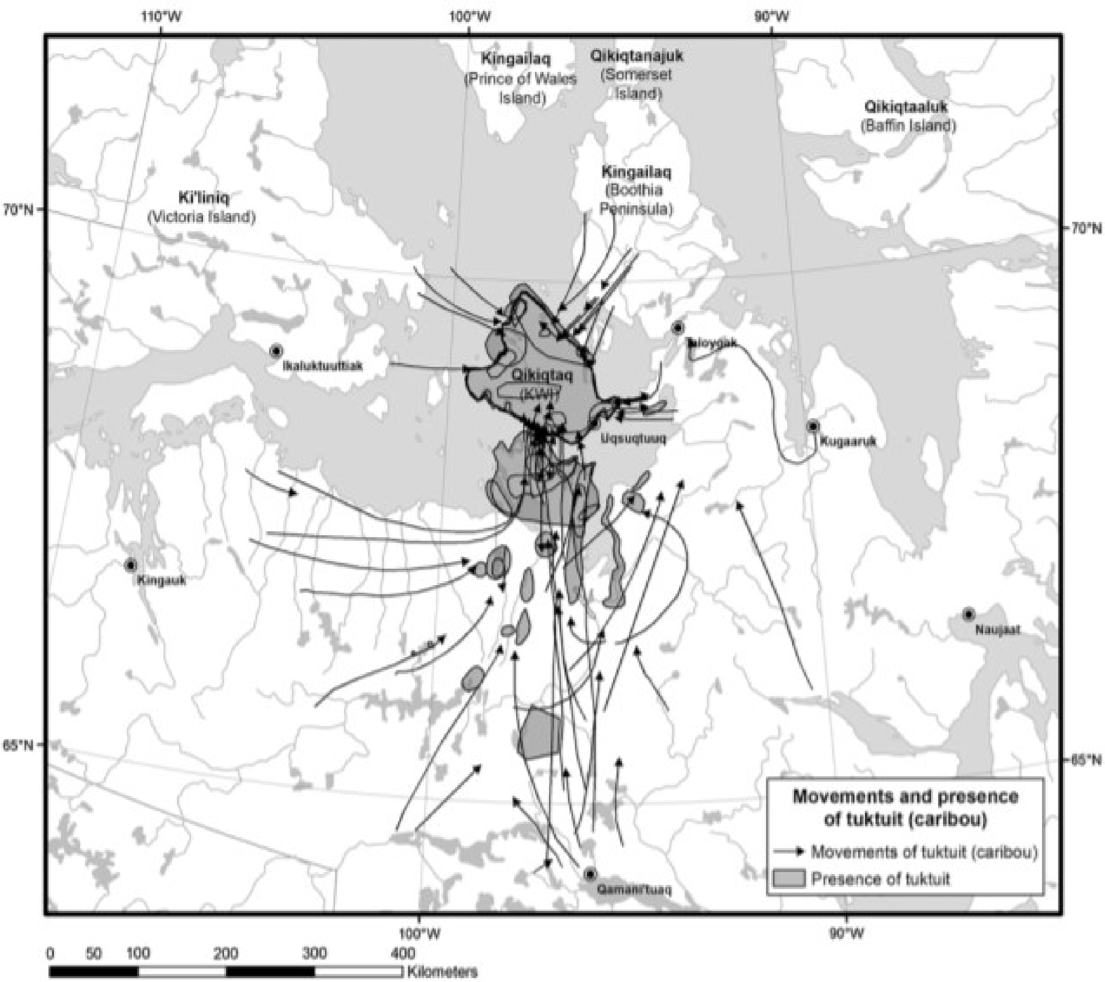

Figure 3.1 - Uqsuqtuurmiut knowledge of regional caribou movement around King William Island (Qikiqtaq) (Ljubicic et al. 2018a, p. 222)

SEASON	MONTHS IN WHICH IT HAPPENS	OCEAN CONDITIONS
START OF SPRING	APRIL	FROZEN
SPRING TO EARLY SUMMER	MAY AND JUNE	BREAK-UP (IN JUNE)
SUMMER	JULY TO BEGINNING OF AUGUST	OPEN WATER
LATE SUMMER	AUGUST	OPEN WATER
EARLY FALL TO LATE FALL	SEPTEMBER AND OCTOBER	FREEZE-UP (IN OCTOBER)
WINTER	NOVEMBER THROUGH MARCH	FROZEN

Figure 3.2 - Seasons in Uqsuqtuuq based on marine conditions (Carter et al, 2017, p. 8).

With caribou using sea ice mainly in spring and fall, and Arctic shipping occurring in the same seasons (as well as in open water in the summer), methods and results of this thesis are organized according to these three seasons (Figure 3.3).

We also expanded our discussions of caribou crossings, use of sea ice, and potential for shipping disturbance through community workshops in Uqsuqtuuq (Section 3.2). Taken together, Uqsuqtuurmiut knowledge of caribou crossings and seasonal marine conditions form the basis for defining the crossing areas for preliminary sea ice analysis, undertaking community workshops, analyzing sea ice charts, and analyzing shipping data (Figure 3.4).

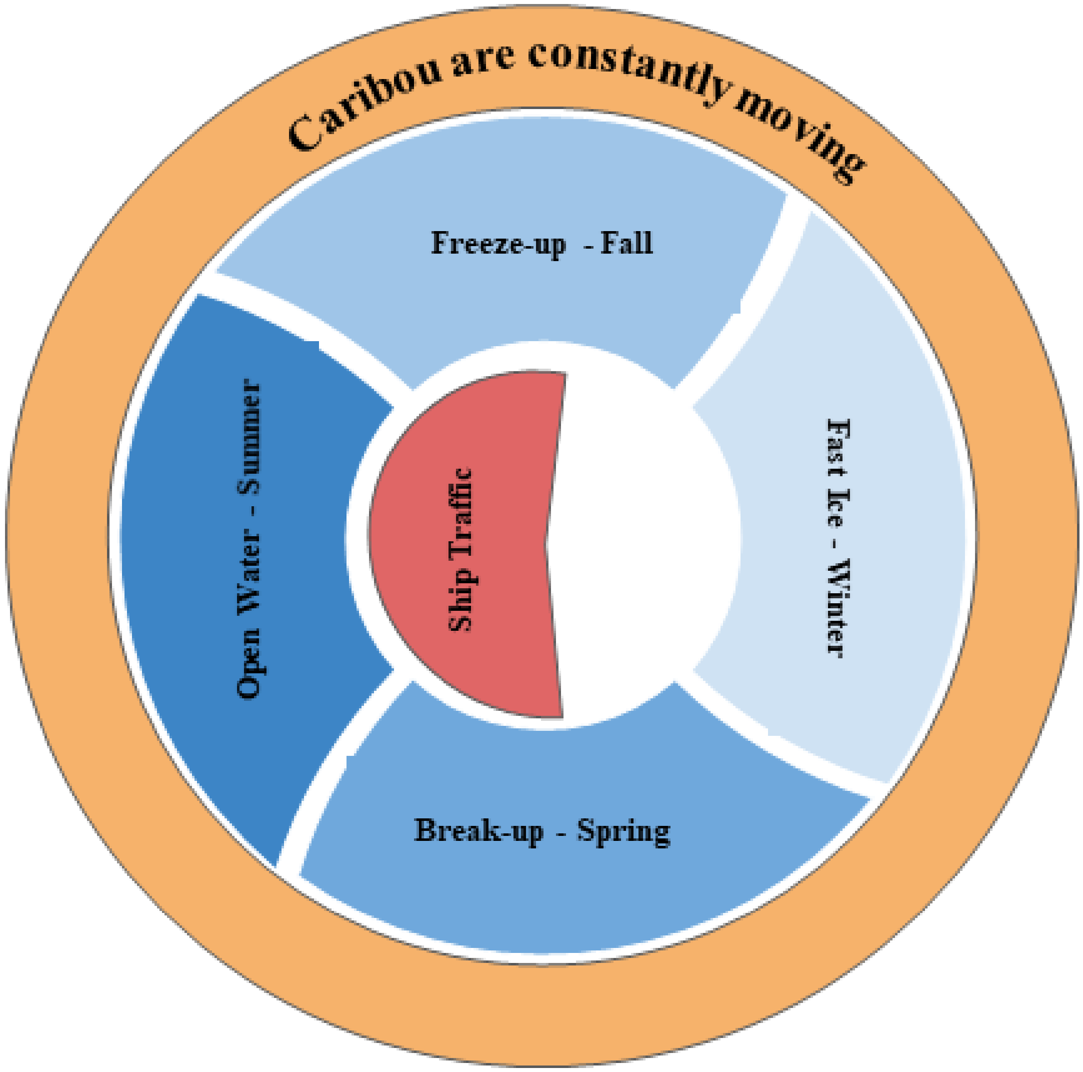

Figure 3.3 - Visual representation of seasonal uses of sea ice highlighting major relationships between themes.

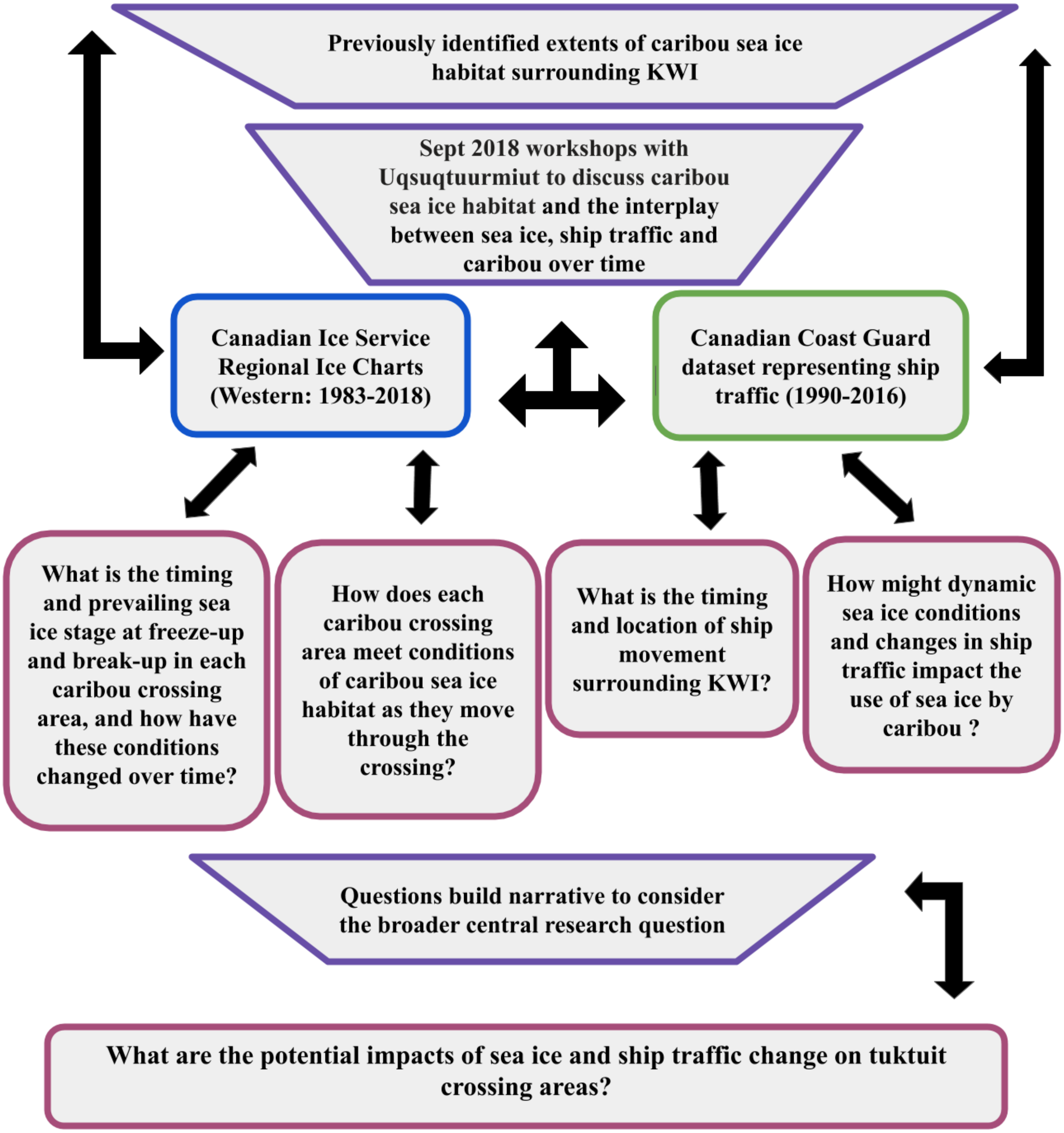

Figure 3.4 - Mixed method research approach guided by Uqsuqtuurmiut knowledge.

3.1.4 – Defining caribou sea ice crossing areas around KWI

Uqsuqtuurmiut knowledge of regional caribou movements around KWI was used to inform the spatial delineation of caribou sea ice crossings for this thesis. In interviews conducted in 2012 and 2013, Elders and hunters in Uqsuqtuuq mapped the routes that caribou typically use to cross to/from KWI (Figure 3.1) (Ljubicic et al. 2018a). We used the greatest extent of lines drawn by Uqsuqtuurmiut in those original maps to create the boundaries of polygons used to delineate the spatial focus for discussions and analyses of sea ice and ship traffic in these areas. This resulted in the definition of 5 caribou crossing areas to the northwest (NW), northeast (NE), east (E), south (S) and west (W), of KWI (Figure 3.5), based on the concentration of lines drawn (Figure 3.1). These are the Blocks referred to in Table 3.1. Coastal and offshore sea ice conditions may vary greatly due to differences in depth, currents, topography, and tides, which could affect ship traffic and routes (Pizzolato et al. 2016). Therefore, I explored potential spatial variations within these crossing areas in case they may have an effect on analyses of sea ice or shipping data. For each crossing area, where there was a distance greater than 25 km from the coastline, I subdivided the polygon to reflect coastal (within 25 km from shore) or offshore (>25km from shore) characteristics (Figure 3.6). These subdivided polygons are referred to as Subsets in Table 3.1.

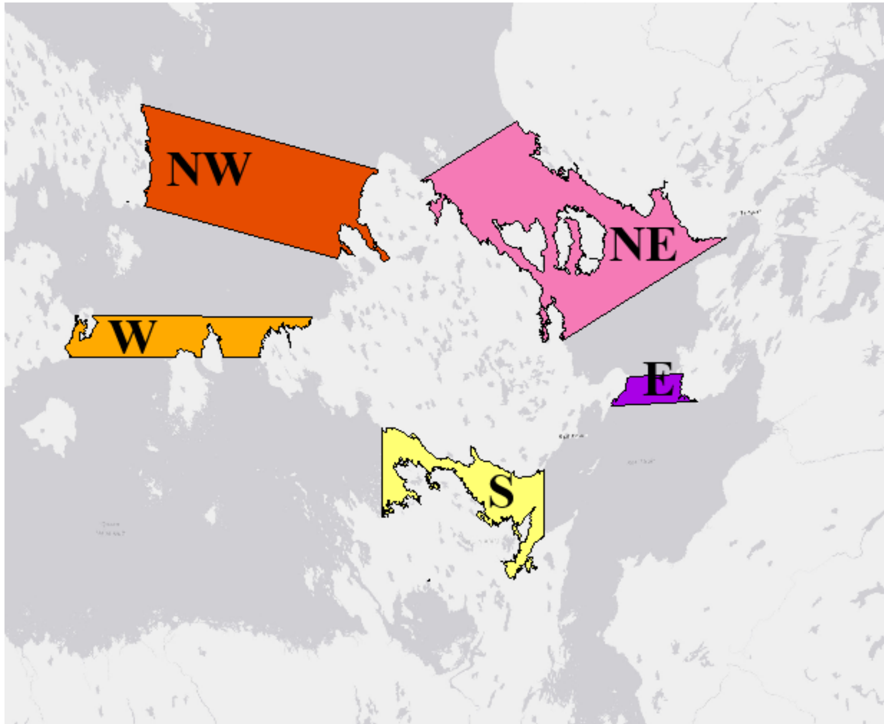

Figure 3.5 - Caribou crossing areas (Blocks for sea ice and shipping analysis) based on the greatest spatial extent of movements mapped by Uqsuqtuurmiut (Figure 3.1)

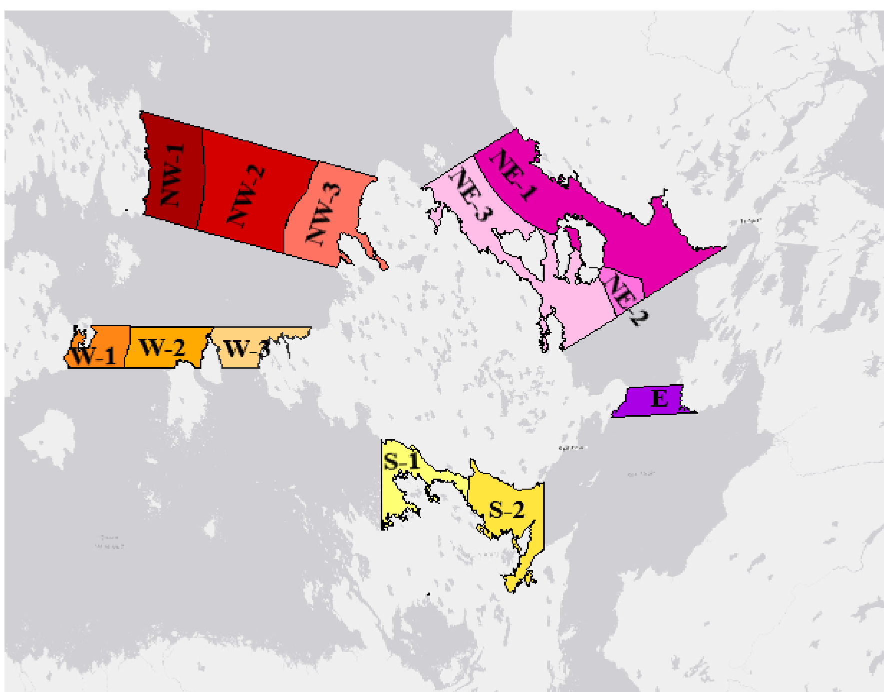

Figure 3.6 - Subsets used to assess potential coastal and offshore variations in ice conditions for caribou crossing areas in Figure 3.5

Table 3.1 - Labels, and descriptions of caribou crossing areas used within our project's analysis

Cardinal Direction	**Label**	**Block (Fig. 3.5) or Subset (Fig. 3.6)**	**Description**
NW	A	Block	North-western coast of KWI to south-eastern Victoria Island. Area crosses Victoria Strait.
NW	A-1	Subset	North-western coast of KWI to south-eastern Victoria Island. Area crosses Victoria Strait and is less than 25 km from coast of Victoria Island.
NW	A-2	Subset	Area crosses Victoria Strait and is an offshore area greater than 25 km from either coast.
NW	A-3	Subset	North-western coast of KWI to south-eastern Victoria Island. Area crosses Victoria Strait and is less than 25 km from coast of KWI.
NE	B	Subset	North-eastern coast of KWI to south-eastern Somerset Island.
NE	B-1	Subset	North-eastern coast of KWI to south-eastern Taloyoak on the mainland. Area is less than 25 km from coast of south-western Taloyoak.
NE	B-2	Subset	North-eastern coast of KWI to south-eastern south-western Taloyoak on the mainland. Area is greater than 25 km from either coast and is therefore offshore.
NE	B-3	Subset	North-eastern coast of KWI to south-western Taloyoak. Area is less than 25 km from coast of KWI.
E	C	Block	Eastern coast of KWI to west coast of Taloyak.
S	D	Block	Southern coast of KWI towards mainland (territory of Gjoa Haven).
S	D-1	Subset	Western side of South block, split before narrowest point.
S	D-2	Subset	Eastern side of South block.
W	E	Block	West coast of KWI to Victoria Island. Area above

			Queen Maud Gulf.
W	E-1	Subset	West coast of KWI to Victoria Island. Area is less than 25 km from coast of Victoria Island.
W	E-2	Subset	West coast of KWI to Victoria Island. Area is greater than 25 km from either coast and is therefore offshore.
W	E-3	Subset	West coast of KWI to Victoria Island. Area is less than 25 km from coast of KWI.

I used an ANOVA to compare differences between subset polygons (Figure 3.5, 3.6). Given that I found no significant differences in freeze-up dates between subsets (Appendix 1), results in Chapter 4 are reported for the block polygons exclusively.

3.2 – Community workshops

In order to build on the previous research by Ljubicic and Okpakok, to respond to local HTA concerns (Section 3.1.2), and to get feedback on preliminary analyses using the five defined caribou crossing areas (Figure 3.5) (Appendix 2, Appendix 3), we travelled to Uqsuqtuuq in September 2018 to facilitate a series of community workshops. Workshops were organized with the help of Okpakok between September 24 and 29, and were co-facilitated by Ljubicic, Okpakok, and myself (with Okpakok also interpreting). Cheryl Johnson and her ECCC colleague Erin Neave also attended as observers. The goal for workshops was to learn from Uqsuqtuurmiut about the interconnections between caribou, sea ice, and shipping around KWI. Each of these topics had been investigated separately by Ljubicic et al. (2018a) and Carter et al. (2017), but the workshops were an important opportunity to gain community insight on relationships between the three.

Workshops discussions were informal and open-ended, and sought to learn from Uqsuqtuurmiut knowledge about:

1. Sea ice as caribou habitat;
2. Local concerns of ship traffic for caribou movement;
3. Changes in timing and conditions of sea ice break-up/freeze-up;
4. Feedback on preliminary results of sea ice and ship traffic analysis (Appendix 3); and,
5. Feedback on maps of caribou crossing areas.

3.2.1 - Workshop facilitation

Okpakok recommended a range of Elders, active hunters, and youth to participate in workshops, based on their knowledge and experience related to caribou, their interest in the topic, and their availability (i.e. purposeful sampling; Harsh 2011). We facilitated workshops according to groups of Elder men (WKSP 2018a), Elder women (WKSP2018b) (Figure 3.7), active hunters (WKSP 2018c), HTA Board members (WKSP 2018d) (Figure 3.8), and Ikaarvik youth and mentors (WKSP 2018e) (Table 3.2). These divisions according to age, gender, and position in the community were important in order to ensure that workshop contributors were comfortable having open discussions and sharing their perspectives freely. Twenty-one Uqsuqtuurmiut contributed to 5 workshop discussions over 3 days (Table 3.2).

Figure 3.7 – Emmelie Paquette and Simon Okpakok facilitating Workshop 2 with Elder women in Uqsuqtuuq (September 26, 2018) (Photo: Gita Ljubicic)

Figure 3.8 – Gita Ljubicic and Simon Okpakok facilitating Workshop 4 with Hunters and Trappers Association Board members in Uqsuqtuuq (September 27, 2018) (Photo: Erin Neave)

Table 3.2 – Uqsuqtuurmiut workshop contributors

Date	Location	Workshop Reference	Contributors
25/09/2018	Nattilik Heritage Centre	WKSP 2018a	David Siksik
			Uriash Puqiqnaq
			Saul Aqslaluq
			Tommy Tavalok
			Paul Kameemalik
			Peter Akkikungnaq
26/09/2018	Nattilik Heritage Centre	WKSP 2018b	Salomie Qitsualik
			Alissa Kameemalik
			Ruth Qirqqut
			Mary Aqilriaq
			Miriam Aglukkaq
			Susie Konana
26/09/2018	Nattilik Heritage Centre	WKSP 2018c	Adam Ukuqtunnuaq
			Jacob Keanik
			George Konana
27/09/2018	Gjoa Haven Hunters and Trappers Association	WKSP 2018d	Ben Putuguq
			Jimmy Qirqqut
			Simon Komangat
			Simon Hiqiniq Sr.
			Willie Aquptanguk
			Wayne Puqiqnaq
27/09/2018	Amundsen Inns North Hotel	WKSP 2018e	Gibson Porter
			Nicole Kununaq
			Betty Kogvik
			Sammy Kogvik
			Sarah Rosengard (researcher)
			Shelly Elverum (researcher)

The workshop plan was the same for the first four workshops, though discussions evolved naturally based on the diversity of contributors, so all topics were discussed by the focus and order varied between groups. Each workshop was broken into three sections, with breaks in between. The initial session (60-90 minutes) included introductions from researchers and contributors, and a review of Ljubicic's and Okpakok's past work focusing on Uqsuqtuurmiut knowledge of caribou, especially related to crossing areas. This facilitated discussions on sea ice as caribou habitat, describing sea ice conditions important for caribou movement and talking about freeze-up and break-up timing. The second session (60-90 minutes) focused on learning about community observations of sea ice conditions and ship traffic, including notable changes. We also showed some preliminary results of sea ice and shipping analysis to receive feedback on how to define sea ice conditions and thresholds relevant to use for caribou movement (Appendix 3). These materials were helpful in sparking discussions about defining sea ice and shipping analysis parameters according to locally important indicators, and contextualizing potential impacts on caribou according to community observations. We concluded the workshop discussions with a third session (30-60 minutes) to discuss approaches to Inuit knowledge representation and mapping from previous caribou research. At the end of the workshop Ljubicic and Okpakok reviewed the collective workshop consent forms (Appendix 4), and we all expressed our gratitude to the contributors for their time and generous sharing of their knowledge.

During our stay in Uqsuqtuuq we also joined one morning of the Ikaarvik: Barriers to Bridges meeting that was happening in the community at the same time. Ikaarvik is a program that aims to create opportunity for Inuit youth to learn about research done in their communities, and to connect researchers with youth to learn from community perspectives and priorities. The Ikaarvik program prioritizes exploring ways that Inuit knowledge and science can work together (Pederson et al. 2020). They invited us to share background on the evolution of our project, and they shared the work they were doing to test the SIKU app (https://siku.org/about) for community use. We also presented preliminary results to get feedback from the two youth and community mentors involved in Ikaarvik in Gjoa Haven, as well as Northern coordinator Shelly Elverum and SIKU coordinator Sarah Rosengard (Figure 3.9),

Figure 3.9 – Emmelie Paquette facilitating Workshop 5 with Ikaarvik youth and mentors in Uqsuqtuuq (September 27, 2018) (Photo: Erin Neave)

Between the workshops, Ljubicic met with representatives of the following organizations to provide updates and leave copies of previous caribou project reports, maps, and posters: Qikirtaq High School, the Nattilik Heritage Centre, the Kitikmeot Inuit Association, the Hamlet Council, the HTA, the Gjoa Haven Film Society.

3.2.2 – Reviewing workshop feedback

In all workshops we received permission from contributors to audio record and take notes throughout discussions. These recordings were brought back to Ottawa, ON to be compiled and transcribed. The English portions of audio recordings were transcribed during the fall of 2018, with additional notes used to complete inaudible portions and to identify the individual speaking wherever possible. In cases where the speaker could not be identified, they were listed as unknown [UN]. While transcribing audio recordings, key themes and messages shared during workshops and meetings were noted. These were used to develop a report of our visit to Uqsuqtuuq describing all of our activities within the community, and key points shared through discussions with Uqsuqtuurmiut (Appendix 5). Hard copies of this trip report were mailed to all contributors and supporting organizations to summarize our activities and outline next steps.

3.2.3 – Thematic content analysis

Thematic content analysis was used to identify and select passages from workshops that related to key research questions (see section 1) and discussion topics section 3.2), as well as emergent themes (Mojtaba Vaismoradi 2013, Mojtaba Vaismoradi and Snelgrove 2019). I initially used NVIVO to conduct a thematic content analysis on transcripts. However, I found the software limiting, and instead preferred to review and code themes using the hard copy of transcripts. This helped to organize Uqsuqtuurmiut contributions around relevant topics and seasons to inform sea ice and shipping analysis.

3.3 – Sea ice analysis

3.3.1 – Canadian Ice Service ice charts

The CIS produces weekly regional ice charts illustrating ice conditions within a given Arctic marine region (Figure 3.10), with a primary mandate of supporting safe ship navigation (Government of Canada 2005). To characterize ice conditions CIS ice forecasters use a combination of satellite imagery, ship and aircraft observations, and other climate information from weather stations and models to create spatial delineations of ice conditions (Government of Canada 2005, Crocker and Carierres 2000). To communicate these conditions, ice charts use what is called an “egg code” (Figure 3.11): a World Meteorological Organization standard for representing estimates of sea ice concentration, stage of development (Appendix 6), and form of ice (Appendix 7) (Government of Canada 2005). CIS image analysts delineate polygons within satellite images by similar ice conditions, and each of these polygons are assigned egg code values to indicate ice conditions within (Government of Canada 2005). All polygons are then combined to create regional charts (Government of Canada 2005). Sea ice concentration data is presented in tenths, which refers to the fraction of the water surface covered with sea ice (Government of Canada 2005). For example, an ice concentration of 9/10 represents 90% ice cover, which could be closely packed sea ice with minimal open water (Government of Canada 2005).

I used the weekly CIS regional ice charts for the Western Arctic (Figure 3.10) based on their consistency of availability (1983-2018), and the timeframe that also relates to relatively recent observations of caribou movement described by Uqsuqtuurmiut (see section 3.1.1; Ljubicic et al. 2018a). The inclusion of digital imagery in 1989, and the availability of RADARSAT satellite imagery since 1996, improved the accuracy and use of CIS products (Government of Canada 2005). Therefore, the variability of accuracy in earlier ice charts (1983-1996) is a potential limitation in the reliability of freeze-up and break-up calculations prior to 1996.

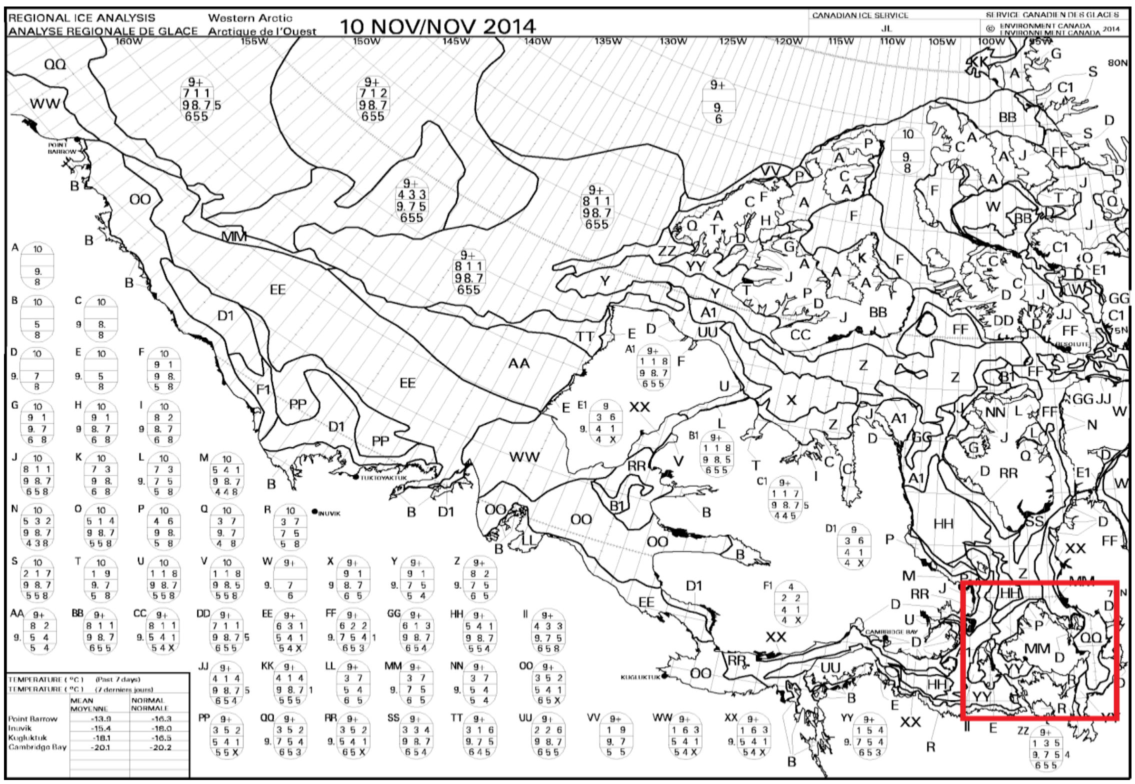

Figure 3.10 - Sample Weekly Regional Ice Chart - Western Arctic - 2014/11/10. Produced by Canadian Ice Service. KWI highlighted in red.

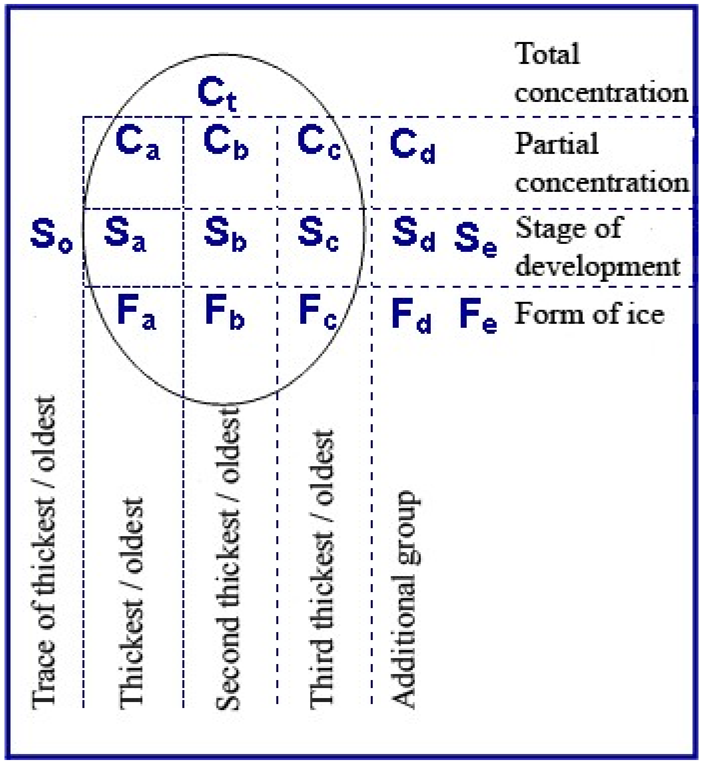

Figure 3.11 - Summary diagram of the Egg Code used by Canadian Ice Service to code sea ice and lake observation (Government of Canada 2005).

3.3.2 - Defining sea ice break-up/freeze-up thresholds and seasonal ice conditions needed for caribou movement

Break-up and freeze-up are commonly defined by CIS, and in the literature, as when the total ice concentration is below or above 5/10, respectively (Kowal et al. 2017; Personal communication, Monpetit 2018). This threshold is based on the capacity of ice-breaking ships to navigate in waters that are 50% ice cover, or less (Kowal et al. 2017). However, for the purposes of this thesis a 9/10 threshold was used, based on Uqsuqtuurmiut knowledge of minimum sea ice conditions needed to support caribou movement (WKSP 2018 a,b,c,d).

Workshop contributors described hikuhaaq (denoting a thickness of 10 cm cm) as the minimum stage of development for sea ice that caribou typically walk on (WKSP

2018a). Contributors also described that caribou walk on very compacted ice, because scattered and mobile ice floes may increase the risk of caribou falling into the water and drowning (WKSP 2018c). For our analysis to be relevant to the community, it was important to use locally defined thresholds that relate to caribou movement on the sea ice, rather than ship movement through the sea ice. Therefore, in calculations I defined break-up as occurring at the first instance when mean ice concentration within a caribou crossing area is below 9/10, and when the dominant ice type is thinner than new ice. Accordingly, freeze-up is defined as occurring when the mean ice concentration within a caribou crossing area is above 9/10, and when the dominant ice type is as thick or thicker than new ice. The length of open water season is the number of days between the break-up and freeze-up dates.

To calculate freeze-up and break-up timing from ice chart egg code values within the caribou migratory areas across years of available data, I adapted a Python code developed by Benoit Monpetit at ECCC (Appendix 8). The script uses the ArcGIS "arcpy" package to extract and calculate egg code values within specific polygons. Using the polygons created to represent the spatial blocks of the five caribou crossing areas (section 3.2, Figure 3.3), these are the general steps performed when running the script for each crossing area using weekly ice charts (1983-2018):

1) Each CIS chart is reprojected to "Lambert_Conformal_Conic" and clipped to the caribou crossing area of interest;
2) An object is created to read all egg code variables defining polygons within each caribou crossing area and a single output for each egg code variable is calculated per caribou crossing area polygon; and,
3) Three egg code variables are calculated: mean ice concentration, the dominant stage of development, and the dominant form of ice.

The resulting freeze-up and break-up dates, and ice conditions at the time, were then used in sea ice trend analysis (Section 3.5) and integrative analysis (Section 3.6)

3.3.3 – Defining the start of the seasonal sea ice cycle

After completing initial freeze-up and break-up calculations, I noticed that freeze-up occurred after January 1 in several years. This made trend analysis difficult, as annual trends were not capturing the full seasonal sea ice cycle. Therefore, I adjusted the dates to be associated with a different starting point in the sea ice cycle (i.e. to start on March 15) (Table 3.3). In this way, calculations of freeze-up and break-up could be represented in the same year. Maximum extent of Arctic sea ice typically occurs within the month of March; therefore, break-up occurs following this maximum extent. Table 3.3 describes annual dates and associated days of the cycle used in calculations.

3.4 – Shipping analysis

3.4.1 – Acquiring ship traffic data

Shipping data for this project was provided through a collaboration with Dr. Jackie Dawson and PhD student Melissa Weber from the Department of Geography, Geomatics and Environment at the University of Ottawa. Dawson recently led a multi-year and multi-community project to examine spatial and temporal changes to shipping traffic in Nunavut, Canada from 1990-2016 (Pizzolato et al. 2014, Pizzolato et al. 2016, Dawson et al. 2018, Dawson et al. 2020). Individual community reports accompanied the analysis that outlined community engagement strategies, and Inuit knowledge that was shared through participatory mapping, focus group discussions, and interviews, including in Uqsuqtuuq (Carter et al. 2017; 2019). Their shipping expertise, connection with

Uqsuqtuuq, and comprehensive shipping dataset was essential to connect sea ice analysis with shipping information to assess culminative potential impacts on caribou.

Table 3.3 - Annual dates and associated day of sea ice cycle used in the project.

Date	**Day of Cycle**
Mar 15	1
Mar 31	17
Apr 15	32
Apr 30	47
May 15	62
May 31	88
June 15	103
June 30	118
July 15	133
July 31	149
Aug 15	164
Aug 31	180
Sep 15	195
Sep 30	210
Oct 15	225
Oct 31	241
Nov 15	256
Nov 30	271
Dec 15	286
Dec 31	302
Jan 15	317
Jan 31	333

3.4.2 – Working with the ship traffic dataset

Dawson shared her shipping dataset according to a data sharing agreement with Ljubicic (Appendix 9). This dataset includes a recently developed geospatial database of ship traffic based on the Canadian Coast Guard (CCG) ship archive data for the NORDREG Zone from 1990 to 2016 (Pizzolato et al. 2014). NORDREG Zone regulations include voluntary requirements to report ship vessel and position information (S.C. 2005, c. 29, s. 18). Therefore, the dataset derived from the CCG archive includes positional data with daily, and sub-daily information for all vessels types within the NORDREG zone. The dataset includes ship name, call sign, International Maritime Organization (IMO) number, entry and exit dates of the NORDREG zone and other non-spatial characteristics.

Dawson's team streamlined the CCG dataset to facilitate later statistical analysis. The data was geo-located using the least-cost path (LCP) approach that considered three variables: 1) distance to land, 2) bathymetric data (ETOPO2v2), and 3) sea ice data (CISDA). Ship types were reclassified into 10 categories based on their purpose and potential environmental threat (Pizzolato et al. 2014, 2016) including the following within our area of interest: Bulk Carriers, General Cargo, Government Vessels and Icebreakers, Passenger Ships, Pleasure Crafts, Tanker Ships, and Tugs/Barges (Appendix 10).

Weber facilitated the shipping data preparation to share for use in my thesis research. Shapefiles of all Block crossings were provided to Weber in the summer of 2018. These were used to extract relevant variables representing ship movement and presence within each caribou crossing area, including:

1) Annual date of the first ship (across all ship types) to enter each caribou crossing area;
2) Annual date of last ship (across all ship types) to exit each caribou crossing area;
3) Annual distance travelled in kilometers (across all ship types) within each caribou crossing area;
4) Annual number of ships (across all ship types) within each caribou crossing area; and,
5) Maps of ship tracks within caribou crossing areas between 2011-2016.

The temporal scope of ship transit analysis is from 1990 to 2016, based on availability of data sources and uses the full range of the data provided by Dawson.

Ships have distinct environmental impacts depending on vessel type, and thus concerns regarding ship traffic may not be consistent across types (Dawson et al., 2017). All ship types present in the Kitikmeot region were considered in our analysis, including: government vessels and icebreakers, general cargo, bulk carriers, tanker ships, passenger ships, pleasure craft, and tug/barge (Appendix 10). So our results include all ships, but our discussion focuses mainly on government vessels and ice-breakers due to concerns expressed by workshop contributions (WKSP 2018a,b,c,d) about the potential disruptive impact of ice-strengthened ships on caribou crossings.

3.5 - Trend Analysis

Autocorrelation was assessed prior to trend analysis using correlogram plotting (Autocorrelation Function (ACF) plot). Trends in sea ice freeze-up and break-up timing, as well as in ship entry/exit and length of shipping season, were assessed for significance using a Mann-Kendall test to detect monotonic trends over all variables. Slopes of significant trends were determined using Sen's slope to calculate the magnitude of the observed trends (Polhert et al. 2018).

3.6 - Integrative Analysis

In order to examine the relationship between ship traffic and ice conditions that vessels encounter during first entry or last exit of caribou crossing areas, I calculated the difference between the date of first ship entry and date of freeze-up each year, in each crossing area. Similarly, I also calculated the difference between the date of last ship exit and date of break-up each year, for each crossing area. Ship entry/exit date was subtracted from observed date of break-up/freeze-up in years where data from both datasets are available (1990-2016). Therefore, a ship that enters a caribou crossing area before break-up will produce a negative value, whereas a ship that enters after break-up will produce a positive value. Conversely, a ship that exits a caribou crossing area before freeze-up will produce a positive value, while a ship that exits after freeze-up will produce a negative value. Sea ice years with negative values highlight when ship traffic was present during periods of useable caribou sea ice habitat in each crossing area, and thus indicate years of greater potential for disruptive impacts of shipping.

Chapter 4: Results

Uqsuqtuurmiut who contributed through community workshops observe – and experience – dynamic, changing environmental conditions every day. As Alissa Kameemalik remarked in WKSP (2018b), “Even Elders today are saying - Are the months falling behind? Or are the months going forward to fast? That comes from the Elders in the community, cause we all know the effects of the climate change, makes everything change.” Contributors discussed caribou movements, sea ice conditions, and potential impacts of shipping in five important caribou sea ice crossing areas documented in previous research (Ljubicic et al. 2018a,b). However, they also emphasized that although these crossing areas are wide, and they are based on previous maps created by Elders and hunters, these should not be confused with specific routes that caribou follow year after year (Ljubicic et al. 2018a). Throughout the previous project lead by Ljubicic and Okpakok (Ljubicic 2018a), Elders emphasized that caribou are mobile animals whose movements are highly variable and dependent on conditions present in their environment at the time: “They are not a permanent resident so they are always moving around” (Workshop 2013a, Ljubicic et al. 2018a, p. 225). Therefore, the lines drawn and represented in Figure 3.1 do not represent specific linear features of caribou movement but indications of caribou crossing areas with bi-directional flow. Caribou respond to changing conditions related to weather, sea ice, predators, food availability, insects, and human disturbance (Poole et al. 2010; Johnson et al. 2016; Mallory and Boyce 2017). Therefore, as we were reminded by Uqsuqtuurmiut, it is important to consider the sea ice habitat we are discussing as highly variable, and that caribou may shift their routes or behaviour in response to climatic and anthropogenic change (WKSP 2018a,b,e). As

Gibson Porter noted in WKSP (2018e), growing ship traffic could influence future caribou movements: “And just thinking about it, like in the future, like years from now, if there is shipping going through, the caribou routes are going to be different.”

Our project aims to describe the seasonal and inter-annual relationships between caribou, ship traffic and sea ice habitat (Figure 3.3). Therefore, the presentation of results is organized according to fall freeze-up, spring break-up, and summer open water seasons. Aglukkaq (WKSP 2018b) described their personal understanding of this relationship between caribou and the dynamic sea ice - “But perhaps it is the movement of caribou that is based on the time changing, because I know for an actual fact that the climate has an effect on caribou. They move to the mainland before the cold season starts.”

4.1 – Fall freeze-up

4.1.1 – Uqsuqtuurmiut knowledge of freeze-up conditions

According to contributors, caribou begin to cross on sea ice in the fall when sufficient sea ice conditions are available (WKSP 2018c,d). Putuguq (WKSP 2018c) explained that hikuaq (new ice) is reliable for caribou to move on. However, he highlighted that these conditions can develop and change rapidly.

Across all workshops, we heard from contributors that the timing of sea ice freeze-up spatially varies within a region according to the geography, climate and marine conditions (WKSP 2018a,b,c,d). One important geographical feature identified as influencing freeze-up timing is the proximity to KWI or the mainland. The ground of the mainland is warmer than that of the island, and thereby, influences the timing of freeze-up of coastal sea ice (WKSP 2018a,b). Water current strength was also highlighted as a potential influence on sea ice freeze-up. George Konana explained in WKSP (2018c), "On those charts that are on the map, the freeze-ups are all different, based on the current, a strong current or weak current." Factors impacting sea ice conditions can be described individually, however, all factors may impact the timing of freeze-up simultaneously. Akkikunagnaq described a lesson he learned from his father, noting the similarities in freeze-up timing between different water bodies and the role of these as indicators of safe sea ice travel for Uqsuqtuurmiut - "[My] late father said when the little bay here [pointing to the map] freezes and you can walk on it, then the narrow strait is frozen - all the way across (WKSP 2018a)." He was describing a bay to the south of KWI (no name available), which had similar timing as the S-crossing area. These small water bodies are narrow/small enough to limit the impacts of large waves that can delay ice formation (WKSP 2018a). George Konana also described bays as places where the sea ice first begins to form (WKSP 2018c). Alissa Kameemalik has also observed this from the air when flying between communities, where she has seen areas of open water within the NW, NE and S-crossing areas in the fall: "All I know is that the narrow part freezes-up much earlier…the smaller body freezes up earlier than the larger body of water. After the narrow part freezes up….Then the larger [water bodies] will then go [freeze-up] after (WKSP 2018b)."

In WKSP (2018c), Ukuqtunnuaq explained that freeze-up occurs simultaneously with the annual increase in caribou movement in the area. Aqslaluq (WKSP 2018a) explained that many caribou move just after freeze-up even if they encounter open water "because they know they need to get to the place they are going." Aglukkaq (WKSP 2018b) also described her observations of caribou moving along the southern shore of

KWI in search of a suitable place to cross towards the mainland, which can occur relatively close to the community. In WKSP (2018b) it was also noted that caribou can swim long distances, and therefore some may cross from the island to the mainland prior to freeze-up.

In WKSP (2018b) contributors explained that the caribou who moved to KWI in the spring for calving use the same route to move back to the mainland in the early fall. They added that this movement begins when calves born on the island are strong enough to move with their mother off of the island to avoid the colder temperatures on the island (compared to the mainland) during the winter. In addition, it was explained that this movement begins before the cold season starts, when the island vegetation is very poor and increasingly common rain-on-snow events further limits the ability of caribou to access the remaining vegetation on the island (WKSP 2018a). Caribou are motivated to move to the mainland where food is more abundant and accessible. Contributors who worked with Ljubicic et al. (2018a) described that this caribou movement typically begins in September; however, contributors in the 2018 workshops described caribou moving across sea ice in October. The timing of caribou will continue to change if they need to adjust their movements due to changing environmental conditions.

In WKSP (2018a) contributors discussed the difficulty caribou face when they fall into open water during their movement on the sea ice. The quickly formed thin new ice often present in the fall is susceptible to breaking as caribou attempt to climb on top, and the water is much colder than in the spring, further restricting movement and preventing their recovery onto the ice (WKSP 2018b). It was explained that caribou, and specifically males and caribou calves (due to their respective large size, and lack of agility) struggle to recover onto the ice if they fall in because the ice is wet and slippery. In addition, if the ice is thick enough it can prevent them from hooking their hooves onto the ice and pulling themselves back onto the surface. Aqslaluq noted the impacts of the weight that caribou gain through summer grazing can affect their ability to recover onto sea ice if they fall into open water. He described “Only two bull caribou can go on ice, because if they are heavy they fall in they can't get back up” (WKSP 2018a). He went on to describe that these conditions enable Uqsuqtuurmiut to hunt caribou in the water, while they are unable to recover in the fall on the wet ice.

Although most discussions focused on caribou movement and critical sea ice habitat, some concern for ship traffic was mentioned. There are concerns for ships passing by that have ice-breaking capacity, especially if ship activity increases during periods of caribou movement in early stages of freeze-up (WKSP 2018b). In WKSP (2018c) contributors talked about observing an increase in ship traffic in the NE-crossing area in the past 5 years, expressing their belief that ship traffic may be contributing to the decreased use of calving areas on the NE coast of KWI. Caribou movement and critical sea ice habitat were more commonly discussed in all workshops than local ship traffic and related impacts on caribou. There is limited community concern during mid-winter as caribou movement slows, and to date no shipping occurs in the winter (WKSP 2018b, Carter et al. 2017). However, the potential for future winter shipping was highlighted by contributors as a concern, as this greatly disrupt both Inuit and caribou use of sea ice as a travel platform (WKSP 2018c).

The following sections provide further examples of Uqsqutuurmiut knowledge regarding NW, NE, and S-caribou crossing areas. Other crossing areas were not specifically discussed.

Northwest Caribou Crossing Area

Uqsuqtuurmiut described general observations of sea ice change over time in the Northwest caribou crossing area; however, it was clearly expressed that there is significant interannual variation in the timing of freeze-up and break-up. Local variability in sea ice presence in this area was noted by Aqslaluq (WKSP 2018a), as he described his experience in the area over time: "One year in the month of September (1972), no water to be seen, you could walk on ice from the land. The following year, the same place and there was no ice."

Northeast Caribou Crossing Area

Contributors in WKSP (2018c) described parallels between the NW and NE-crossing areas, noting the delayed timing in sea ice freeze-up in each area due to strong currents breaking apart early stages of sea ice, bringing water with different temperatures and a potential for mobile ice. Parallels were also drawn between the timing of freeze-up in the NE and S-crossing areas. Keanik and Konana noted that both crossings now freeze progressively later, towards early November (WKSP 2018c). Keanik noted that the NE-crossing area has large amounts of old ice moving from further north. However, he described that in the past 5 years the amount of old ice present has significantly diminished (WKSP 2018c).

South Caribou Crossing Area

Sea ice conditions and the timing of freeze-up and break-up within the S-crossing area (Figure 3.3) were frequently discussed amongst all workshop contributors.

Uqsuqtuurmiut described the importance of the S-crossing area for Inuit travel, and caribou movement (WKSP 2018a,b,c,d). The proximity of the S-crossing area to the community facilitates access compared to other crossing areas, and its narrow width reduces travel time to access the mainland. In addition, the S-crossing area freezes earlier than other crossings in the fall, and so may allow for earlier travel/movement and creates more opportunities for caribou hunting.

Uqsuqtuurmiut spent the most time discussing timing of freeze-up in the S-crossing area, as it is the most used by caribou and people. Akkikungnaq explained his experiences travelling from KWI to Richardson Point on newly formed ice on a snow machine in September of 1972. However, Akkikungnaq affirmed that there is interannual variation in the timing of freeze-up in the S-crossing area (WKSP 2018a).

Workshop contributors observed the entire S-crossing to be frozen from KWI to the mainland by the end of October in the early 1980s (WKSP 2018a). Aglukkaq (WKSP 2018b) described how a freshwater bay near Uqsuqtuuq is used as an indicator of the start of sea ice freeze-up in the S-crossing area: “From what I know, when we first moved to Gjoa Haven, the freeze-up for Swan Lake starts in September and part of the beginning of October the bay [no name available] freezes up. Once the bay freezes up larger areas start freezing up.” Qitsualik added that Chantrey Inlet was typically frozen by mid-October, and caribou would start moving through the area as they went inland for the winter after spending the summer on KWI (WKSP 2018b).

Tavalok (WKSP 2018d) described other conditions that may impact the earlier freeze-up timing of the S-crossing: “My own reason for why that [S-crossing area] freezes up earlier than any other water body is because it is narrow with small creeks flowing into that area that decreases the salt in the sea water. So that could be one of the reasons it could freeze up earlier...more freshwater flows there.” The low surface salinity in this area may expediate freeze-up in this area.

Contributors described that the fall movement of caribou from KWI towards the mainland begins in October and results in many caribou being observed around Uqsuqtuuq. The movement begins from the calving areas on the northeast of the island and moving towards the narrow S-crossing area (WKSP 2018c). Caribou may move westward and southward towards the coastline of the S-crossing area where they congregate prior to crossing (WKSP 2018c,d). In WKSP (2018c) Qitusalik described her observations of caribou at S-crossing area: “So at this time of year (late October), I would go to the narrow part. I have noticed that the caribou do congregate around that area to wait for the freeze-up to cross-over. At times I could see some caribou swimming over before the freeze-up.”

In WKSP (2018c) Putuguq described his observations of caribou reacting to sea ice formation: “From my own knowledge, from what I have heard and seen, when the weather starts cooling down, like today, the caribou would start moving through the narrow part. Most of them are waiting for the freeze-up, but a certain number can swim across, and I heard that some do swim across. But most would wait for the freeze-up around the southern part of the island.” He clarified that this movement is most intense in late October in the S-crossing area.

All contributors explained their concern for, and understanding of, the impacts of climate change on changing sea ice conditions. Aglukkaq (WKSP 2018b) explained that freeze-up used to start at the end of September but expressed concerns of it occurring later (did not specify when): “With climate change, now freeze-up is happening much much later. … With climate change it is hard to predict when it will happen because it seems to have shorter winters because of late freeze up, and longer summer because of the late freeze-up.” Contributors (WKSP 2018c) shared impacts of unpredictable and changing sea ice on their ability to use Simpson Strait for travel. The narrow passage within the S-crossing area is not always frozen in time for travel and as a result, Ukuqtunnuaq at times takes a longer route to cross to the mainland in the fall in order to avoid open water.

4.1.2 - Sea ice trend analysis for freeze-up timing

Sea ice analysis demonstrated no statistically significant changes in freeze-up timing in each caribou crossing areas (Appendix 1, Appendix 11), and no autocorrelation was detected. Nevertheless, below I review the qualitative patterns observed over time for each of the 5 crossing areas (Table 4.1, Figure 4.1).

Northwest Caribou Crossing Area

No significant trends were observed in the timing of freeze-up in the NW-crossing area, with freeze-up ranging from Sept 07 (1989) to Nov 25 (2002; 2004). In the majority of years freeze-up occurred between Sept 20 and Oct 25. Freeze-up conditions ranged from big floe to fast ice, and consisted of a variety of stages of ice (Figure 4.1). The majority of stages observed at freeze-up were medium first-year ice, second year ice, old ice, and multi-year ice. Multi-year ice was more abundant in the NW-crossing area compared to other crossing areas (i.e. in 7 sea ice years across the time period). Freeze-up conditions were not met in 14 sea ice years in the NW-crossing area. In these years, sea ice concentration did not exceed 7-8 tenths.

Table 4.1 - Summary of sea ice freeze-up dates by crossing area between 1983-2018.

	NW	NE	E	S	W
Trend (# of freeze-up dates: p-value)	24:0.28	32: 0.58	35:0.51	35:1	24:0.15
Date of earliest freeze-up	Sept 07, 1989	Sept 03, 1989	Aug 11, 2009	Aug 11, 2009	Aug 29, 1987
Date of latest freeze-up	Nov 25, 2002; 2004	Oct 20, 2010	Oct 06, 2010	Sept 24, 2010	Jan 11, 2017
Median date of freeze-up	Oct 14	Sept 14	Sept 11	Sept 06	Oct 22
Percentage of freeze-ups with dominant stage of ice (%)					
New Ice		6%	3%	3%	
Grey-white Ice		7%	17%	28%	
Thin First -year Ice	20%	69%	81%	66%	26%
Medium First-year Ice	28%	6%			25%
Thick First-year Ice					21%
Second-year Ice				3%	
Multi-year Ice	36%	12%			21%
Old Ice	16%				8%
Percentage of freeze-ups with listed form of ice (%)					
Pancake Ice			2.78%	2.78%	
Small Floe		3.03%		8.33%	4.17%
Medium Floe	4%	3.03%		5.56%	
Big Floe	28.00%	21.21%	11.11%	11.11%	29.17%
Vast Floe	24.00%	12.12%	8.33%	5.56%	12.50%
Fast Ice	44.00%	60.61%	77.78%	66.67%	54.17%
Years without freeze-up (%)					
	40.00%	8.57%			31.43%

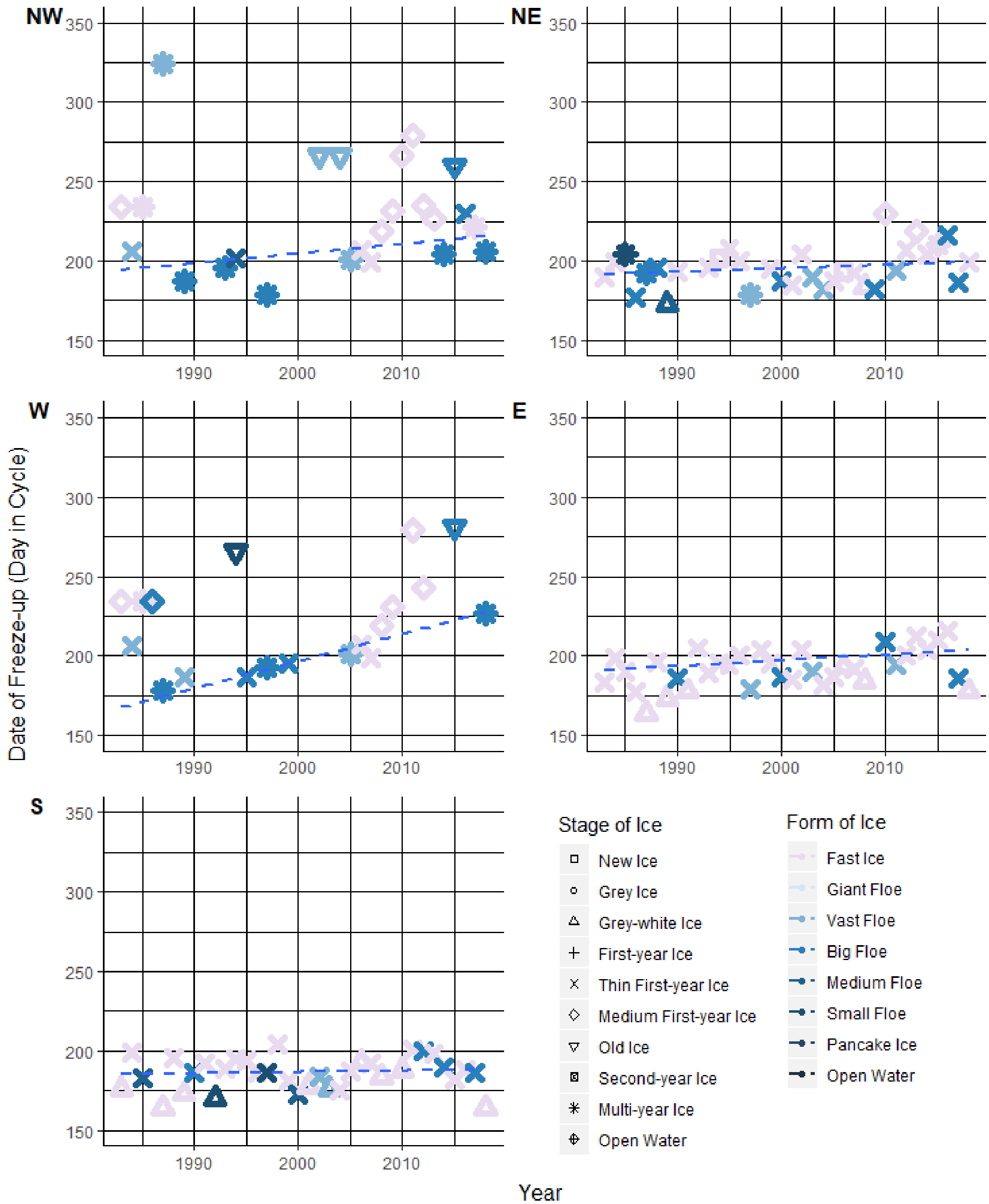

Figure 4.1 - Dates of sea ice freeze-up between 1983-2018 ice sea ice years within crossing areas (Day 01 - Mar 15, Day 103 - June 15, Day 195 - Sep 15, Day 317 - Jan 15). Dashed blue lines represent non-statistically significant Theil-Sen trend lines.

Northeast Caribou Crossing Area

Freeze-up occurred in the NE-crossing area between Sept 03 (1989) and Oct 20 (2010), with the majority of years ranging from Sept 20 to Oct 25. Freeze-up observed in the NE-crossing area was more consistent throughout the years than the NW-crossing area (Figure 4.1). Freeze-up conditions were not met in 3 sea ice years (1991, 1992, 1998), which coincided with years that freeze-up did not occur in the NW-crossing area. The majority of ice stages observed at the time of freeze-up were thin to medium first year ice, with some (>5) instances of new ice, grey-white ice, and multi-year ice throughout the time period (Figure 4.1).

East Caribou Crossing Area

Freeze-up occurred between Aug 11 (2009) and October 06 (2010). Freeze-up in this eastern crossing occurs earlier than NW and NE-crossing areas, likely due to it being a smaller, narrower body of water. Stages and forms of ice in the E-crossing area were very consistent across the timeframe with thin first-year ice occurring 29 times, and fast ice observed 28 times across 35 sea ice years (Figure 4.1). There were few years where other ice stages and forms occurred, with the exception of pancake ice (new ice - Aug 11, 2009), and several instances of big and vast floes. Date of freeze-up, and sea ice conditions observed at time of freeze-up were similar between years within E-crossing area; ex. thin first-year ice was observed as a big floe on Sept 6, 1990 and on Sept 7, 2000. The z-value for all crossing areas were positive, meaning values in the last decade fall above the population means, and indicating a potential change in recent years towards later freeze-up (although not detected as a significant trend) (Appendix 11).

South Caribou Crossing Area

Freeze-up in the S-crossing area occurred between Aug 11 (2009) and Sept 24 (2010), with most years ranging from Aug 21 to Sept 15. Like the E-crossing, stages and forms of ice at dates of freeze-up were very consistent across the time period in the S-crossing. While most sea ice years observed thin-first year ice at the time of freeze-up (24 dates), grey-white ice (10 dates) was more common than in the E-crossing area. Fast ice was most often observed at the date of freeze-up across sea ice years (24 dates). Thicker second-year ice was observed on Aug 28 1986 (small floes with second-year ice), and suggests conditions within 1985 and 1986 enabled sea ice to remain over a summer season, or the area captured older pieces of mobile ice from more northern waters (Figure 4.1).

West Caribou Crossing Area

No significant trends were observed in freeze-up dates in the W-crossing area and freeze-up occurred between Aug 29 (1987) and Jan 11 (2017). Freeze-up occurs later in the W-crossing than any of the other crossing areas, with the latest date of freeze-up being recorded in 2017 (Jan 11). Stages and forms of ice varied greatly amongst annual cycles of sea ice freeze-up. All forms of ice except giant floes were observed multiple times in the W-crossing, as was common in the S-crossing (Figure 4.1). However, unlike other crossings, stages of ice varied amongst sea ice years, and fast ice was observed less often (<10 dates).

4.1.3 - Ship exit trend analysis during freeze-up

Mann-Kendall and Sen's slope analyses were conducted on dates of ship exit (day of year) in each crossing area amongst ship types. Bulk carrier ships and ships designated as "Other" occurred less than 3 times within the time period, and were not considered in the remainder of the results due to their small sample size and resulting minimal potential to impact caribou sea ice habitat. Table 4.2 and Figure 4.2 summarize the timing of the last ship to exit each crossing, by ship type.

Table 4.2 - Summary of the timing of the last ship exit from each crossing area between 1990-2016 (bolded values in table represent statistically significant trends ($p<0.05$).

	NW	**NE**	**E**	**S**	**W**
All Ships					
Earliest date of ship exit	July 29, 1993	Aug 20, 2006	Aug 13, 2001	Aug 14, 1994	July 20, 1993
Latest date of ship exit	Oct 26, 2015	Oct 17, 2007	Oct 19, 2008	Oct 22, 2008	Oct 26, 2015
Government Vessels and Icebreakers					
Trend (# of dates of ship exit of type; sen's slope (p-value)).	27; 0.1	27; 0.12	27; 0.45	27; 0.23	**27; 1.61 (0.00)**
Earliest date of ship exit	Aug 08, 2000	Aug 26, 1995, 2012	Aug 20, 2003	Aug 23, 2007	Aug 15, 1993
Latest date of ship exit	Oct 26, 2015	Oct 16, 2010	Oct 16, 2011	Oct 22, 2008	Oct 26, 2015
% of years present	100%	100%	100%	100%	100%
General Cargo					
Trend (# of dates of ship exit of type; sen's slope (p-value)).	**10; 3.5 (0.02)**	9; 0.34	9; 0.14	3; 0.3	10; 0.18
Earliest date of ship exit	Sept 01, 2001	Sept 08, 2016	Sept 06, 2016,	Aug 27, 2013	Sept 06, 2014
Latest date of ship exit	Oct 05, 2016	Sept 30, 2013	Sept 21, 2013	Oct 19, 2009	Oct 05, 2016

% of years present	37.04%	33.33%	33.33%	11.11%	37.04%
Pleasure Crafts					
Trend (# of dates of ship exit of type; sen's slope (p-value))	12; 0.17	17; 0.11	16; 0.11	12; 0.1	**12; 3 (0.0)**
Earliest date of ship exit	Aug 22, 2007	Aug 13, 2001	Aug 13, 2001	Aug 14, 1994	July 20, 1993
Latest date of ship exit	Sept 26, 2013	Sept 03, 2013	Sept 19, 2012	Oct 16, 2010	Sept 26, 2013
% of years present	44.44%	62.96%	59.26%	44.44%	44.44%
Passenger					
Trend (# of dates of ship exit of type; sen's slope (p-value)).	**25; 0.61 (0.03)**	11; 0.09	11; 0.09	06; 0.45	**26; -1.225 (0.01)**
Earliest date of ship exit	July 29, 1993	Aug 20, 2006	Aug 20, 2006	Aug 23, 2006	Aug 23, 2000
Latest date of ship exit	Oct 17, 2002	Sept 26, 2010	Sept 25, 2010	Sept 25, 2009	Oct 22, 1998
% of years present	92.59%	40.74%	40.74%	22.22%	96.30%
Tanker					
Trend (# of dates of ship exit of type; sen's slope (p-value)).	**7; 3.5 (0.01)**	7; 0.34	7; 0.14	6; 0.3	7; 0 .18
Earliest date of ship exit	Sept 16, 2014	Sept 11, 2012	Sept 06, 2012	Aug 18, 2011	Sept 05, 2016
Latest date of ship exit	Oct 06, 2015	Oct 05, 2015	Sept 29, 2015	Sept 25, 2010	Oct 06, 2015
% of years present	25.93%	25.93%	25.93%	22.22%	25.93%
Tug/Barge					
Trend (# of dates of ship exit of type; sen's slope (p-value)).	**21; 0.718 (0.01)**	**26; 0.5 (0.08)**	**25; 0.5 (0.01)**	26; 0.07	26; 0. 17
Earliest date of ship exit	Aug 14, 1992	Sept 10, 1994	Sept 10, 1994	Aug 19, 2008	July 30, 2001

Latest date of ship exit	Oct 12, 2012	Oct 17, 2007	Oct 19, 2008	Sept 29, 2005	Oct 12, 2002
% of years present	96.30%	96.30%	96.30%	96.30%	85.19%

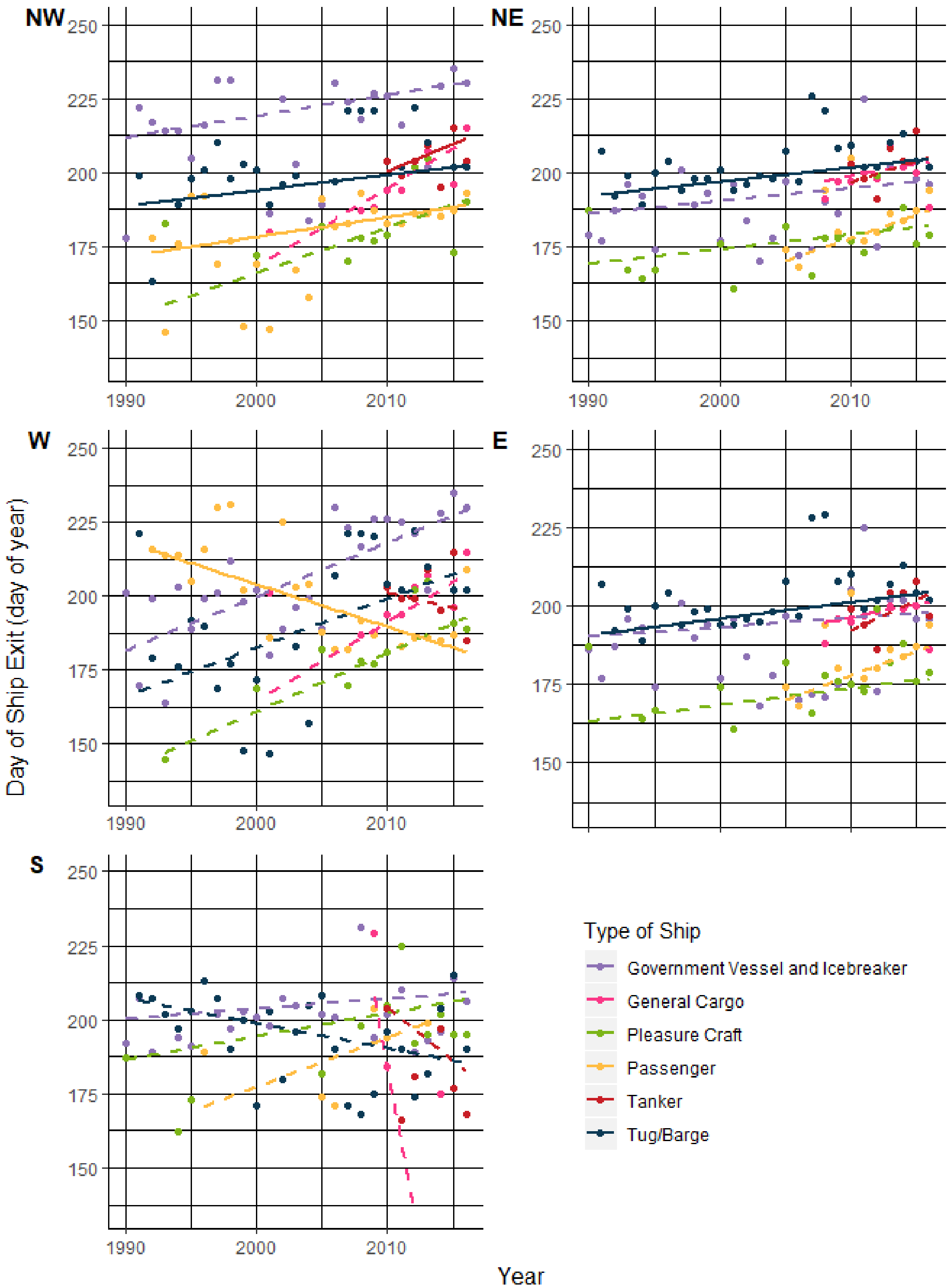

Figure 4.2 - Dates of ship exit (designated by ship type) into each crossing (represented as day of year; Day 01 - Mar 15, Day 103 - June 15, Day 195 - Sep 15, Day 317 - Jan 15) Dashed (non-statistically significant) and solid (statistically significant) lines represent Theil-Sen trend lines (p-value = 0.05).

Northwest Caribou Crossing Area

Dates of ship exit amongst all ship types ranged from July 29 (1993) to Oct 26 (2015) (Figure 4.3). The range of dates representing ship exit were varied based on ship types, with some differences in ship exit between types. Tanker ships were present in the NW-crossing area following 2010 and were observed to exit the area late in the shipping season from Sept 16 (2014) to Nov 06 (2015). This is relative to the earlier exits of pleasure crafts ranging from Aug 22 (2007) to Sept 26 (2013), and shows that the timing of exit is related to ship type (and likely to their capacity to navigate in ice-filled waters).

Mann-Kendall analysis detected significant trends in the timing of ship exit for general cargo ($p = 0.015$), passenger ($p = 0.033$), tanker ($p = 0.015$), and tug/barge ($p = 0.012$) ships. General cargo and tanker ships exhibited a trend towards ships exiting 3.5 days earlier per year (Appendix 12, Table 4.2). Passenger and tug/barge ships experienced the smallest changes in the timing of ship exit (0.6 days/yr and 0.7 days/yr earlier, respectively) (Appendix 12, Table 4.2). This suggests similarities in patterns of change amongst some ship types, with general cargo and tanker, passenger and tug/barge respectively changing at similar rates (Figure 4.2).

Northeast Caribou Crossing Area

Ship exits observed in the NE-crossing area ranged from Aug 20 (2006) to Oct 17 (2007) amongst all ship types. Tug/barge were the latest ships to leave the crossing area ranging from Sept 10 (1994) to Oct 17 (2007), which is later than tug/barge ships in the NW-crossing area. This was also the only crossing-area observed to exhibit significant change towards later ship exit (i.e. 0.5 days/year for tug/barge ships, $p = 0.07$).

Government vessels and icebreakers were present in all years, and pleasure crafts were present 17 times throughout the timeframe, suggesting the potential for long-term impact of these ship types on caribou habitats. General cargo, passenger and tanker ships begin to make voyages in the NE-crossing in later years (after 2005, 2008, 2010 respectively (Figure 4.2).

East Caribou Crossing Area

Ship exits observed in the E-crossing area range from Aug 13 (2001) to Oct 19 (2008) amongst all ship types. Like the NE-crossing area, a significant trend is observed in the timing of tug/barge ship exit ($p = 0.013$), at the same rate of change towards later exit of 0.5 days/year (Appendix 12, Table 4.2). Also, like the NE-crossing area, tug/barge ships left the E-crossing area later than other areas.

South Caribou Crossing Area

No significant trends were observed in the timing of ship exit in the S-crossing area. Ship exits ranged from Aug 14 (1994) to Oct 22 (2008). The staggered exit of ships observed in other crossings was not apparent in the S-crossing area, all ship types had similar ranges of entry (Figure 4.2).

Like the NE-crossing area, tanker ships started to be present in the S-crossing area after 2010. Passenger ships were the second least abundant in the S-crossing, observed only 6 times between 1990-2016 (1996, 2005, 2006, 2009, 2010, 2013). General cargo was the least common in the S-crossing, observed 3 times in the later years (2009, 2010, 2014).

West Caribou Crossing Area

The timing of ship exit ranged from July 20 (1993) to Oct (2015), the widest range of dates. As was observed in the S-crossing, the timing of ship exit out of the W-crossing varied across years within ship types, providing little to no evidence for the staggered exits of the Northern crossing areas.

Government vessels and icebreakers experienced significant change towards later exit of crossing areas at changing at a rate of 1.6 days/year; between 1990-2000 values. Pleasure craft ships changed at a rate of 3 days/year towards later freeze-up and were observed 12 times in the period. However, passenger ships have changed towards an earlier exit during our time period at a high rate of 1.2 days/year (details of sen's slope and z-value in Appendix). All trends of ship types had high standards of deviation, meaning these trends may represent relatively varied/sporadic values (z = 3.678, 3.086, -2.505, respectively).

4.2 – Spring break-up

4.2.1 – Uqsuqtuurmiut knowledge of break-up

Qitsualik (WKSP 2018b) described break-up timing: "I know that sea ice break-up around Gjoa Haven is in the month of July, and before that is when caribou are crossing over on the ice." By understanding sea ice features (including the definition of break-up), several contributors described that the break-up of sea ice in one area can be used as an indicator of potential break-up in another area (WKSP 2018b). Careful observation of ice conditions in specific places enables Inuit to understand the temporal sequence of sea ice availability around KWI that could be used for caribou movement (as well as their own travel).

Many Uqsuqtuurmiut contributors described caribou movement wherein caribou interact with sea ice during break-up. Caribou may attempt to cross the sea ice in the spring but some Uqsuqtuurmiut have observed caribou not crossing or attempting to swim across straits in the spring (WKSP 2018c,d). These interactions are particularly prominent during springtime caribou movement: "Caribou walk across to KWI, but the movement, especially in the springtime, crosses over in large numbers" (Qitsualik in WKSP 2018c). The ice conditions that caribou encounter along the coastal zone impact their ability to cross sea ice habitat and move from the mainland to the island. In WKSP (2018d), Hiqniq described sightings of caribou drowned or frozen in a lead in the spring, which he believes fell into the water and were unable to recover onto the ice. Contributors in WKSP (2018d), added that breaking sea ice, and newly formed cracks can lead to caribou falling into the water and being unable to recover onto the mobile or cracking ice, drowning. In WKSP (2018d), it was explained that it is difficult to assess caribou interactions with open water across the whole ice region, so it is not possible to estimate the number of caribou that die by drowning/freezing each year.

In WKSP (2018a), it was explained that spring ice conditions pose challenges to caribou and impacts their ability to recover onto the sea ice. Fallen caribou struggle to recover onto the sea ice, because spring sea ice is often above the water level due greater sea ice thickness in the spring compared to new ice formation in the fall, making it difficult for caribou to grasp onto and pull themselves up onto the sea ice. Thick spring sea ice means that caribou may slide back into the water in their attempts to recover onto the sea ice (WKSP 2018c). As he facilitated WKSP (2018a), Okpakok described a moment he observed of caribou struggling to cross sea ice migratory areas in late spring as the ice was thinning and breaking apart: “The ice had become very thin and dark. In the month of July, I saw two caribou crossing over. They were going very very slow, to check if ice is strong enough to hold, sort of moving back and forth to see if it can hold. One went through the ice to see if it could hold. Because of the texture of the ice, the caribou managed to get back on the ice. The caribou fell in the water three times while trying to cross to the island. Caribou fell into the water, didn't take long 60-65 seconds before getting back on the ice. It seems to put its hooves forward, and then pull itself forward. It latches onto nearby ice, and scoots back onto the ice. And perhaps that happens all the time, they manage to get back on the ice. The ice was thin enough, pretty much level with sea water. So maybe that makes a difference.”

The following sections provide further examples of Uqsuqtuurmiut knowledge regarding NE and S-caribou crossing areas. Most of the discussion focused on the S-crossing area in the spring due to the importance of this crossing to facilitate the movement of caribou (and people) between the mainland and KWI. Other crossing areas were not specifically discussed.

Northeast Caribou Crossing Area

Contributors in WKSP (2018c) explained that caribou can move through the NE-crossing area to the island beginning in March or April; however, it was also discussed that caribou are most common in the area between June and July (WKSP 2018c,d). Caribou movements occur just before the coastline ice melts (WKSP 2018c).

South Caribou Crossing Area

This narrow area has unique environmental properties that may impact timing and conditions of sea ice break-up (WKSP 2018b,c). In WKSP (2018c), Ukuqtuunuaq described his experiences on the sea ice in early spring, observing the strong current cause the ice to thin from underneath the surface: "In May, I think, I have gone across and you could see little blacks holes. I didn't see right away. But when I kept going, you could see another one and another one, I kept seeing holes, and you could see the current and it was covered in snow." The strong currents are also a key factor in the earlier timing of break-up in the S-crossing, where open water is present by July. However, the narrow width of the S-crossing area may offset the effect of currents on sea ice formation in the fall, with freeze-up timing compared to other crossing areas (despite its earlier break-up timing) (WKSP 2018b). In WKSP (2018b), Alissa Kameemalik explained that the narrow expanse of the S-crossing leads to fewer and smaller waves that do not disturb or alter sea ice break-up and freeze-up compared to larger water bodies with large waves.

It was clarified that caribou movement in the S-crossing begins in April with initial sightings of caribou in the Back River area, and caribou become most common in S-crossing area between May and July (WKSP 2018b). Contributors described that caribou move to the shore of the northern mainland and look for a place to cross onto KWI (WKSP 2018b,c). In WKSP (2018c), it was described that this northward movement facilitates calving on the island with cooler temperatures. When caribou are moving onto the island in the spring, contributors in WKSP (2018d) explained that female caribou arrive first to the island, followed by the male caribou, moving towards calving areas in the northeast of KWI. Caribou will also move away from the shore if they cannot find an area suitable for crossing (WKSP 2018b).

Aglukkaq (WKSP 2018b) described that she has observed caribou by Ogle Point in July, and though some may cross, she has seen caribou fall into water where sea ice was not thick enough. Thin sea ice may be difficult to differentiate from open water, and this may lead to caribou falling into the open water.

4.3.2 - Sea ice trend analysis for break-up timing

Using the Mann-Kendall analysis, no significant changes in the timing of break-up was detected (Appendix 1, 11). Nevertheless, below I review the qualitative trends observed over time for each of the crossing-areas (Table 4.3, Figure 4.3).

Table 4.3 - Summary of sea ice break-up dates by crossing area between 1983-2018 (bolded values in table represent statistically significant trends ($p<0.05$)).

	NW	**NE**	**E**	**S**	**W**
Trend (# of break-up dates: p-value)	33:0.28	33:0.58	35:0.51	35:1	33:0.15
Earliest date of break-up	May 16, 2010	May 16, 1988	Apr 15, 2017	Apr 15, 2017	May 06, 2017
Latest date of break-up	Aug 25, 1988; 1998	Aug 10, 2005	Jul 03, 1992	Jul 11, 1987	Aug 12, 2010
Median date of break-up	June 13	June 14	May 23	May 25	June 17
Percentage of break-ups with listed stage of ice (%)					
Open Water	87.50%	94.44%	100%	100.00%	97.14%
New Ice	6.25%	2.78%			2.86%
Grey Ice	6.25%	2.78%			
Percentage of break-ups with listed forms of ice (%)					
Open Water	18.18%	42.86%	41.67%	58.33%	54.29%
Pancake Ice		2.86%			
Small Floe	9.09%	5.71%		2.78%	5.71%
Medium Floe	21.21%	8.57%	8.33	2.78%	8.57%
Big Floe	30.30%	17.14%	11.11%	2.78%	5.71%
Vast Floe	21.21%	22.86%	33.33%	25.00%	22.86%
Giant Floe				5.56%	
Fast Ice			2.78%	2.78%	2.86%
Years without break-up (%)					
	5.71%	5.71%			5.71%

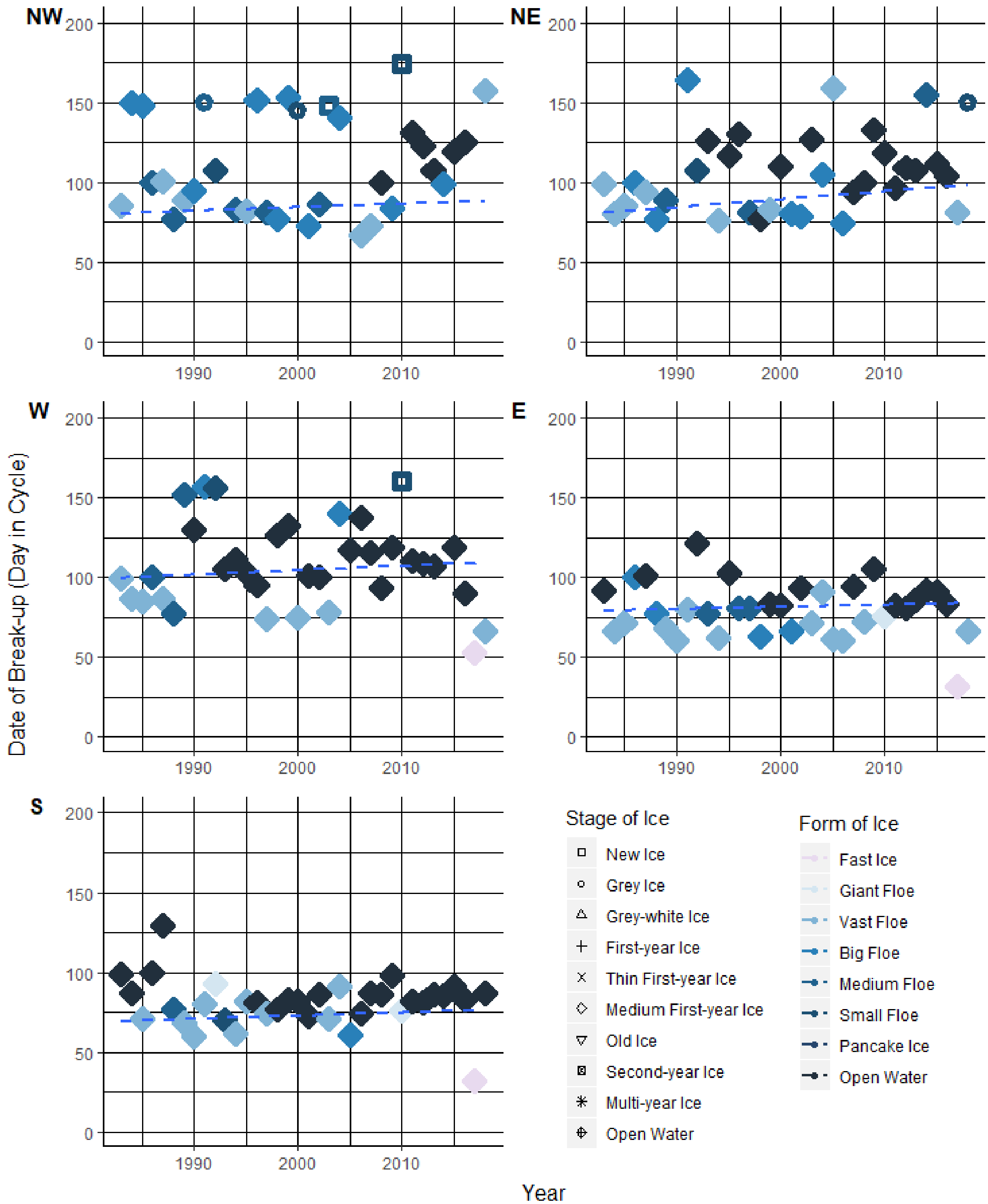

Figure 4.3 - Dates of sea ice break-up within 1983-2018 ice sea ice years within crossing areas (Day 01 - Mar 15, Day 103 - June 15, Day 195 - Sep 15, Day 317 - Jan 15). Dashed blue lines represent non-statically significant Theil-Sen trend lines.

Northwest Caribou Crossing Area

Break-up in the NW-crossing ranged from May 16 (2010) to Aug 25 (1988; 1998), with most years ranging from June 12 to July 7. Break-up conditions were not met in 1993 or 2005. In these sea ice years, while sea ice concentrations did fall below 9/10, stage of sea ice did not meet conditions of break-up as fast ice was observed with relatively sporadic and wider distribution of values compared to other crossing areas (Figure 4.3).

Many of the break-up dates were first observed as open water, suggesting that the bulk of melting is occurring within a maximum of 1 week (i.e. the time between available CIS ice charts). There were select observations of new ice (30 Jul 2003 with medium floe; 25 Aug 2010 with small floe) and grey ice (01 Aug 1991 with medium floe]; 27 Jul 2000 with small floe) at time of break-up that occurred outside of the typical range of dates, suggesting that environmental circumstances impacting melt were more anomalous in these years compared to others.

Northeast Caribou Crossing Areas

Break-up in the NE-crossing ranged from May 16 (1988) to Aug 10 (2005), with the majority of years ranging from May 23 to July 12. Timing of break-up varied across the time period and break-up conditions were not met in two sea ice sea ice years (1991, 1992) (Figure 4.3). Similar to NW-crossing area, the majority of break-up dates were observed with open water conditions, with one instance of new ice observed at break-up (Jul 19 1990 with pancake ice). This break-up occurred outside of the typical range of dates, and with different ice conditions from other years. Floes of various sizes were identified in open water, highlighting that open water designations based on ice concentration alone may fail to identify different stages of sea ice melt in assessments of sea ice change.

East Caribou Crossing Area

Break-up in the E-crossing ranged from Apr 15 (2017) to Jul 03 (1992), with the majority of years ranging from May 23 to Jun 12 (earlier than the NW and NE-crossing crossing area). The latest break-up observed in E-crossing was over 66 days earlier than NW and NE counterparts. At time of break-up in 2017 fast ice was observed as the dominant type of ice in the area. All break-ups in the E-crossing area were observed with a relatively narrow range of break-up dates (Figure 4.3), and with open water, suggesting that break-up occurs faster than is captured in a seven-day period between CIS ice charts observations.

South Caribou Crossing Area

Break-up in the S-crossing area ranged from Apr 15 (2017) to Jul 11 (1987). The narrow range of dates and lack of significant change resulted in a tight, horizontal trendline (Figure 4.3). The earliest date of break-up in the S-crossing was observed Apr 15 (2017), the same as in the E-crossing tha year. This suggests that anomalous conditions in 2017 impacted the early break-up of sea ice during these dates. Fast ice was observed at the time of break-up, suggesting that break-up was not uniform, with areas of open water and of fast ice.

West Caribou Crossing Area

Break-up in the W-crossing area ranged from May 06 (2017) to Aug 12 (2010), like the NE-crossing area, break-up conditions were not met in 2 sea ice sea ice years (1988, 1997). While the earliest date of break-up in the W-crossing is later than S-crossing and E-crossing areas, the earliest break-up for all crossing areas occurred in 2017. This suggests that climatic and anthropogenic factors in 2017 impacted E, S, and W crossings areas impacting break-up timing simultaneously. The majority of sea ice break-up was observed between May 28 and Jul 07. The range of common break-up dates is broader than those in NW, E, S-crossing areas, though similar to that of NE-crossing area. All break-up dates were observed with open water, except for 2010 which had the latest date of break-up and had mostly new ice in small floes. This suggests that 2010 had anomalous conditions that slowed or delayed break-up relative to other years. A a variety of sizes of ice floes were observed throughout the time period. Fast ice was observed during the break-up of 2017, which is the latest observed break-up within W-crossing area and coincides with the latest break-up observed in E and S-crossing (Figure 4.3).

4.3.3 - Ship entry trend analysis during break-up

Mann-Kendall and Sen's slope analyses were conducted on dates of ship entry (day of year) in each crossing area amongst ship types (Table 4.3, Table 4.4, Figure 4.4).

Table 4.4 - Summary of ship entries into each crossing area between 1990-2016 (bolded values in table represent statistically significant trends ($p<0.05$)).

	NW	**NE**	**E**	**S**	**W**
All Ships					
Earliest date of ship entries	July 01, 2015	Aug 01, 2011	Aug 01, 2001	July 01, 1993	July 16, 2008
Latest date of ship entries	Sept 21, 2016	Sept 29, 2015	Sept 21, 1997	Oct 05, 2015	Sept 24, 2010
Government Vessels and Icebreakers					
Trend (# of dates of ship entries of type; sen's slope (p-value)).	**27; -0.79**	**27;-0.48 (0.01)**	27; 0.01; -0.77	27; 0.23	**27; -1.5 (0.01)**
Earliest date of ship entries	July 16, 2008	Aug 07, 2013	Aug 02, 2008	Aug 17, 1998, 1999	July 16, 2008
Latest date of ship entries	Aug 27, 1992	Sept 21, 1997	Sept 21, 1997	Sept 04, 2014, 2015	Sept 20, 1990
% of years present	100%	100%	100%	100%	100%
General Cargo					
Trend (# of dates of ship entries of type; sen's slope (p-value))	10; 0.12	10; 0.76	9; 0.76	10; 0.3	10; 0.18
Earliest date of ship entries	Aug 15, 2016	Aug 20, 2016	Aug 20, 2016	Aug 07, 2009	Aug 20, 2001
Last date of ship entries	Sept 04, 2011	Sept 12, 2011	Sept 12, 2011	Aug 18, 2014	Sept 04, 2011
% of years present	37.04%	37.04%	33.33%	37.04%	37.04%
Pleasure Crafts					
Trend (# of dates of ship entries of type; sen's slope (p-value))	16; 0.18	16; 0.3	16; 0.06	12; 0.73	12; 0.45
Earliest date of ship entries	July 01, 2015	Aug 01, 2011	Aug 01, 2001	Aug 07, 2013	July 01, 2005
Last date of ship entries	Aug 27, 2009	Sept 03, 1990	Sept 04, 1990	Aug 23, 2012	Aug 13, 2012
% of years present	44.44%	62.96%	59.26%	44.44%	44.44%

Passenger					
Trend (# of dates of ship exit of type; sen's slope (p-value))	12; 0.01; 1	11; 0.30	11; 0.39	3; 1	26; 0.23
Earliest date of ship entries	July 28, 1993	Aug 04, 2006	Aug 17, 2013	Aug 04, 2006	July 21, 1999
Latest date of ship entries	Aug 28, 2009	Sept 04, 2014	Sept 04, 2014	Sept 08, 2010	Aug 26, 2009
% of years present	44.44%	40.74%	40.74%	11.54%	96.30%
Tanker					
Trend (# of dates of ship exit of type; sen's slope (p-value))	7; 0.12	7; 0.75	7; 0.76	7; 0.3	7; 0.18
Earliest date of ship entries	Aug 31, 2011	Aug 31, 2010	Sept 06, 2012	Aug 05, 2014	July 31, 2011, 2012
Latest date of ship entries	Sept 11, 2013	Sept 29, 2015	Sept 22, 2015	Aug 24, 2010	Sept 10, 2014
% of years present	25.93%	25.93%	25.93%	25.93%	25.93%
Tug/Barge					
Trend (# of dates of ship entries of type; p-value; sen's slope)	26; 0.43	26; 0.79	26; 0.63	26; 0.63	23; 0.00
Earliest date of ship entries	July 24, 2006	Aug 25, 1995	Aug 19, 2000	July 01, 1993	July 25, 2006
Latest date of ship entries	Sept 21, 2016	Sept 21, 2016	Sept 18, 2010	Oct 05, 2015	Sept 24, 2010
% of years present	96.30%	96.30%	96.30%	96.30%	85.19%

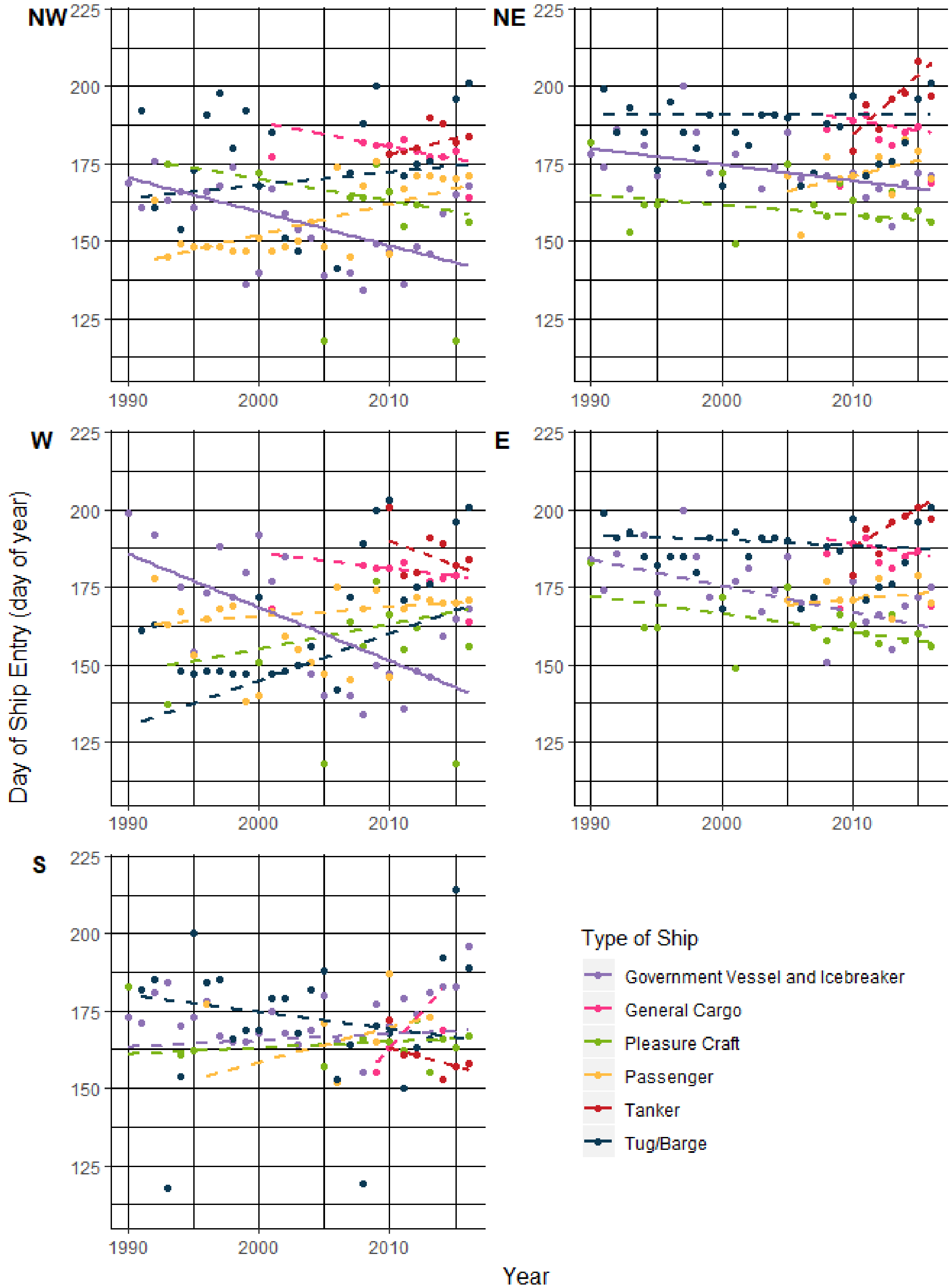

Figure 4.4 - Dates of ship entry (designated by ship type) into each crossing (represented as day of year; Day 01 - Mar 15, Day 103 - June 15, Day 195 - Sep 15, Day 317 - Jan 15) Dashed (non-statistically significant) and solid (statistically significant) lines represent Theil-Sen trend lines (p-value = 0.05).

Northwest Caribou Crossing Area

Dates of ship entry in the NW-crossing area ranged from July 01 (2015) to Sept 21 (2016), and varied by ship type. Pleasure crafts entered first, between July 01 (2015) and Aug 27 (2009), while tug/barge ships entered last, between July 24 (2006) to Sept 21 (2016). All ships except tanker and general cargo, were observed in the crossing prior to 1992; general cargo was first observed in 2001, and tankers in 2010.

According to the Mann-Kendall analysis, government vessels and icebreakers ($p = 0.033$), and passenger ships ($p = 0.008$) experienced significant change in the timing of initial ship movement in the NW-crossing area (Table 4.5, Table 4.6). Government vessels and icebreakers are entering this area earlier by 0.8 days/year. In contrast, the timing of passenger ship entry into the NW-crossing area became later at a rate of 1 day/year (Figure 4.4).

Northeast Caribou Crossing Area

The timing of ship entry in the NE-crossing area ranged from Aug 01 (2011) to Sept 21 (2016). Similar to the NW-cross, pleasure crafts entered first, between July 01 (2015) and Aug 27 (2009). After 2010, tug/barge ships entered last, ranging from June July 24 (2006) to Sept 21 (2016). Passenger ships were initially observed in the crossing in 2005, later than in the NW-crossing area where these ships have been observed since 1992 (Figure 4.4, Table 4.5, Table 4.6). Within the NE-crossing area, government vessels and icebreakers experienced significant change towards earlier ship entry at a rate of 0.5 days/year ($p = 0.006$), ranging from Aug 20 to Sept 21 (1997) .

East Caribou Crossing Area

The timing of ship entry in the E-crossing area ranged from Aug 01 (2001) to Sept 21 (1997) between 1990-2016. Similar to the NE-crossing, tankers and passenger ships were not observed in the crossing prior to 2010 and 2005, respectively. Government vessels and icebreakers in this eastern crossing also experienced significant change in their timing of initial ship movement, shifting at a rate of 0.8 days/year earlier ($p = 0.001$) and ranging from Aug 02 (2008) to Sept 21 (1997) (Table 4.5, Table 4.6, Figure 4.4).

South Caribou Crossing Area

No significant change in the timing of ship entry was detected in the S-crossing area, which is consistent with the lack of change observed in the exit of ships from this crossing. Timing ranged from July 01 (1993) to Oct 05 (2015) across all ship types and is the widest range of ship entry dates relative to other crossing areas. Passenger ships were observed only 3 times in this crossing area (2009, 2010, 2014), and general cargo ships only 6 times (1996, 2005, 2006, 2009, 2010, 2013) (Table 4.5, Table 4.6, Figure 4.4).

West Caribou Crossing Area

The timing of ship entry in the W-crossing area ranged from July 16 (2008) to Sept 24 (2010), the second broadest range of timing, which is very similar to the range observed in the NW-crossing area. Passenger ships occurred 25 times in the W-crossing since 1992, within similar dates as the NW-crossing. It is likely that passenger ship voyages cross both areas as they transit through this section of the NWP.

Similar to the NE and E-crossing areas, only the date of government vessel and icebreakers entry into the W-crossing crossing area experienced significant change, with ships entering 1.5 days/year earlier ($p = 0.007$) (Table 4.6, ranging from July 16 to Sept 20 (2010).

4.4 - Summer open water

4.4.1 - Uqsuqtuurmiut knowledge of open water and multi-year ice conditions

When open water is present along the coastline, caribou movement to/from KWI generally stops (WKSP 2018c). Contributors explained that caribou do not go on or approach the moving ice; however, they will at times use the crossing areas if there are just small localized patches of open water (likely polynyas).

Caribou tend to be on KWI in the summer (after spring movements across the sea ice), in order to distance themselves from the warming mainland (WKSP 2018b,d). Contributors described female caribou and calves congregating on the NE part of KWI in the summer. Therefore, caribou are less common in the southern coastal areas of KWI in the summer (and in the S-crossing area) than in the fall and spring WKSP (2018b).

Over the summer months, Uqsuqtuurmiut observe multi-year ice within larger water bodies surrounding KWI (WKSP 2018d). Contributors described that large pieces of multi-year ice remain in the open water towards Boothia Peninula (to the east and northeast) and Prince of Wales Island (to the north) in the summer season because of strong currents (WKSP 2018b).

Aglukkaq (WKSP 2018b) described the impact of climate change on caribou seasonal movement, along with other wildlife: "Because of climate change, not only caribou are remaining on the island much longer, but other species have moved onto the island because during the summer, the hot season…animals move to cooler areas on the island. And so caribou, grizzly and muskox and other species of animals have moved because of the intense heat during the summertime on the mainland. So as the freeze-up is becoming much later and later, it keeps the animals on the island longer than they would normally stay."

Some Uqsuqtuurmiut expressed concerns about ship traffic close to caribou calving areas, and potential ship disturbance influencing caribou movement. We learned that during shipping seasons in the past 5 years, caribou are less populated in their typical calving areas in northeast KWI (WKSP 2018c). Some contributors believed that loud noises from near-by ships travelling close to coastal area may have impacted the distribution of female caribou and calves (WKSP 2018c,d).

When reviewing the maps of shipping routes around KWI in community workshops (2011-2016), Uqsuqtuurmiut expressed concern about ship traffic in the summer season. Porter (WKSP 2018e) voiced his uncertainty regarding the lack of local information about ship traffic in the region: "Like you can see on maps and I was wondering why they are going there. The private ships, like why are they going in there?". In WKSP (2018b) contributors explained that pleasure crafts move around Arctic waters for leisure photography and adventure travel, and they had observed icebreakers making open water to facilitate the movement of these small pleasure ships in areas of fast ice. So while pleasure crafts themselves do not impact ice conditions, if they are supported by icebreakers this can have broader implications for caribou. Keanik (WKSP 2018c) explained that ships do not stay within determined travel routes and move freely in open water. He expressed concerns for the protection of caribou and their habitat, and questioned the limited capacity Inuit have in identifying, determining, and understanding what ships are in nearby waters. He attributed this gap in information to the lack of transparent reporting and management by the shipping industry and federal government.

4.4.2 - Sea ice trend analysis in the open water season

Mann-Kendall and Sen's slope analyses were conducted on the length of open water season in each crossing area, and no significant changes were identified in any of the caribou crossing areas (Figure 4.5, Appendix 11). In years where freeze-up and/or break-up conditions were not met, no length of open water season could be calculated.

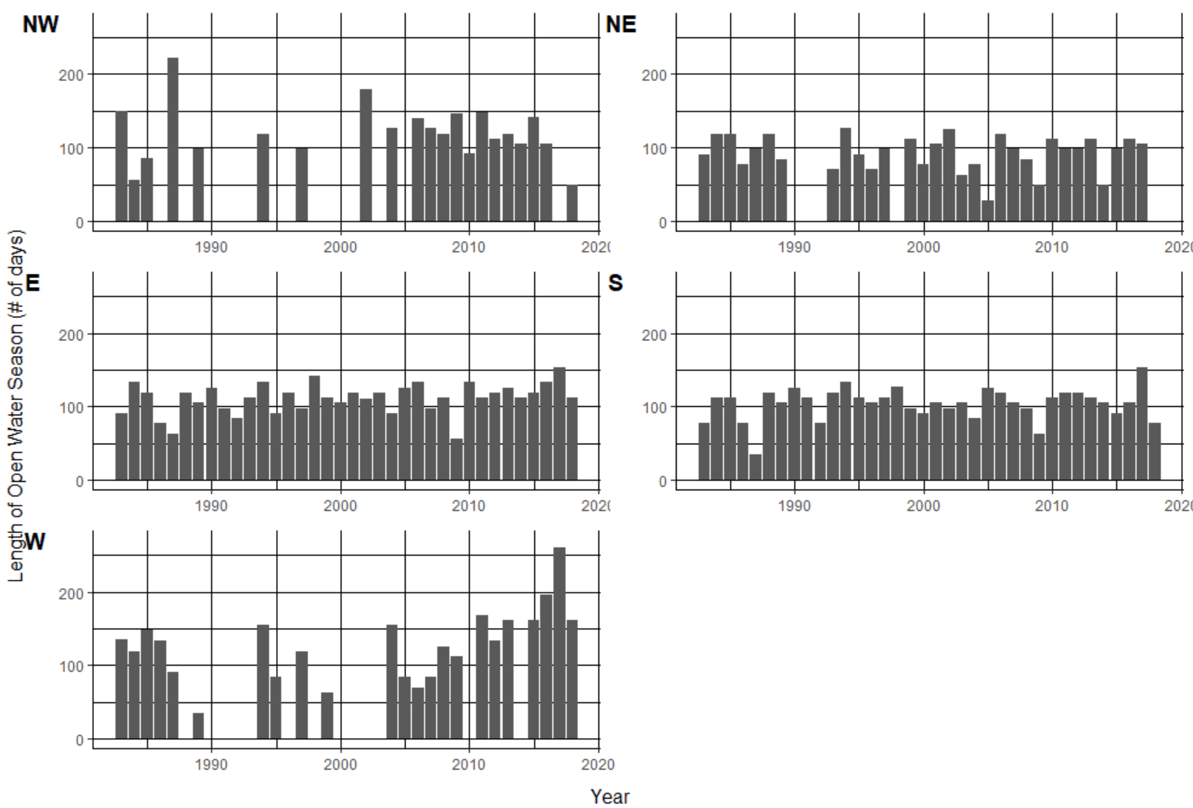

Figure 4.5 - Length of open water season in caribou crossing areas between 1983-2018.

Northwest Caribou Crossing Area

The length of summer open water season in the NW-crossing ranges from 49 (2018) to 223 (1987) days long (Figure 4.5). The longest open water seasons occurred in 1987 and 2002, and the shortest occurred in 1984 and 2008, highlighting considerable variability in the NW-crossing.

Northeast Caribou Crossing Area

No significant trend in length of open water season was observed in the NE-crossing area; however, the length of season could not be calculated in 3 sea ice years (1991, 1992, and 1998) because freeze-up conditions were not met. Length of open water season ranged from 28 (2005) - 126 (1994) days long (Figure 4.5).

East Caribou Crossing Area

No significant trend in length of open water season was observed in the E-crossing area, with length of open water season ranging from 56 (2009) - 154 (2017) days long. The range of values is similar in what was observed in NE-crossing; however, the shortest and longest seasons were over 25 days longer than the two northern crossings. This is attributable to the much earlier break-up observed in E-crossing areas relative to NW and NE-crossing areas (Section 3.1.2).

South Caribou Crossing Area

No significant trend in length of open water season was observed in the S-crossing area, with a broad range of open water season lengths from 35 (1987) to 154 (2017) days long, and the majority being between 70 and 130 days. This range of values is broader than that observed in NE and E-crossing areas, with more extreme high and lows than other crossings. season.

West Caribou Crossing Area

No significant trends in length of open water season were identified in the W-crossing area, although the length of the open water season could not be calculated in 11 sea ice years because freeze-up conditions (related to stage of ice) were not met. Lengths of open water season ranged from 35 to 260 days. This range of values is greater than any other crossing area, and alongside the lack of significant trends, highlights substantial interannual variability in the length of open water season. This will have implications for the capacity of Inuit, caribou and ship captains to navigate across, or within, sea ice in this area between KWI and Victoria Island.

4.4.3 - Ship traffic trend analysis in the open water season

Our trend analysis looked at length of shipping season and distance travelled in each caribou crossing area and was summarized by caribou crossing area (Table 4.5, Figure 4.6, Table 4.6, Figure 4.7).

Northwest Caribou Crossing Area

The length of shipping season in the NW-crossing ranged from 0 to 109 days long between amongst all types (Table 4.5, Figure 4.6). The shipping season for government vessels and icebreakers ranged from 9 (1990) to 89 (2006) days long, tankers ranged from 7 (2014) to 23 (2015) days long, and general cargo ranged from 3 (2001) to 51 (2016) days long. General cargo ships have the shortest shipping seasons, while pleasure crafts (0 (2000) to 64 (2005) days long) and passenger ships (0 (2001) to 109 (2002) days long) have the widest range of season length. In the shortest seasons, general carbo ships and pleasure crafts had just a single ship transit throughout the entire season (Table 4.5, Figure 4.6). A significant increase in the length of shipping season was detected for government vessels and icebreakers (1.4 days/year, $p = 0.008$) and general cargo and tanker ships (both at 4 days/year, $p = 0.007$) (Table 4.5).

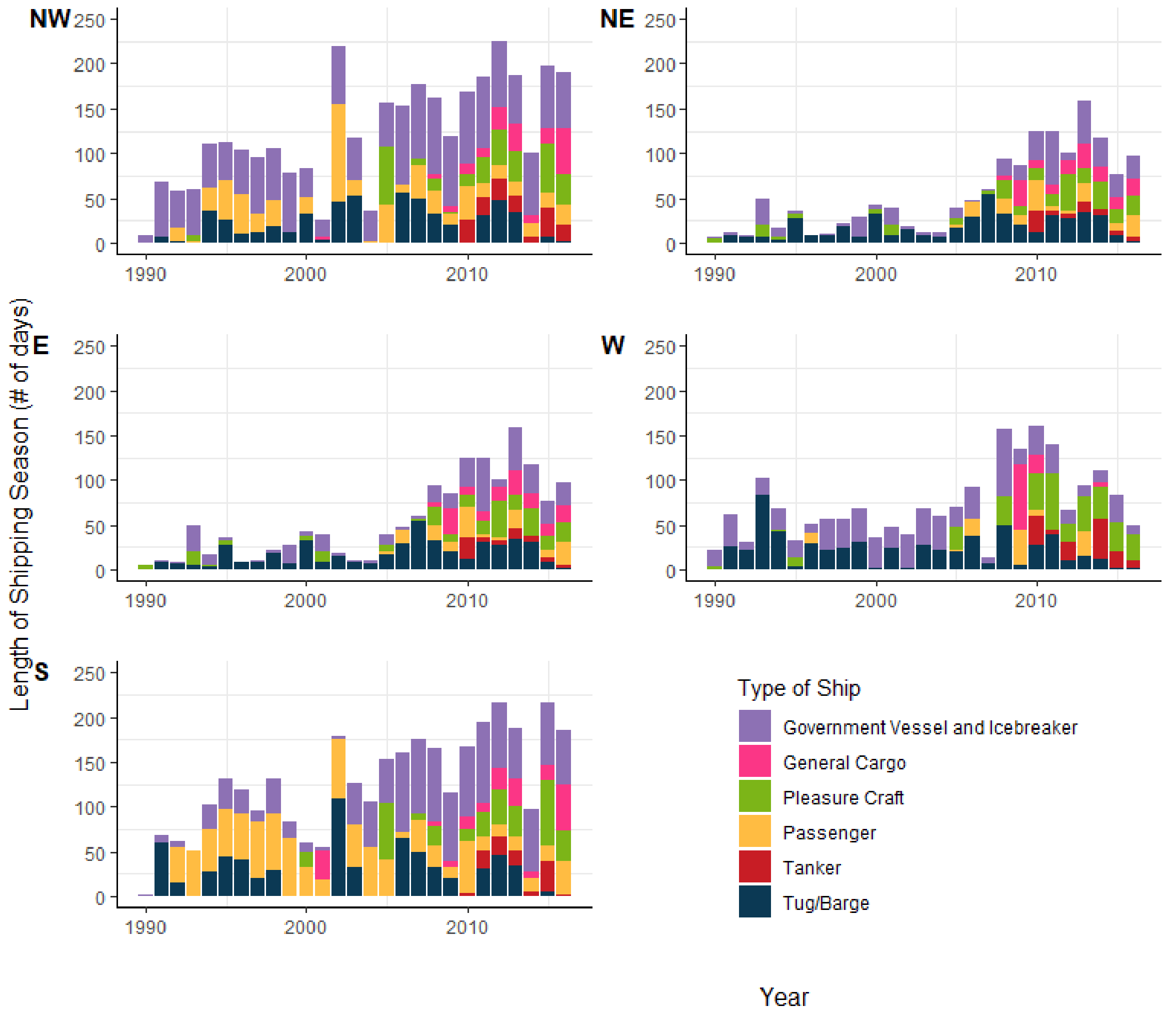

Figure 4.6- Length of shipping season (by ship type) within each caribou crossing area

Table 4.5 - Summary of trend analysis representing changes in the length of shipping season in each caribou crossing area (by ship type) between 1990-2016 (bolded values in table represent statistically significant trends ($p<0.05$)).

Area	Ship Type	p-value	Sen's slope	Z-value
NW	GVIB	**0.01**	1.2	2.65
NW	GC	**0.01**	4	2.68
NW	PC	0.05	3.8	1.92
NW	PS	0.71	-0.3	-0.38
NW	TK	**0.01**	4	2.68
NW	TB	0.37	0.92	0.91
NE	GVIB	**0.00**	1	2.97
NE	GC	0.25	1.07	1.15
NE	PC	**0.00**	1.24	3.14
NE	PS	0.94	0.4	0.08
NE	TK	0.25	1.07	1.15
NE	TB	0.04	0.64	2.04
E	GVIB	**0.01**	0.69	2.58
E	GC	0.40	1.54	0.84
E	PC	**0.01**	1.31	3.48
E	PS	0.53	0.75	0.62
E	TK	0.40	1.54	0.84
E	TB	**0.03**	0.75	2.17
S	GVIB	0.53	-0.18	-0.63
S	GC	0.3	-34	-1.05
S	PC	0.09	2.75	1.73
S	PS	0.45	2.8	0.75
S	TK	0.3	-34	-1.05
S	TB	0.07	-0.75	-1.81
W	GVIB	**0.00**	3	3.98
W	GC	0.24	2	1.17
W	PC	**0.05**	3.66	1.99
W	PS	0.18	-1.49	-2.36

W	TK	0.24	2	1.17
W	TB	0.54	-0.57	-0.61

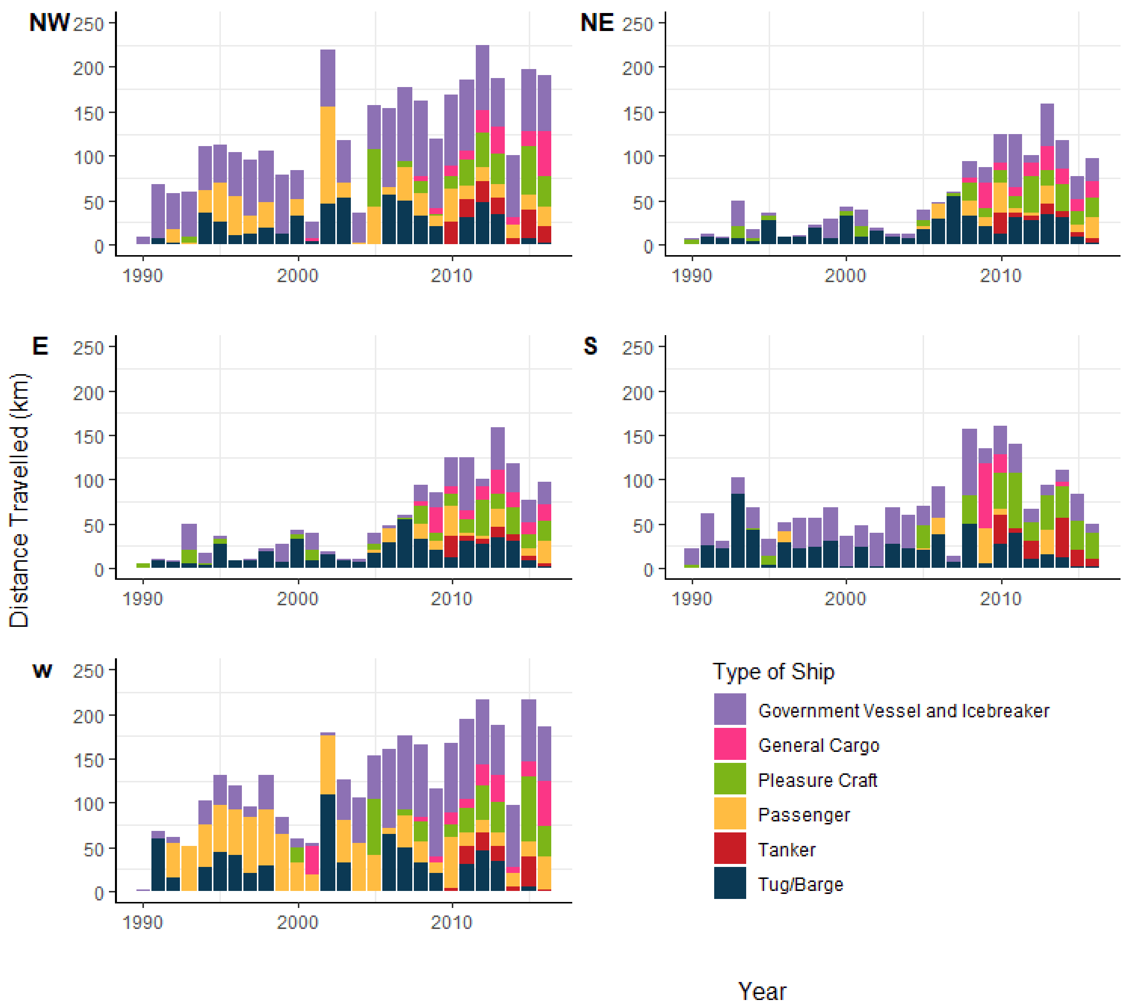

Figure 4.7 - Distance travelled (by ship type, in 100s km) within each caribou crossing area

Table 4.6 - Summary of trend analysis representing changes in annual distance travelled in each caribou crossing area (by ship type) between 1990-2016 (bolded values in table represent statistically significant trends ($p<0.05$)).

Area	Ship Type	p-value	Sen's slope	z-value
NW	GC	0.07	386.63	1.79
NW	GVIB	**0.01**	93.67	2.25
NW	PC	0.15	324.92	1.44
NW	PS	**0.01**	117.84	2.78
NW	TB	0.9	5.93	0.13
NW	TK	0.13	-997.93	-1.50
NE	GC	0.60	119.45	0.52
NE	GVIB	**0.03**	59.92	2.25
NE	PC	0.9	5.93	0.13
NE	PS	0.35	-240.07	-0.93
NE	TB	0.9	5.92	0.13
NE	TK	0.76	26.31	0.30
E	GC	0.35	100.77	0.94
E	GVIB	0.09	33.87	1.72
E	PC	**0.00**	248.08	1.2
E	PS	0.64	-208.83	-0.47
E	TB	0.63	20.43	0.49
E	TK	1	-4.065	0
S	GC	1	-119.45	0
S	GVIB	**0.02**	41.13	2.93
S	PC	**0.01**	256	2.67
S	PS	0.26	-705.04	-1.13
S	TB	**0.04**	-123.06	-2.03
S	TK	0.71	-338.50	-0.38
W	GC	0.07	454.63	1.79
W	GVIB	0.30	83.98	2.17
W	PC	0.09	307.04	1.71
W	PS	**0.01**	117.84	2.78

W	TB	0.48	-63.62	-0.71
W	TK	0.37	-429.7	-0.90

The NW-crossing area also experienced significant growth in the distance ships travelled within the area. Though moderate peaks did occur prior, 2006 and 2010, 2016 had noticeable spikes in the distance travelled across ship types (Table 4.6, Figure 4.7). In 2006, government vessels and icebreakers were responsible for the vast majority of ship movement during the summer season and experienced a large increase in distance travelled from the year before (1689 km in 2005 and 3413 km in 2006). Government vessels and icebreakers travelled the greatest distance in 2016 (6019 km), while the shortest distance they travelled was 235 km in 1990. Government vessels and icebreakers exhibited a significant increase in distance travelled (93.7 km/year, $p = 0.014$), along with passenger ships (117.8 km/year, $p = 0.005$) (Table 4.6). Beginning in 2008, the pleasure crafts travelling 4236.33 km the NW-crossing area, and became increasingly common with a peak of 9125km travelled in 2011. Similarly, starting in 2010 tanker ships travelled 5428 km, and ranged from 1191km (2014) to 7725km (2011) in the next 5 years.

Northeast Caribou Crossing Area

The length of shipping season in the NE-crossing area ranged from 0 to 61 days long, which is shorter than its NW-crossing counterpart. Pleasure crafts ranged from 2 (1994) to 42 (2012), general cargo ranged from 5 (2008) to 29 (2009) and passenger ships rang from 1 (2014) to 34 (2010) respectively. Governmental vessels and icebreakers also experienced multiple shipping seasons of 1 day, and 1 transit (1990, 1992, 1997);

however, they also experienced almost the full range of shipping season lengths [1(1990, 1992, 1997) to 61 (2011)].

Significant trends towards a lengthening of the shipping season were observed for government vessels and icebreakers (1 day/year), and pleasure crafts (1.2 days/year), although with relatively high standard deviations (Table 4.5, Figure 4.6). Tub/Barge ships also experienced a significant increase in the length of shipping season at a rate of 0.6/days ($p = 0.041$) (Table 4.5) with a range of 1 (1992, 2001, 2016) to 56 (2007) days long.

The NE-crossing area experienced more moderate and stable growth in distance travelled by ship than its NW counterpart. Distance travelled across ship types initially peaked in 2005, and traffic sustained moderate growth in the subsequent years. The initial increase in distance travelled occurred as passenger ships began entering the NE-crossing area and travelled 6967.52 km with the season. This was relatively sustained across most years (ranging from 1742.57 km in 2008 to 6967.52 km in 2005) except for lows in 2014 (955.59 km) and 2012 (706.32 km) (Table 4.6, Figure 4.7). While pleasure crafts have been present in the waters surrounding KWI prior to 2008, they greatly increased in the NE-crossing area in 2008 traveling 6442.36 km with 6-fold increase in number of ships traveling (from 1 to 6 vessels). General cargo ships were first observed in 2008, and remained relatively stable with a relatively narrow range of values of distance travelled, ranging from 1001.8km (2014) to 5623.7km (2012) with 1-3 ships present per season. Only government vessels and icebreakers showed significant growth in the distance travelled, at a rate of 59.92 km/year ($p = 00.25$) and ranging from 270 km (1997) to 4918.3 km (2011) (Table 4.6, Figure 4.7).

East Caribou Crossing Area

Similar to the NE-crossing, the length of shipping season in the E-crossing area ranged from 0 to 61 days long between 1990 and 2016, and had the most narrow range of values. Tanker ships typically experienced short shipping seasons, ranging from 0 (2011, 2012, 2016) to 20 (2010) days long, with 3 instances of single transit through the area (2011, 2012, 2016). There was also a similar trend towards lengthening season for pleasure crafts (1.3 days/year, $p = 0.004$), and tub/barge (0.8 days/year, $p = 0.047$). Pleasure crafts typically experienced shorter seasons than their tug/barge counterparts, ranging from 2 (1994) to 42 (2012) days long, compared to 1 (1992, 2001, 2016) to 56 (2007) days long. The range of shipping season for tug/barge ships are almost identical to the NE-crossing area, suggesting that tug/barge transit routes typically move through both crossing areas during a voyage. Government vessels and icebreakers also displayed a lengthening trend in shipping season at a rate of 0.7 days/year ($p = 0.01$), ranging from 0 (2006) to 61 (2011) days long. General cargo ships were not observed in the E-crossing until 2008.

The first observation of passenger ships in the E-crossing area is in 2005, with ships travelling 6967 km in the season and 5126 km in 2006. In 2007, there was a significant drop to 1742 km travelled, with values hitting lows in 2012 (559 km) and 2014 (706 km), similar to the NE-crossing area. Pleasure crafts had a peak distance travelled in 2008 (5560 km), and ranged from 1535 km (2009) to 4881 km (2012) in subsequent years. They also exhibited a significant increase in distance travelled over time at a rate of 248.1 km/year ($p = 0.03$) (Table 4.9). General cargo ships travelled the least distance relative to other ship types, ranging from 304 (2010) to 2459 (2015) in the

E-crossing area. Tankers travelled between 56 km (2016) to 2351 km (2014) in a season, with values comparable to those observed in government vessels and ice breakers though not in the same year. This suggests that factors impacting the distance travelled by tankers, may be different than those impacting government vessels and icebreakers. Distance travelled by government vessels and icebreakers were the least in a given year compared to other ship types, ranging from 93 km (2006) to 2524km (2016), with 18 seasons of less than 1000 km. Tug/barge ships travelled the greatest distance amongst all ships, with peaks in 2007 (11,194 km) and 2008 (8991 km) with 4 ships observed as opposed to the 1-3 ships observed in the remainder of the time period (Table 4.6, Figure 4.7).

South Caribou Crossing Area

The length of shipping season observed in the S-crossing area ranged from 1 to 84 days, with variations across ship types and no significant trends (Table 4.9, Figure 4.6). This suggests that the potential for ship transits to impact caribou sea ice habitat vary greatly across the years. Passenger ships were observed less frequently in the S-crossing compared to other crossings, ranging from 3 (2005) to 39 (2009) days (in 6 years after 1996). General cargo ships occurred only 3 times (2009, 2010, 2014) with 2 ships observed in each year and the shipping season ranging from 6 (2014) to 74 (2009) days long.

There was also no significant trend in the distance travelled by ships in the S-crossing area. General cargo ships were present in 3 years, each with 2 ships travelling less than 900 kilometers. Similar to the E-crossing area, tug/barge ships exhibited the widest range of values from 396.3 km travelled in 2016 to 11,053.8 km in 1994. Tankers travelled the shortest distance in 2011 (300.6km) and 2016 (461.3km), coinciding with the same years as minimal tug/barge travel. This suggests that similar environmental factors may be impacting the distance tanker and tug/barge ships can travel. Also similar to the E-crossing area, the distance travelled by passenger ships peaked in 2005 (6967.52 km) and 2006 (5139.45 km), with other shorter distances ranging from 288.41km (2013) to 1510.56km (2009). Therefore, it is likely that ships moved through both the E and S-crossings during their seasonal transits in 2005 and 2006. While the distance travelled by pleasure crafts has not consistently grown over time in the S-crossing, the number of ships observed peaked at 11 in 2014, and remained relatively high in 2015 (8) and 2016 (8) (Table 4.6, Figure 4.7).

West Caribou Crossing Area

The length of open water season in the W-crossing ranged from 0 to 109 days long, across ship types. This is a similar range as in the NW-crossing area, and is the widest range of values relative to other crossings. Passenger ships were observed in the W-crossing since 1992, and season lengths ranged from 7 (2006) to 66 (2002) days long. In 2002, the longer shipping season of 66 days included the transits of only two ships, suggesting that these ships stayed for a longer period of time relative to other ships types in the crossing area. General cargo ships were initially observed in the W-crossing after 2001, suggesting fewer opportunities for general cargo ships to impact caribou sea ice habitat. Since 1999, there were also 6 instances of tug/barge ships with 0 to 1 days of shipping season. Shipping seasons for government vessels and icebreakers ranged from 1 (1993) to 89 (2011) days long, and pleasure crafts experienced shipping seasons ranging from 0 (2009) to 73 (2015) days long. Again these two have significant increases in the length of shipping season, with government vessels and icebreakers increasing by 3 days/year ($p = 0.0001$) and pleasure crafts by 3/7 days/year ($p = 0.047$) (Table 4.5, Figure 4.6).

General cargo ships were present in the W-crossing area and travelled similar distances in the same years as in the NW-crossing (2001, 2008-2016) suggesting ships travel through both areas in their voyages. The distance travelled by pleasure crafts since 2010 is greater than earlier years, with values consistently above 2500 km and ranging from 6-11 vessels a year. A significant increase in the distance travelled by passenger ships is observed in the W- crossing area at a rate of 117.8 km/year ($p = 0.006$). The distance travelled by passenger ships peaked in 2010 (4654.98 km), 2015 (4634.27 km), and 2016 (7372.84 km), with additional ships observed in the crossing (5, 6, 7 respectively). The distance travelled by tug/barge ships peaked in 1994 (12016.01 km), and 2007 (24247 km), similar to what was observed in the NW-crossing area. Government vessels and icebreakers varied greatly in the distance travelled across the years, ranging from 971.7km (2010) to 7036km (2016) (Table 4.6, Figure 4.7).

4.5 - Other considerations of the interplay between sea ice and ship traffic

In workshops, Uqsuqtuurmiut also discussed environmental conditions and caribou behaviour that were not limited by season.

Aqslaluq explained that sea ice movement and lack of movement is impacted by ocean tides and currents. He explained that Tumarakkaquti describes sea ice that does not stay in one place, but moves into other areas via water currents. Aqslaluq understands these relationships through his own experience on the sea ice.

Our project did not cover caribou movement in and on frozen, freshwater bodies, though it is referenced in comparison to sea ice melt and formation time. Kameemalik (WKSP 2018b) and Ukuqtuunuaq (WKSP 2018c) confirmed that sea water and freshwater have different qualities that impact how they freeze, break-up and support wildlife movement. Sea water is flexible due to salinity, so thinner ice can support movement from heavier animals and Inuit, while freshwater ice is more brittle at the same thickness and so can crack more easily.

Porter (WKSP 2018e) described caribou behaviour within their habitat questioning how altered environment features may be used for facilitating caribou movement across sea ice. Porter (WKSP 2018e) stated; “They won't walk on [just] anything, they don't know what is a bridge. They won't say ‘Oh that's a bridge, let’s go on a bridge that is safe to go on’.”

Contributors highlighted that while caribou are continuously moving, some remain year-round on Uqsuqtuuq, and the small, nearby Hat Island (WKSP 2018c). The continuous presence of caribou means that some hunting does occur on the island mid-winter (WKSP 2018c).

In WKSP (2018c), it was explained that caribou crossing areas surrounding Uqsuqtuuq have been used for a very long time, as evidenced by campsites near the important S-crossing areas. In WKSP (2018d), contributors discussed and described as the main trails that are followed each year in migratory movement to and from KWI. They have been used for so long that in places the trail can resemble a ditch. However, it was noted that caribou are constantly moving, regardless of the season and this impacts their overall distribution (WKSPa, 2018). As Hiqniq (WKSP 2018a) explained: “When caribou are walking in a herd, a large herd, even before they become visible, you can see a cloud dust dark area on the horizon, and then you can hear the hooves later on that are made by caribou. That means the caribou in a large herd are following a leader, at times they may take a rest, then get up again and follow."

Contributors discussed ship traffic primarily in terms of season; however, Putuguq (WKSP 2018c) explained the continuous concern for sea ice travel as long as icebreakers are present: "So because of that if the ship happened to move through that area, a person who has gone out to the mainland before the ship goes through. Trying to go back home, they would get stuck, get stranded because they are unable to go across a thin ice that has been caused by ships to open the water. Because of no aircrafts available to do the retrieving of the person who is stranded, so because of that they have refused any ship traffic in the wintertime. This might not stop in the future, but at this time they are unable to make their route through that channel because of people from the island to the mainland movement is constant."

Chapter 5: Discussion

Research drawing on Uqsuqtuurmiut knowledge, in concert with sea ice and shipping data, seeks to examine the interplay between caribou movement, sea ice conditions, and ship traffic. To undertake an integrated discussion of the results presented in Chapter 4, this chapter is organized according to the research questions outlined in Chapter 1, including:

1. What is the timing and prevailing sea ice stage at freeze-up and break-up in each caribou crossing area, and how have these conditions changed over time?

2. How does each caribou crossing area meet conditions of caribou sea ice habitat?

3. What is the timing and location of ship movement surrounding KWI?

4. How might dynamic sea ice conditions and changes in ship traffic impact the use of sea ice by caribou?

Taken together, this discussion seeks to develop a narrative that addresses the central research question about the potential impacts of sea ice and ship travelling change on caribou crossing areas around KWI.

5.1 - Timing of freeze-up and break-up and prevailing sea ice stages in caribou crossing around KWI

No significant trends in the timing of freeze-up and break-up were detected in caribou crossing areas between 1983 and 2018 and there was high interannual variability in the timing of transitional ice seasons in the waters surrounding KWI (Table 4.1, Table 4.4). This lack of statistically significant trends may be attributed to our definition of freeze-up and break-up that is based on Uqsuqtuurmiut knowledge of reliable caribou habitat. This definition is unique to the study of these transitional seasons timing and may thus produce results distinct from what is predominantly identified in other studies. Differences in sea ice conditions amongst crossing areas indicates that some are more reliable for caribou movement, whereas other areas pose greater challenges to their movement.

Uqsuqtuurmiut explained that they had observed a change towards later freeze-up in the NE, and S-crossing areas in the past 5-10 years (WKSP 2018c); however, most contributors highlighted that interannual variability in sea ice conditions made it difficult to identify typical timing for freeze-up and break-up surrounding KWI (WKSP 2018a,b,d). This is consistent with high interannual variability observed in the timing of freeze-up and break-up within the NWP, with no statistically significant trends towards later freeze-up and earlier break-up (Stroeve et al. 2012; Stroeve et al. 2014). However, more variability (noise) in the dataset means it is harder to detect a statistically significant trend, especially over a short period, and this lack of statistical power may explain why no significant trends were detected in the timing of freeze-up and break-up. The z-value for all crossing areas were positive, meaning the timing of freeze-up in the last decade fell above the population mean and may suggest a change in recent years towards later freeze-up that was not detected as a significant trend (Appendix 13).

Freeze-up timing in the NW, NE, and W-crossing areas typically ranged from early September to early December with median values of October 14, September 20, and October 20, respectively (Table 4.1). Though the range of freeze-up dates observed within the NE-crossing area were similar to those of the NW, and W-crossing areas, the median value indicates differences in the timing of freeze-up amongst the crossing areas.

Break-ups amongst these crossings were very similar ranging from mid-May to mid-August with median values of June 13, June 14, and June 17, respectively (Table 4.4). The consistency in break-up timing observed amongst crossing areas suggest that environmental characteristics influencing sea ice break-up are more consistent across the NW, NE and W-crossing areas relative to characteristics influencing freeze-up. High interannual variability was observed within these crossings in both freeze-up and break-up, which complicates interpretations of spatial variation amongst the crossings. The timing of freeze-up in particular may be attributed to common geographic and ocean characteristics features in the three crossing areas. Contributors attributed the relatively later freeze-up in these crossing areas to strong water currents that breaks apart freshly frozen ice, and delays freeze-up (WKSP 2018c). The large fetch of the NW, NE, and W-crossing areas creates large waves that can disrupt sea ice freeze-up (WKSP 2018b,c). Later break-up was observed in the NW, NE and W-crossing areas relative to the E, and S-crossing areas (Table 4.4), which may be attributed to different environmental conditions amongst the NW, NE, and W-crossing areas and the E, and S-crossing areas. In addition, break-up criteria were not met in the NW, NE and W crossing areas across all sea ice years (Table 4.4). In these sea ice years, while mean ice concentrations did fall below 9/10, and did not satisfy our criteria for break-up as the dominant ice type observed was thicker than new ice. Our project's definition did not consider break-up occurring at stages of ice thicker than grey-white ice and therefore, did not identify break-up in years where thick ice conditions were dominant in the spring. Due to these limitations of our analysis, it is likely that break-up did occur in each sea ice year amongst all crossing areas even though sea ice conditions did not consistently meet our criteria for break-up in the NW, NE and W-crossing areas.

In the E and S-crossing areas freeze-up timing ranged from early August to late September with similar median dates amongst the crossings, September 11 and September 06 respectively. Break-up timing ranged from mid-April to mid-July with very similar median dates of May 23, and May 25 respectively. Freeze-up and break-up timing is consistent in the E, and S-crossing area suggesting environmental conditions influencing the timing of freeze-up and break-up are relatively similar amongst these crossing areas over time compared to NW, NE and W-crossing areas. Workshop discussions focused on sea ice conditions primarily in the S-crossing as it is an important area for caribou and Inuit movement (WKSP 2018 a,b,c,d). Contributors described two environmental conditions in the S-crossing area that influence the timing of freeze-up. Strong water currents slow freeze-up by physically breaking apart freshly frozen ice, however, this delay is offset by the narrow fetch of this crossing area, which restricts the formation of large waves (WKSP 2018c,d). The E-crossing is also very narrow (<25 km) which may prevent the formation of large waves and delay sea ice freeze-up, although this was not explicitly mentioned by workshop contributors. Contributors also indicated that the salinity of surface water in the E and S-crossing areas was relatively low (extending towards Chantrey Inlet and Rasmussen Basin), which would expedite sea ice freeze-up (WKSP 2018d; Carter et al. 2017). Environmental conditions observed in the E, and S-crossing areas suggests differences between the fall and spring in the relative importance of water currents, surface salinity and geography regarding their respective ability to influence freeze-up and break-up timing.

Open water conditions were typically observed at the time of break-up, which may suggest that break-up initiates and quickly reaches open water conditions within 1 week. Multi-year ice was observed in the NW, NE, and W-crossing areas over time (Table 4.1, Table 4.4). Discussions in workshops did not focus on the local geography of multi-year ice, however, contributors highlighted mobile multi-year ice (likely pack ice) in the NW, and NE-crossing areas that can move into the S-crossing areas (WKSP 2018c). The presence of multi-year ice and icebergs has been documented in other Nunavut communities as influencing the timing of freeze-up where it becomes grounded (Laidler and Ikummaq, 2008; Laidler et al., 2008; Laidler et al., 2009; Laidler et al., 2010), so multi-year ice could potentially influence the timing of freeze-up in these shallow areas around KWI. Contributions from workshops, and our sea ice analyses are consistent with reports by Haas and Howell (2015), and Howell and Brady (2019) who described a trend towards larger influxes of multi-year ice from the Arctic Ocean basin to lower latitude waters of the CAA between 1997-2016. The NW, NE and S-crossing areas have regions of persistent open water (Table 4.1, Table 4.4) and these areas of open water may lead to an influx of pack ice (Haas and Howell 2015; Howell and Brady 2019). However, there was no evidence of open water in the W-crossing area, suggesting that this influx of multi-year ice from the north may have not been possible within the crossing area. In addition, there was no evidence of multi-year ice in the S-crossing area, but contributors did describe multi-year ice in the area. Our analysis only identifies the dominant ice types within each caribou crossing area at freeze-up and break-up, and therefore, multi-year ice may have been present in S-crossing area in lower concentrations.

Young and thin ice (thin first-year ice, new ice, and grey-white ice) were the dominant ice types present in the E, and S-crossings areas in the fall, and spring, with evidence of year-round open water in the S-crossing (WKSP 2018c,d). Collisions of thin mobile sea ice can create pressure ridges and ice deformation producing barriers to movement on the sea ice (Post et al. 2013; Bourbonnais and Laserre 2015). Ridges are more likely to form in the spring as ice breaks off and becomes mobile (Post et al. 2013). Our sea ice analysis did not detect pressure ridges, and their occurrence around KWI were not discussed in workshops. However, the dominant presence of thin ice in the E, and S-crossing areas, and the evidence of persistent open water in the S-crossing area, may have led to the creation of pressure ridges or deformed ice in the spring and fall.

The NW, and NE-crossing areas have evidence of year-round open water (Table 4.4, WKSP 2018a,b,c), whereby freeze-up conditions were not met in all sea ice years. Uqsuqtuurmiut described small areas of open water with mobile pack ice in the S-crossing area, that are smaller than those observed in the NW, and NE-crossing areas (WKSP 2018 a,b,c) and may represent polynyas. Stroeve et al. (2012, 2014) observed a trend towards more areas of year-round open water throughout the Arctic Ocean from 1979 to 2013. Our project may better identify local variation in areas of persistent open water than Stroeve et al. (2012, 2014) because of the smaller scale of our observations. Areas of open water can act as barriers to the movement of caribou and Inuit, and therefore, understanding the persistence of open water is important alongside sea ice conditions.

5.2 - Timing and location of reliable caribou sea ice habitat around KWI

In workshops, Elders and hunters described hikuhaaq as the minimum sea ice thickness that caribou need to walk on (WKSP 2018a,b,c). This equates to new ice in CIS terminology (corresponding to a thickness of >10 cm), and was used to define freeze-up and break-up thresholds for sea ice analysis (see section 3.3.2). Contributors also indicated that caribou walk on closely packed ice avoiding mobile ice (WKSP 2018c). Caribou are known to assess sea ice quality and features during their crossings and respond to these conditions during their movement through their sea ice habitat. For example, caribou have been observed moving slowly and cautiously on thin and dark coloured sea ice (WKSP 2018a,d). Joly (2012) observed similar behaviour by caribou in Kotzebue Sound, Alaska. An Uqsuquurmiut contributor described caribou avoiding artificial features or altered environment features during their sea ice crossings (WKSP 2018e). While caribou are heavier than people, they can use sea ice thinner than Inuit can because their body weight is more distributed (WKSP 2018c). Therefore, it is important to keep in mind that our definitions of freeze-up and break-up were developed according to caribou use of sea ice habitat and may not reflect ice conditions necessary for Uqsuqtuurmiut travel on foot or snow machines.

Our caribou-centric definition of freeze-up was not met in the NW, NE, W-crossing areas in some years. Large areas of open water and the presence of pack ice in the fall may have contributed to the lack of freeze-up within the NW and NE crossing areas. The NW and NE-crossing areas did not freeze over in 1998 according to our freeze-up criteria, which may be attributed to warm temperatures observed across the

NWP that year along with minimum sea ice extent and evidence of rapid summer melt (Howell et al. 2010).

These areas of open water were likely barriers to caribou movement, and caribou may have responded to unstable sea ice conditions in a variety of ways to facilitate crossing in relation to dynamic freeze-up and break-up conditions. For example, Dumond and Lee (2012) observed Dolphin-Union caribou avoiding areas of open water within Victoria Strait. Alternatively, caribou may swim through areas of open water and straits. Indeed, Dolphin-Union caribou have also been observed swimming large distances (<100 km) across Victoria Strait (Poole et al. 2010, Dumond et al. 2013). Though caribou can assess sea ice quality, thin sea ice is difficult to distinguish from open water and therefore, they may fall into the open water (WKSP 2018c). In the fall, caribou may struggle to recover from the waters as the ice is just forming (WKSP 2018b), and, in the spring, the sea ice is thick and wet which is difficult to gain traction on during recovery (WKSP 2018b). As caribou interact with open water (within closely packed ice, and across straits), they are at risk of drowning, or freezing following recovery onto the sea ice (WKSP 2018a,b,c,d; Thorpe 2001, Poole et al. 2010, Dumond et al. 2013).

Contributors did not describe frequent caribou movement within the NW, NE and W-crossing areas (WKSP 2018a,b,c,d), which makes sense in relation to the dynamic sea ice conditions present in these crossings (Section 4.2.2, Section 4.3.2). However, in previous work, Uqsuqtuurmiut described that as caribou move from Boothia Peninsula to KWI through the NE-crossing area in the spring, they use Matty and Qikiqtarjuaq Islands as part of their route (Ljubicic et al. 2018a). Caribou using the NE-crossing area may be

Barren-ground caribou moving north or east from the mainland (likely from the Ahiak and Wager Bay herds), or Peary caribou moving south from the CAA via Boothia Peninsula (Ljubicic et al. 2017; 2018a). Caribou using the NW and W-crossing areas are likely Peary or Dolphin-Union caribou from the near-by Victoria Island (Poole et al. 2010, Dumond and Lee 2012, Dumond et al. 2013), but these crossings seem the least frequently used according to Uqsuqtuurmiut (WKSP 2018b; Ljubicic et al. 2018a). Determining which sub-species and/or herds that use each crossing area is speculative and based only on sparse literature and the proximity of each crossing area to known caribou ranges. Uqsuqtuurmiut in workshops did not distinguish sea ice habitat or use of crossings by herd. Even so, they have their own local naming conventions (Ljubicic et al. 2018b). Biological caribou designations on KWI are uncertain (Johnson et al. 2016, Ljubicic et al. 2017, GN 2011, Section 2.1.2), which makes it difficult to interpret the use of crossings according to particular sub-species or herd behaviour.

Freeze-up and break-up criteria were met every year between 1983-2018 in the S and E-crossing areas. Caribou that use the S and E-crossing areas were mainly described as Barren-ground caribou (likely from the Ahiak or Wager Bay herds; Ljubicic et al. 2017), moving to/from the mainland (Adelaide Peninsula and Boothia Peninsula) and KWI (Ljubicic et al. 2018a). Uqsuqtuurmiut have observed caribou moving around small areas of open water that persist in landfast ice due to strong currents in the S-crossing area (likely a reference to localized polynyas; WKSP 2018c). These polynyas are not very extensive and therefore sea ice can reach over 9/10 in each sea ice year indicating the S-crossing area is reliable for caribou movement. Contributors highlighted the S-crossing areas as being the most important and most commonly used in the fall and spring by both caribou and Inuit (WKSP 2018a,b,c,d; Ljubicic et al. 2018a), which may be attributed to the seasonally available sea ice habitat across all years. The S-crossing area is also in closer proximity to the mainland and larger numbers of Barren-ground caribou have been observed moving across the sea ice relative to the sub-species observed in the NW, NE, and W-crossing areas (GN 2011; Ljubicic et al. 2018a). The ranges of Ahiak, Bathurst, Beverly, Lorillard, Melville and Wager Bay Barren-ground caribou herds may imply movement to or through Adelaide Peninsula and Boothia Peninsula (with potential for crossing to KWI, if needed, for food, calving, or to avoid insects on the mainland). This is in comparison with Peary caribou to the north or Dolphin-Union caribou to the west (WKSP 2018a,b,c,d; Miller et al. 2004, Miller et al. 2006, Nickels et al. 2005, Dumond et al. 2013, Johnson et al. 2016, Ljubicic et al. 2017).

The timing of freeze-up and break-up in all crossing areas had high interannual variation, which suggests that caribou may adapt to these dynamic conditions by adjusting the timing of their crossing through sea ice habitat. In WKSP (2018b), Qitsualik described her observations of caribou moving away from the shore if they could not find an area suitable for crossing. This avoidance of unreliable sea ice may have ecological consequences on caribou populations stemming from their use of sea ice to complete reproductive cycles and respond to changing resource availability (Dumond et al. 2013, Nicholson et al. 2015, Johnson et al. 2016, section 2.1.3 and 5.5). This response to unreliable conditions by caribou may lead to changes in their migration movement and/or range (GN 2011, Mallory and Boyce 2017, Ljubicic et al. 2018a). This may affect the accessibility of caribou for Uqsuqtuurmiut and other nearby communities, complicating their capacity to hunt caribou in traditionally used areas (GN 2011, Ljubicic et al. 2018a).

5.3 - Timing and location of ship voyages around KWI

We observed temporal and spatial variation in the timing of ship voyages in the waters surrounding KWI. The NW, and W-crossing areas experienced a broader range of shipping season lengths and greater distance travelled by ships relative to the NE, E, and S-crossing areas (Table 4.2, Table 4.5, Table 4.6). Within the NE, E, and S-crossing areas the length of shipping season is similar (mid-August to mid-September, Table 4.6), and ship voyages were typically shorter and less spatially concentrated in these areas compared with the west side of KWI. Trends in the timing and distance of ship voyage varied by ship type amongst all crossings (Table 4.2, Table 4.5, Table 4.6). Dawson et al. (2018) describes shipping patterns in the NWP over time, and suggests that the spatial variation and increases in ship voyages over time reflects the changing needs of communities, government agencies, and opportunities for resource exploration and tourism.

In community workshops, contributors expressed concerns regarding government vessels and icebreakers, pleasure craft vessels, and passenger ships because their traffic have significantly increased in the NWP over the last decade (WKSP 2018a,b,c,d, Carter et al. 2017, Dawson et al. 2018). Tanker and general cargo ships were not present in the majority of sea ice years, and there was a change towards the later exit of these types of ships in the NW-crossing area (Table 4.1, Table 4.4). This may suggest tanker and general cargo ship traffic is changing at similar rates and have similar voyage timing. Tug and barge ships demonstrate high-interannual variation in the timing of their voyages. Change was observed in the distance travelled by tug/barge ships in only the S-crossing area, which can be attributed to bringing goods to Uqsuqtuuq. The minimal presence, distribution and change observed amongst these non-ice-strengthened ship types suggests limited impact of these ship types on sea ice. Icebreakers can break-apart sea ice making it difficult and dangerous for caribou or people moving across sea ice (Poole et al. 2010, Pizzolato et al. 2014, Johnson et al. 2016, Carter et al. 2017). While pleasure crafts and passenger ships are not ice-strengthened, and thus do not physically disrupt the sea ice, the movement of these small vessels in ice-infested waters can be hazardous and may result in the need for emergency services which are expensive and complicated to provide (Carter et al 2017). Such emergency response often involves the deployment of the Coast Guard and involves ice-breaking to rescue a vessel unable to navigate out of dangerous ice conditions (Carter et al. 2018). The remainder of the discussion will focus specifically on these ship types because of their capacity to impact sea ice habitat, or they are at particular risk in dynamic sea ice conditions.

Government vessels and icebreakers can be found throughout the NWP (Dawson et al. 2018). Around KWI, government vessels and icebreakers were present in all years and in all crossing areas between 1990-2016, typically between mid-July and late-September (Table 4.2, Table 4.5). However, the NW and W-crossing areas had the greatest concentration of ship traffic (Figure 5.1). Trends towards longer shipping seasons were observed in all crossings, except for the S-crossing area (Table 4.5). A significant trend towards later exit of government vessels and icebreakers was observed in the W-crossing area, and towards earlier entry of ships in the NW, NE and W-crossing areas (Table 4.3, Table 4.5). In recent years, ship voyages have occurred late into the fall increasing the likelihood of ships impacting ice conditions during freeze-up in caribou crossing areas. Conversely, ship voyages early in the spring increases the likelihood of ships encountering – and affecting – sea ice prior to break-up. The trends in timing of government vessel and icebreaker movement in the NW, NE and W-crossing areas suggests there will be continued lengthening of the shipping season in the future. It is likely that government vessels and icebreakers will continue pushing towards earlier voyages in the spring and later voyages in the fall, with subsequent consequences for sea ice and caribou habitat. The multi-year ice in the NW, and NE- crossing areas may impede the voyage of the government vessel and icebreakers. Though icebreakers can proceed in areas of multi-year ice, their movement is significantly slowed (Guy and Laserre 2016). We observed a statistically significant increase in the distance travelled by government vessels and icebreakers within the S-crossing area, however, there was evidence of substantial interannual variability in the timing of both ship exits and entries in the crossing area over time (Table 4.6). Therefore, the impacts of ship traffic on sea ice in this important southern crossing area may likewise be highly variable. Government vessels and icebreakers are the largest proportion of ship traffic in the CAA since 1990. In addition, government, military and research vessels are becoming more common in the region, and are predicted to increase in the near future with the release of six Arctic Offshore Patrol Ships starting in the summer of 2020 (Dawson et al. 2018, Government of Canada 2020).

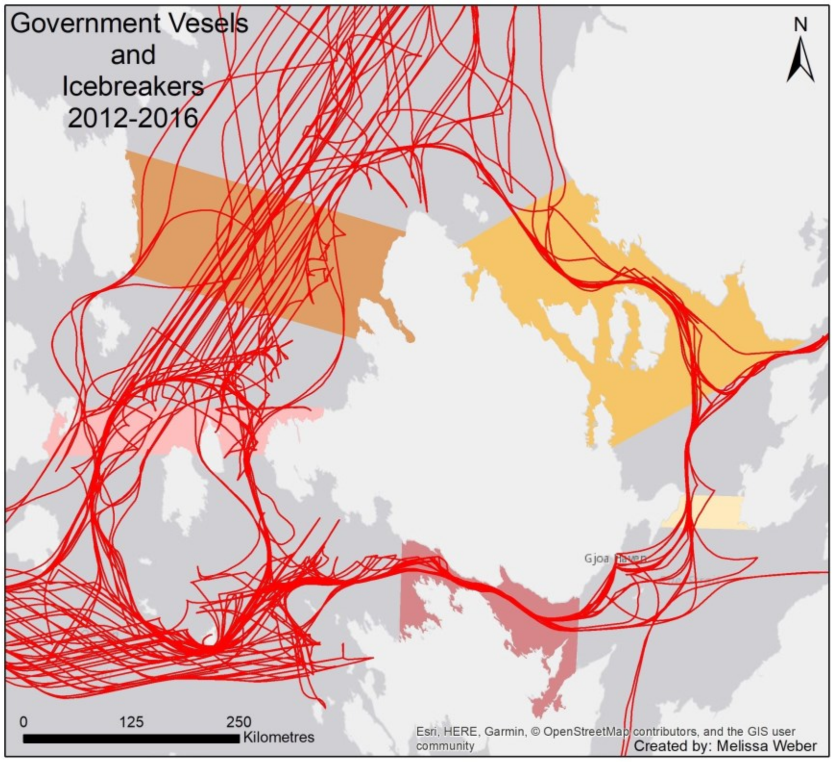

Figure 5.1 – Voyages of government vessels and icebreakers between 2012-2016 surrounding Uqsuqtuuq by ship type (created by Melissa Weber).

Though passenger ships had fewer voyages than pleasure crafts or government vessels and icebreakers, they had a wide distribution in the waters surrounding KWI (Figure 5.2). These ship voyages likely reflect destinations for wildlife tourism both within and outside of Northern communities (Dawson et al. 2018). In the waters surrounding KWI, passenger ships stayed in offshore waters except for a few specific destinations for excursions or community visits such as Uqsuqtuuq (Figure 5.2). Passenger ships were present in the W-crossing area across most years (Table 4.5); however, they had sporadic presence in all other crossing areas occurring in less than <50% of years (Table 4.5). There was a statistically significant trend in passenger ships traveling longer distances over time within the NW, and W-crossing areas (Table 4.6). In addition, as seen in Figure 4.2 the majority of passenger ship voyages are in those crossing areas, and seem to move widely through space. This suggests that passenger ships move primarily through the NW and W-crossing area, likely with Cambridge Bay as a destination. In all crossing areas, passenger ships were typically present between early-August and late-September. A trend towards later exit of passenger ships was observed in the NW, and W-crossing areas (Table 4.2); however, there was no significant change in the length of the shipping season. This suggests that passenger ships are shifting their voyage season later in the year, without changing the length of time they spend in the western crossings. This seasonal shift may lead to increased interactions between passenger ships and sea ice, resulting in hazardous conditions for passenger ships and potentially requiring ice-breaking support or emergency response (Carter et al. 2017).

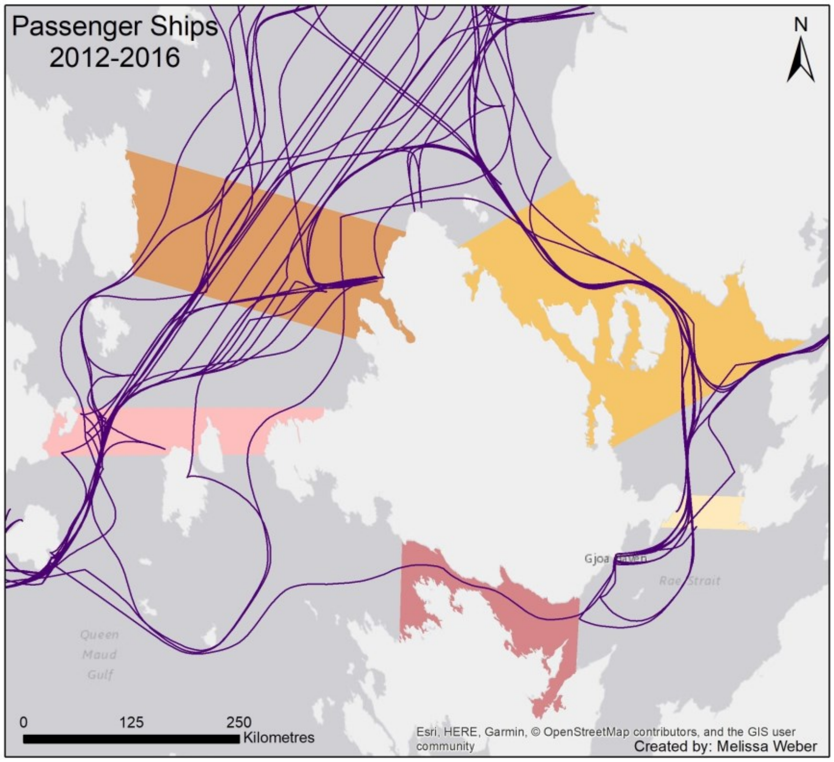

Figure 5.2 - Voyages of passenger ships between 2012-2016 surrounding Uqsuqtuuq by ship type (created by Melissa Weber).

Pleasure crafts have experienced the most rapid growth in the NWP in terms of kilometers travelled, and broader spatial distribution (Dawson et al. 2018). A similar pattern of increasing pleasure crafts is observed in the waters surrounding KWI, especially in the NW and W-crossing areas (Figure 5.3). Pleasure crafts are sporadically present within all crossing areas (Table 4.3, Table 4.5), and are present in every year following the mid-2000s (Figure 4.6). They have a slightly larger temporal range than other ship types, with pleasure crafts typically being found in crossings between early-August to mid-October (Table 4.3). Because of their small size, pleasure crafts sail very close to the coast and into inlets. This proximity to coastal areas increases the likelihood of pleasure crafts disturbing caribou that are nearby on the land, mostly through auditory or physical (i.e. human presence) disturbance (McKenna et al. 2011, Carter et al. 2017).

The increase of pleasure craft voyages (among other ship types) in the NWP (Dawson et al. 2018) have the potential to impact other caribou crossing areas, particularly Peary caribou moving between Boothia Peninsula, Somerset Island, and Prince of Wales Island, and Dolphin-Union caribou moving through Victoria Strait (Poole et al. 2010, Dumond et al. 2013, Johnston et al. 2016). The increases in distance travelled, and the relatively late exit of pleasure crafts from the W-crossing, may lead to more opportunities for pleasure crafts encountering sea ice in the near future if current trends continue. The W-crossing area also has evidence of multi-year ice and dynamic conditions (Table 4.1, Table 4.4), and thus a higher chance of the need for ice-breaking support or emergency response (Guy and Laserre 2016). Uqsuqtuurmiut have observed ice-breakers creating routes through the sea ice for the sailing of pleasure craft vessels in pack ice (WKSP 2018b). Additional analyses of the shipping data would be needed to understand the relationships between ice-breakers and pleasure craft ships over time, and is an important focus for future investigations.

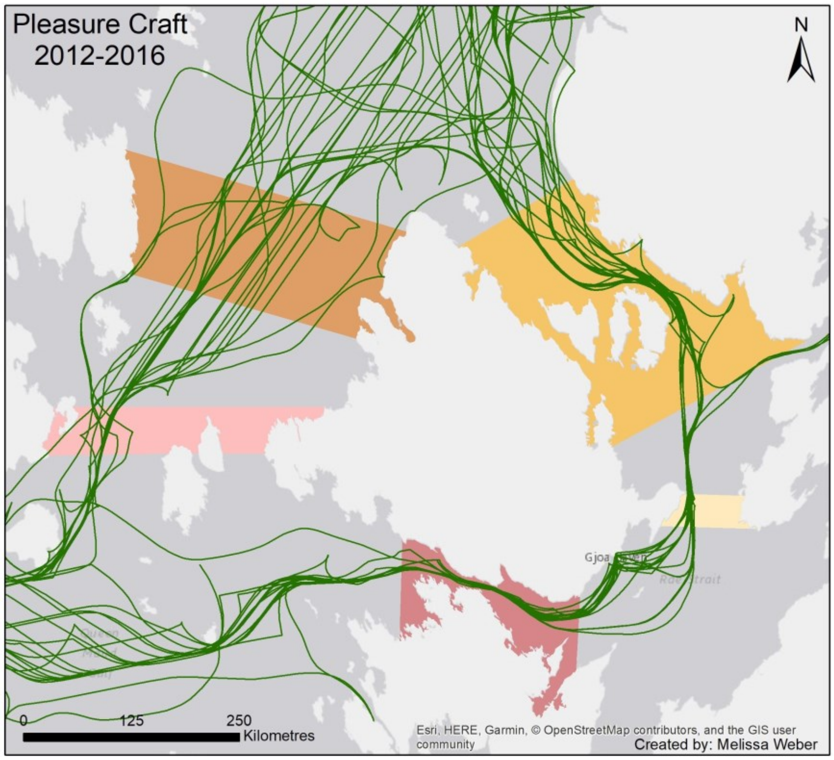

Figure 5.3 - Voyages of pleasure crafts between 2012-2016 surrounding Uqsuqtuuq by ship type (created by Melissa Weber).

5.4 - Impacts of sea ice and ship traffic on caribou sea ice habitat around KWI

We understand from Uqsuqtuurmiut the challenges that caribou face in using sea ice to cross to/from KWI. Caribou encounter – and adjust to – the high degree of variability in freeze-up and break-up timing, as well as ice conditions in these transitional seasons (section 5.1). However, the increased potential for disruption of sea ice with growing ship traffic in the NWP (section 5.3) creates additional barriers to caribou movement (Johnson et al. 2016, Carter et al. 2017). Our analyses showed spatial and temporal variation in the potential interactions between ship transit and sea ice conditions necessary for caribou movement. Looking at all three in concert, this section integrates previous findings to identify critical timing and areas when interactions between ship traffic and sea ice may have detrimental consequences on caribou use of their habitat. We acknowledge that the precision of timing represented in our analysis is limited by the weekly production of CIS charts; therefore, the actual date of freeze-up and break-up may vary up to six days before or after the specific timing of ship transit. Uqsuqtuurmiut described that conditions of freeze-up and break-up can occur very rapidly, overnight or over a couple days (WKSP 2018c). The precision of the CIS charts used is too coarse to identify these quick changes.

In the fall across all years, the last ships to exit the NW-crossing area did so prior to freeze-up (Figure 5.4). This was similar in the W-crossing area as well, with the exception of a government vessel/ice-breaker exiting only 2 days after freeze-up in 1995 (Figure 5.5). Therefore, in these western crossing areas ships are unlikely to have interacted with – or impacted – newly developed sea ice. However, Uqsuqtuurmiut described substantial interannual variation in the timing of freeze-up in the NW-crossing. At freeze-up, ships encountered primarily multi-year ice and open water (Table 4.1). These areas are difficult for caribou to cross and as a result these crossing areas may not be as frequently used (WKSPa,b,c,d; Johnson et al. 2016, Ljubicic et al. 2018a). Dumond et al. (2013) observed caribou on the mainland south of Victoria Island in December with ice on their fur, likely from falling into open water and recovering onto the sea ice. In addition, Poole et al. (2010) described high mortality associated with the Dolphin-Union caribou crossings in Victoria Strait, west of KWI, in the fall-early winter and mid-winter. These observations of caribou indicate that there are environmental conditions within Victoria Strait that are impacting the movement and survival of Dolphin-Union caribou. Thorpe (2001) described caribou moving to the mainland from Victoria Island in October and November, which overlaps with ship traffic in the NW, and W-crossing areas that can occur up to late October. The persistence of open water and mobile multi-year sea ice suggests the sea ice conditions in this area may be problematic for caribou movement.

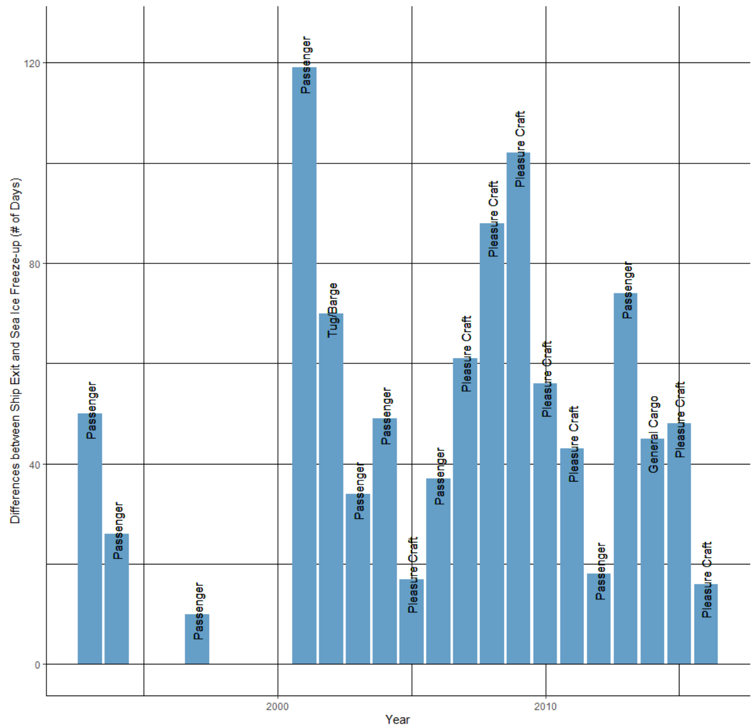

Figure 5.4 - Difference between sea ice freeze-up and ship exit within the NW-crossing area (Where: Blue indicates ships within the crossing area prior to freeze-up, red indicates ships within the crossing area after freeze-up).

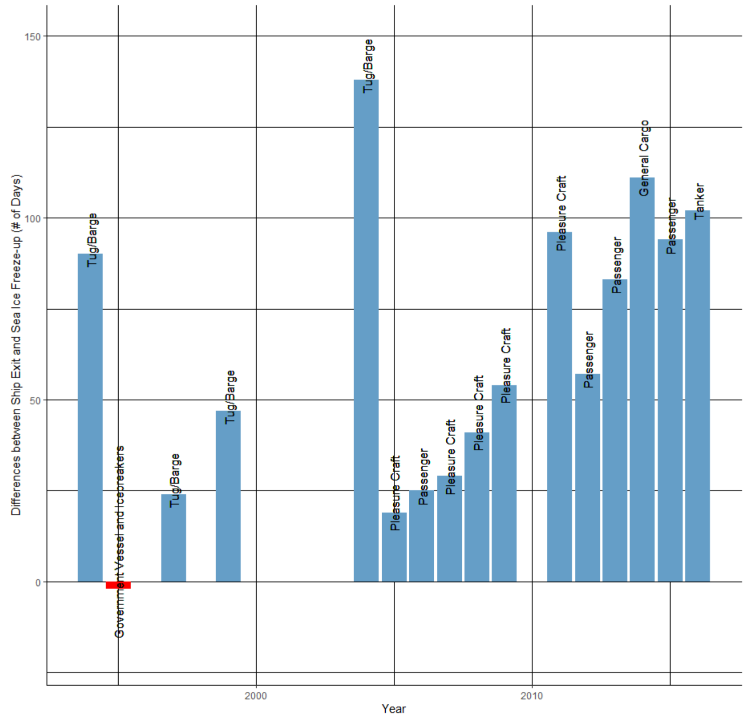

Figure 5.5 - Difference between sea ice freeze-up and ship exit within the NE-crossing area (Where: Blue indicates ships within the crossing area prior to freeze-up, red indicates ships within the crossing area after freeze-up).

Compared to the western side of KWI, there are more years in the NE, E, and S-crossing areas where the last ship exit occurs after freeze-up, and these are primarily tug/barge or government vessels/ice-breakers (Figure 5.6, 5.7, 5.8). However, the potential risk associated with interactions between ship traffic and sea ice are not consistent amongst these crossings. Ships encounter more multi-year ice in the NE-crossing area relative to the E and S-crossing areas (Appendix 13). Ships in the E-crossing area encountered primarily open water conditions in the fall prior to freeze-up (Appendix 13), suggesting that ships are unlikely to impact caribou sea ice habitat despite some evidence of interaction. Ships in the NE-crossing area encountered primarily multi-year ice and thick-first year ice in the fall (Appendix 13). This suggests that ship traffic may interact with developing sea ice late in the fall, as well as multi-year ice that is present year-round (Table 4.1). These interactions may produce barriers for caribou movement across the sea ice (Carter et. 2017), and the multi-year ice may present hazards to the tug/barge ships that are the last to exit following freeze-up (Figure 5.6). No ships exited any caribou crossing area following freeze-up in the last seven years of our time frame suggesting these voyages occur during the summer with little interaction with caribou or sea ice.

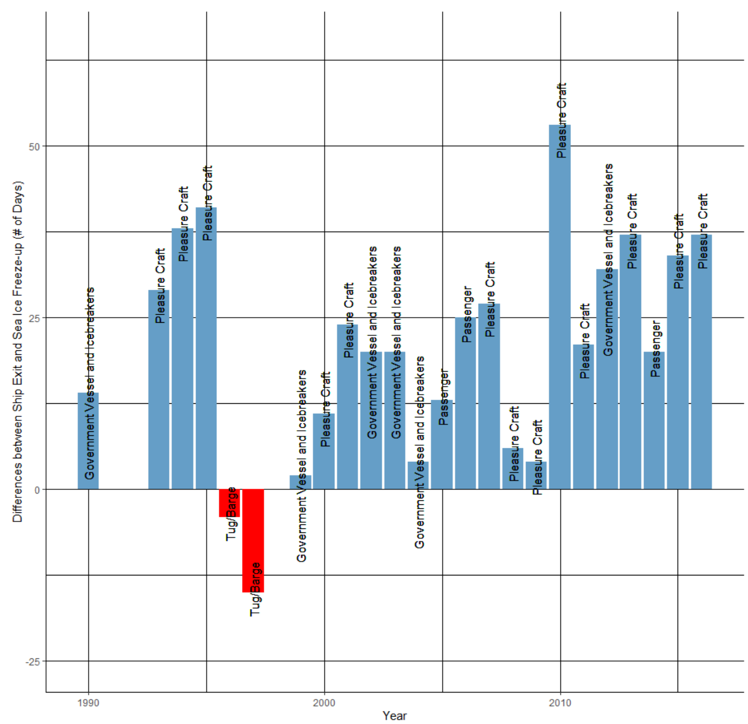

Figure 5.6 - Difference between sea ice freeze-up and the timing of ship exit within the NE-crossing area (Where: Blue indicates ships within the crossing area prior to freeze-up, red indicates ships within the crossing area after freeze-up).

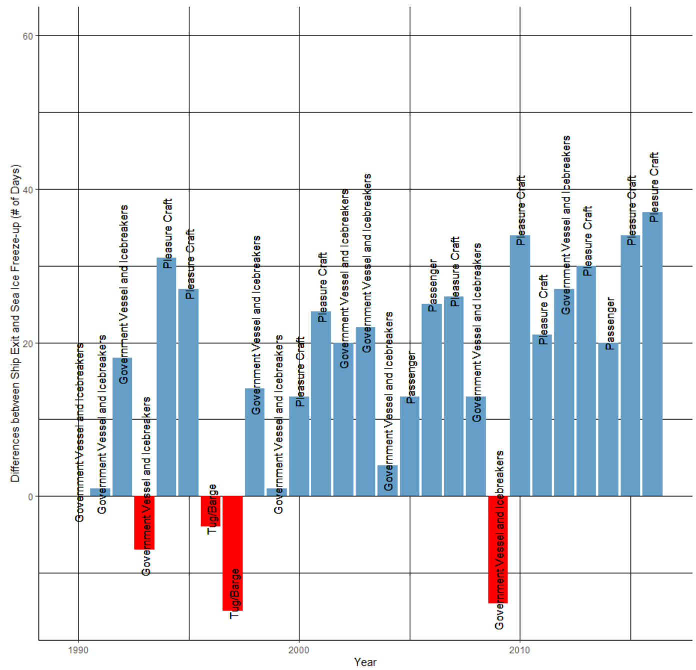

Figure 5.7 - Difference between sea ice freeze-up and ship exit within the E-crossing area (Where: Blue indicates ships within the crossing area prior to freeze-up, red indicates ships within the crossing area after freeze-up).

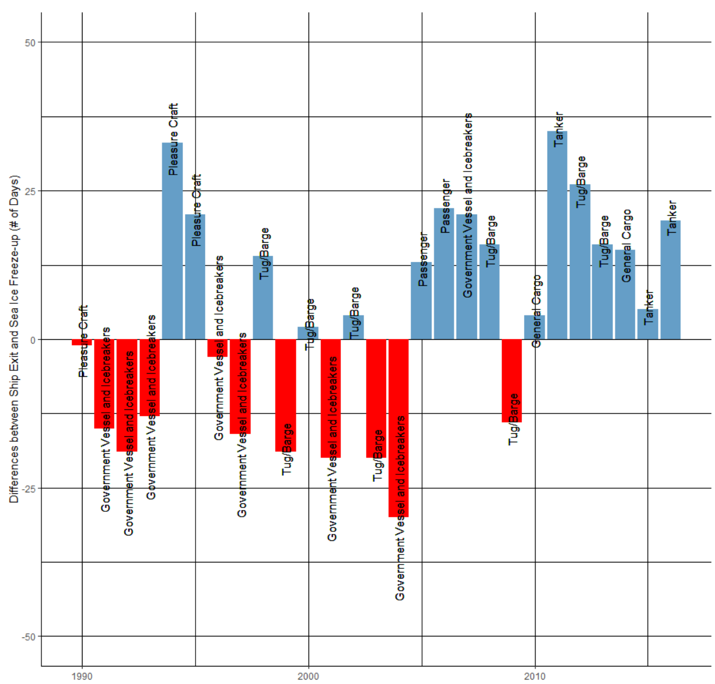

Figure 5.8 - Difference between sea ice freeze-up and ship exit within the S-crossing area (Where: Blue indicates ships within the crossing area prior to freeze-up, red indicates ships within the crossing area after freeze-up).

Ships exiting the S-crossing area after freeze-up were most common (i.e. in 11 years) and were the latest (up to 30 days and average of 15 days) after freeze-up of all crossing areas (Figure 5.8). With the S-crossing area also being the most important and consistently used by caribou (WKSPs; Ljubicic et al. 2018a), the cumulative effects of dynamic sea ice conditions and a trend toward later ship exits (Table 4.3) have the greatest potential impact on caribou. This may be attributed to the relatively earlier freeze-up in the S-crossing area, late voyages of government vessels and icebreakers through Simpson Strait, and the high interannual variation in freeze-up timing observed in the crossing area (Table 4.1) and explained by Uqsuqtuurmiut (WKSP 2018a). In addition, ships encounter primarily open water conditions, grey-white ice, and thin-first year ice when moving through the S-crossing area in the fall (Appendix 13). This supports that ships are encountering newly developed sea ice from that year and open water conditions likely attributed to localized polynas in the S-crossing area.

No significant changes were observed in the timing of freeze-up or the length of open water season in the S-crossing area (Table 4.1, Table 4.5), so it appears that the timing of ship transit is shifting to later exit dates rather than a lengthening of the overall shipping season. This pattern leads to substantial risk of ship traffic impacting sea ice formation in the fall, and accordingly the greatest potential consequences for caribou sea ice habitat in this most important S-crossings area. Contributors (WKSP 2018c) described impacts of unreliable sea ice conditions in the fall in the S-crossing area. Uqsuqtuurmiut explained that the S-crossing areas are not always frozen by late October when caribou are moving through the area (WKSP 2018c). This impacts Uqsuqtuurmiut's ability to travel on sea ice with the S-crossing area. Barriers within sea ice created by ship traffic decreases the ability of Inuit to make safe travel decisions and reach areas and/or wildlife needed for the production of cultural activities. Inuit individual freedom, and capacity to predict sea ice conditions may also be impacted by increasing ship traffic challenging their ability to make safe travel decisions (Carter et al. 2017, Olsen et al. 2020). KWI and the mainland (Adelaide Peninsula and the Back River area) are very important to Uqsuqtuurmiut and any potential hazards or barriers to sea ice travel in the S-crossing may substantially impact caribou hunting (Ljubicic et al. 2018a) and access to traditional homelands (Ljubicic et al. 2018b). Furthermore, Uqsuqtuurmiut have strongly expressed that there should be no winter ship transit in the waters surrounding KWI, as this could seriously disrupt and prevent safe Inuit travel on the sea ice that largely occurs mid-winter (Carter et al. 2017; Dawson et al. 2020).

The potential impacts of ship traffic on sea ice in caribou crossing areas are greater in the fall than in the spring. Only in the NW and W-crossing areas do ships enter prior to break-up (Figure 5.9, 5.10), and this occurs in six years. As ships enter these western crossings they encounter multi-year and thick-first year ice (Appendix 13). In 1999 and 2000 government vessels and ice-breakers were the earliest to enter in the W-crossing areas (17 and 5 days prior to break-up), and they could potentially impact caribou sea ice habitat if they were breaking consolidated pack ice. Qitirmiut described caribou to the Northwest of King William Island moving to the mainland from Victoria Island between April, May and June (Thorpe 2001). No ships enter the NW, and W-crossing area prior to mid-July, suggesting limited overlap in the timing of ship voyages and caribou sea ice crossings in the spring. The earliest entry was of a passenger ship in the NW, and W-crossing areas in 2010 (28, and 14 days prior to break-up days prior to break-up), and although they would not be breaking the ice, it may increase risks of accidents and potential need for emergency response. This voyage may be possible through assistance by icebreakers opening channels for the passage of the passenger ships, or they may have travelled in ice-infested waters risking hazards to their ship.

The assessment of ship and sea ice interactions during break-up is limited by the parameters defined for ice conditions in the calculation scripts. Our project's definition of sea ice break-up considered ice less than 9/10 concentration, and thinner than new ice, according to Uqsuqtuurmiut descriptions of ice conditions useable by caribou. However, what was realized after analyzing the results was that the new ice threshold is relevant for freeze-up, but for break-up any ice concentration less than 9/10 (of any thickness) would be difficult for caribou movement. Therefore, further refinement of break-up analysis is needed to assess the potential of ships to disrupt caribou crossing areas in the spring. A qualitative assessment of CIS data representing sea ice conditions in the S-crossing area demonstrates a bias in our current definition of break-up towards later break-up by an average of 2 weeks. In over 60% of years, total sea ice concentration in the S-crossing area was below 9/10 with predominantly thick-first year or old ice observed. This would have not been identified as break-up within the project's current definition, and so break-up that impacts caribou movement would have occurred earlier than what our results suggest. Other crossing areas may be similarly impacted, and further analysis is needed to understand the implications of earlier break-up and adjusted break-up threshold definitions.

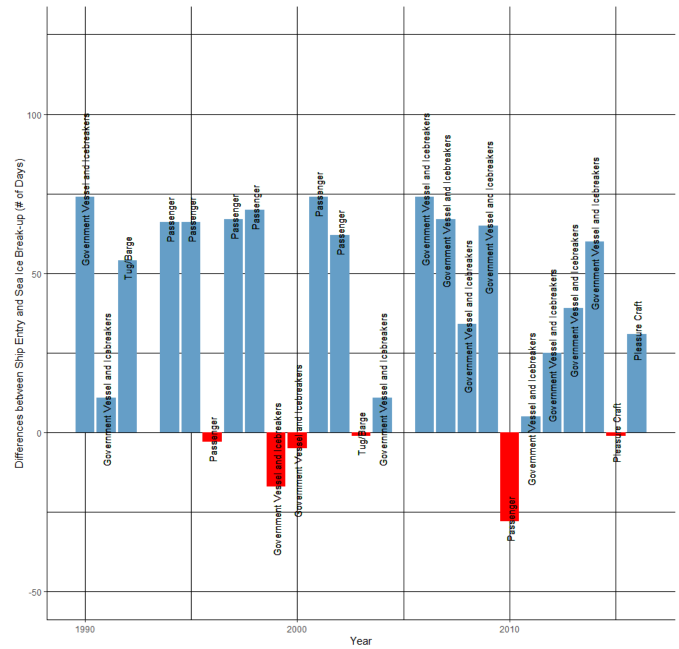

Figure 5.9 - Difference between sea ice break-up and ship entry within the NW-crossing area (Where: Blue indicates ships within the crossing area after break-up, red indicates ships within the crossing area before break-up).

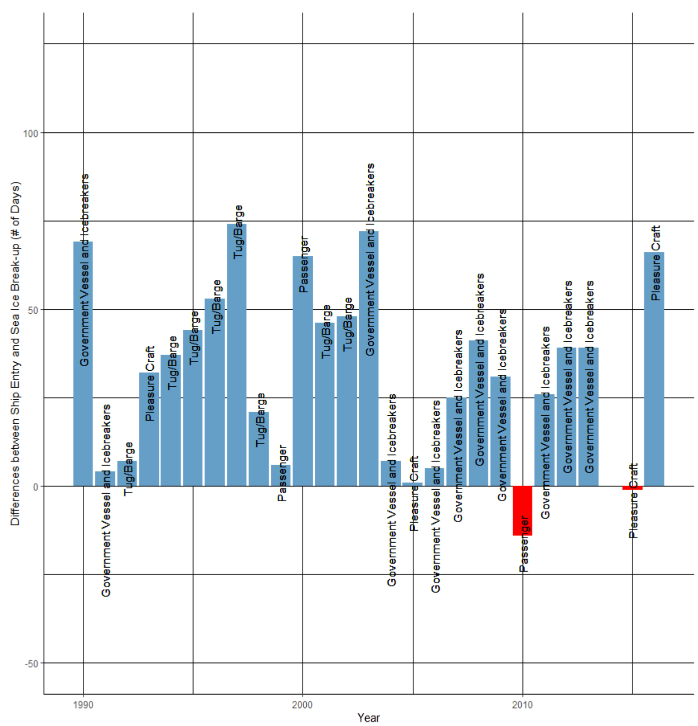

Figure 5.10 - Difference between sea ice break-up and ship entry within the W-crossing area (Where: Blue indicates ships within the crossing area after break-up, red indicates ships within the crossing area before break-up).

In the NE, E, and S-crossing areas no ships entered prior to break-up (Figure 5.11, 5.12, 5.13), and most ships encountered open water conditions (Appendix 13). This suggests a low likelihood that ship traffic is disrupting caribou sea ice habitat in these eastern and southern crossings because break-ups had already occurred as ships were entering the areas. Contributors described that most of the caribou movement on sea ice in the spring occurs between May, June and July (WKSP 2018b). All ship types except for tug/barge ships always entered the S-crossing area following August 01, suggesting that ships were not interacting with caribou or their sea ice habitat in the spring. However, an Uqsuquturmiut Elder described sighting of caribou drowned or frozen in a lead in the spring in the S-crossing area. Leads can occur at any time of the year, and therefore, there may be areas of unreliable sea ice habitat with the S-crossing area, regardless of the timing of ships voyaging through the crossing area in the spring.

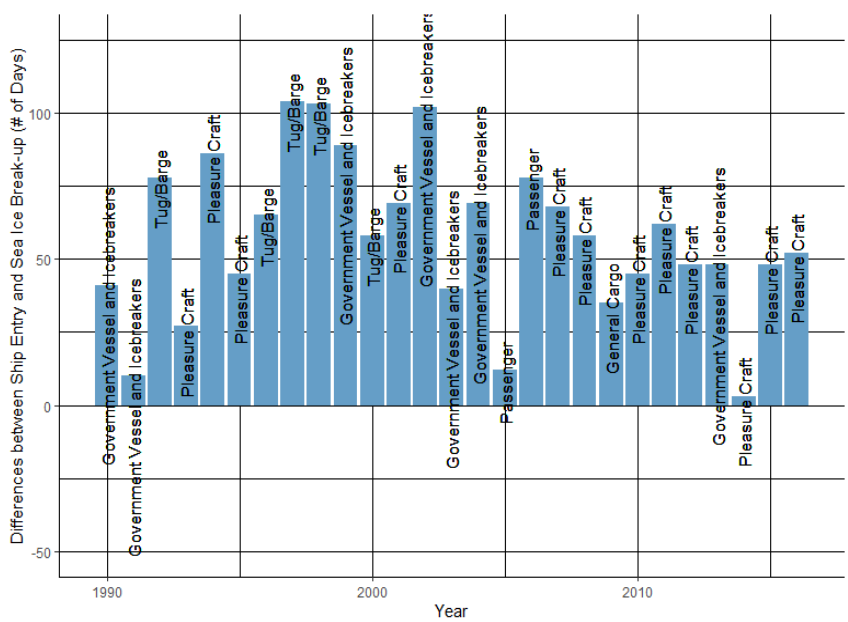

Figure 5.11 - Difference between sea ice break-up and ship entry within the NE-crossing area (Where: Blue indicates ships within the crossing area after break-up, red indicates ships within the crossing area before break-up).

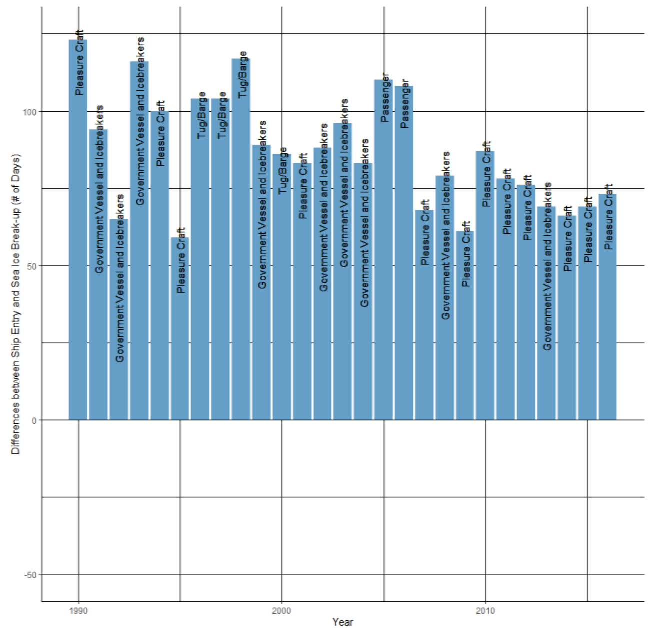

Figure 5.12 - Difference between sea ice break-up and ship entry within the E-crossing area (Where: Blue indicates ships within the crossing area after break-up, red indicates ships within the crossing area before break-up).

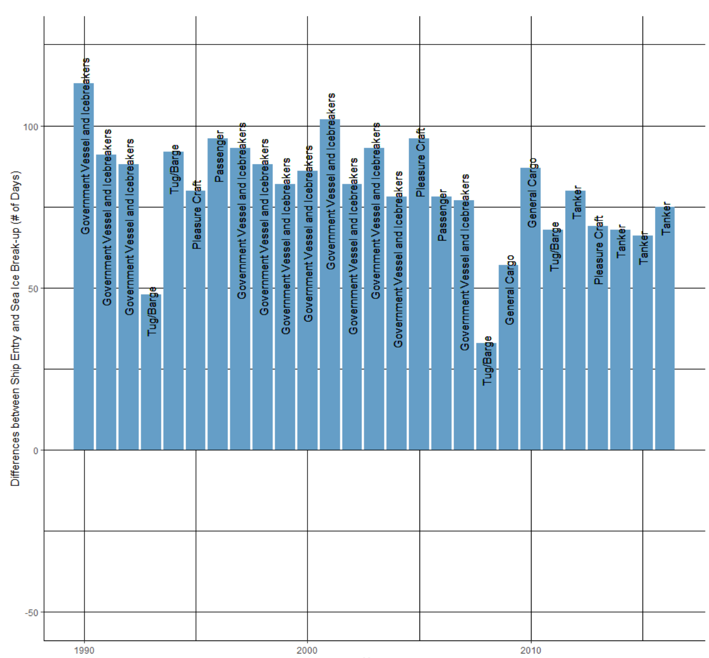

Figure 5.13 - Difference between sea ice break-up and ship entry within the S-crossing area (Where: Blue indicates ships within the crossing area after break-up, red indicates ships within the crossing area before break-up).

Despite no trend observed in the timing of sea ice freeze-up and break-up, our work highlights the complex interplay of sea ice conditions, ship transit timing, and the multifaceted challenges these may pose for caribou as they move through their sea ice habitat. These challenges can have long term implications to population health, and thus their interrelated consideration in future sea ice and shipping assessments in relation to caribou health are important.

5.5 - Future implications of sea ice dynamics and changes in ship traffic on caribou sea ice habitat around KWI

This discussion of caribou sea ice habitat has largely focused on recent impacts of dynamic freeze-up and break-up timing, and stages of sea ice; however, anomalous years may be representative of future conditions and have associated implications for caribou sea ice habitat. Freeze-up criteria were not met in 1998 in the NW, and NE-crossing areas because conditions did not develop above 8 tenths concentration. This may be attributed to the continuous open water in the areas, warm temperatures that were observed with minimum extent values, and evidence of rapid melt in the greater NWP in 1998 (Howell et al. 2010). Government vessels and icebreakers were operating in the NW-crossing area prior to break-up in 1998 and 1999. More years with these sea ice and ship traffic conditions may have long terms consequences on caribou sea ice movement.

Overall reductions in sea ice growth in winter resulting in net loss of sea ice have been reported across the Arctic since the 1980s (Gascard et al. 2017). These changes coincide with substantial interannual and interdecadal variation that complicate predictions of the timing of open water in summer months in the Arctic (Gascard et al.

2017). Laliberte et al. (2015) suggest that the CAA will be ice-free for the summer of 2075. The dynamic sea ice conditions in the CAA caused by variability in multi-year ice is likely to continue to make shipping in the NWP risky and challenging (Howell et al. 2013; Laliberte et al. 2015). Using predictive environmental models (General Circulation Models), Stephen and Smith (2015) suggest that the presence of multi-year ice in the region may restrict transit routes to low or moderate densities in the next century. Indeed, Laliberte et al. (2015) suggest that the persistence of multi-year ice will increase the need for changes to the shipping industry, including for example: mandatory hull reinforcement, improved environmental and emergency response capabilities, enhanced charting of the local and regional variability in sea ice conditions, and the increased use of low impact shipping corridors informed by Inuit knowledge (Pizzolato et al. 2014; Laliberte et al. 2015; Gascard et al. 2017; Dawson et al. 2018; Dawson et al 2020).

Caribou need to assess sea ice conditions prior to using crossing areas each year and are selective in their decision to cross sea ice, swim straits, or avoid sea ice crossings. In particular, concerns for caribou falling into open water and the challenges of recovering onto the sea ice are emphasized (WKSP 2018a,c,d; Miller et al. 2005; Dumond et al. 2013; Mallory and Boyce 2017). This suggests that caribou do respond to dynamic sea ice conditions behaviourally; however, there may be long-term consequences of these responses such as the potential for increased mortality (especially of female caribou because they are first to cross sea ice in the spring) that could negatively impact population dynamics (Poole et al. 2010; Mallory and Boyce 2017). Additional consequences may relate to the possibility of population declines associated with the changes in or the loss of sea ice habitat (COSEWIC 2011, Johnson et al. 2016).

Spatial variations were observed in the sea ice habitat around KWI could influence caribou survival and persistence differently related to different sub-populations. The NW, NE and W-crossing areas around KWI are likely used by Peary and Dolphin-Union caribou, and they may be susceptible to range contraction due to the loss of sea ice connectivity, and/or dynamic sea ice conditions (Poole et al. 2010; Post et al. 2013). The small population sizes of these caribou sub-species, compounded with unstable sea ice conditions between islands and the mainland may lead to reduced genetic variation with consequences of reduced fitness and potential for reduced adaptive capacity to deal with long-term environmental variability and change (Post et al. 2013). Future changes in the timing of freeze-up and break-up, and overall unreliable sea ice caribou habitat in the northern crossing areas could also impact the parasitic loads for Dolphin-Union and Peary caribou (Post et al. 2013). More research is needed to understand how movement across sea ice may impact parasitism and how that may change in the future if caribou sea ice habitat is lost.

Barren-ground caribou are likely to be particularly impacted by changes in sea ice in the S-crossing area. The S-crossing is very important for connecting KWI with the mainland, for both Uqsuqtuurmiut and caribou, especially during critical fall and spring caribou movements onto/off of the island (WKSP 2018a,b,c,d; Ljubicic et al. 2018a). The trend towards later exit of ships from the S-crossing indicates a serious potential for disturbance of sea ice affecting caribou movements in the fall, despite the lack of evidence for changing sea ice conditions. Caribou move south to Adelaide Peninsula and east or northeast to Boothia Peninsula just after fall freeze-up, in order to access food and migrate to inland wintering areas (Ljubicic et al. 2018a). If fall caribou movements are restricted by unstable sea ice conditions this may prevent caribou from accessing high quality forage needed for successful reproduction (i.e. calving, rearing and rutting; Miller et al. 2005, Poole et al 2010). The timing of sea ice change may not coincide with changes in plant phenology, and thus, the timing of caribou movement to the desired areas may be mismatched with the availability of their needed resources at set location (Mallory and Boyce et al. 2017). Range contraction also limits the ability of caribou to move throughout their entire range in response to poor environmental conditions or stressors. The limitations imposed on movement may impact population growth and increase caribou vulnerability to extreme environmental events (Miller et al. 2005).

Our research highlights the importance of Inuit knowledge guiding an integrative analysis of the potential impacts of sea ice and shipping change on caribou sea ice habitat around KWI. Despite limited observations of temporal change in the timing of freeze-up and break-up, future projections highlight the spatial complexity of open water and multi-year in the CAA and NWP in the next century. These dynamic sea ice conditions pose potential increased risks for the people and animals who share this marine space.

Chapter 6: Conclusion

6.1 – Overview of results and key messages

Our project used data sources based in western science and Uqsuqtuurmiut knowledge to achieve an understanding of the interactions between caribou use of sea ice habitat, sea ice change, and ship traffic around King William Island (KWI) over time. Central to our efforts is the recognition and consideration of the relationships between Inuit, caribou and sea ice as extending beyond basic transportation and economic development concerns.

Workshops with Uqsuqtuurmiut, along with sea ice chart analysis, highlight substantial temporal and spatial variation in the five sea ice crossing areas typically used by caribou around KWI. Our results depict a dynamic and challenging environment for seasonal caribou movements with considerable interannual variability between crossing areas and no statistically significant long term trends. The timing and conditions of freeze-up and break-up were most similar in the NW, NE, and W-crossings, and with common presence of open water the ice conditions necessary to support caribou movement were not consistently met in these three crossing areas. Contributors also described multi-year ice and areas of persistent open water in the NW and NE-crossing areas. Sea ice conditions in the S and E-crossing areas were also similar to each other. In particular, the S-crossing area was identified in workshops as critical for both caribou and Inuit movement between KWI and the mainland, and appears to be the most reliable, despite some multi-year ice and smaller areas of open water (polynyas) that may be present locally.

Despite substantial variability in the timing and conditions of sea ice freeze-up and break-up periods, trends in the timing of ship entry and exit of government vessels and icebreakers, pleasure crafts and tug/barge ships is similar amongst all crossing areas, with a large interannual variation in the length of shipping season. This suggests that ship movement is not dependent on local sea ice conditions as ships meet very different conditions in each crossing area. Increased interactions between ships and sea ice increases the likelihood for ships to create barriers (i.e. leads, cracks and ridges) within the sea ice crossing areas, creating challenges for the movement of caribou and people.

6.2 – Significance of work in relation to research, policy, and community goals

This project addresses a previously identified gap in caribou research on KWI (Ljubicic et al. 2017), and builds upon previous research learning from Uqsuqtuurmiut knowledge of caribou based on community priorities (Ljubicic et al. 2018a,b). It also brings together diverse information sources and community research collaborations (Johnson et al. 2016; Carter et al. 2017; Ljubicic et al. 2018a) to examine interconnected ecological, behavioural, and disturbance (i.e. shipping) factors that can influence caribou use of their sea ice habitat. We put into practice calls to action from the Government of Nunavut (GN 2011) by drawing on different forms of evidence, using community-identified sea ice thresholds and areas of interest to execute a holistic analysis exploring the complexity of factors influencing caribou use of sea ice habitat. In addition, we aimed to follow priorities identified by ITK (2018) in the *National Inuit Strategy on Research* by building on previous research, addressing community concerns, and being guided by Uqsuqtuurmiut knowledge.

Prioritizing Uqsuqtuurmiut knowledge of the interplay between caribou, sea ice, and ship traffic highlights the complexity of the system, and draws attention to how community members may be impacted by changes both in caribou movement and in the sea ice space they share. Results of this project can help to inform co-management policies and decisions by highlighting the importance of considering sea ice freeze-up and break-up thresholds based on community-identified ice conditions necessary for caribou movement, accounting for interannual variability, and monitoring long terms changes around known crossing areas. In addition, outcomes may be used by the community to educate youth and community members on the locations, timing and conditions of reliable caribou sea ice habitat surrounding their community, and the potential impacts of ship traffic on these areas that people share with caribou. We encourage those engaged in wildlife co-management and the Arctic marine shipping industry to consider these areas of caribou habitat and the multi-faceted challenges that caribou encounter when moving through sea ice.

6.3 – Future directions

Our next priority in the fall of 2020 is to develop results summary reports for workshop contributors, supporting community organizations, and relevant Nunavut government departments. These will be mailed hard copy to everyone involved, as well as made available at: https://straightupnorth.ca/caribou-and-sea-ice-crossings/. Furthermore, workshop recordings will be provided to the Nattilik Heritage Centre as a local archive, and all related future publications will be shared with community and regional organizations. We will continue to work closely with Simon Okpakok to develop journal articles and conference presentations to help mobilize the results of this Master's research.

Our approach provides insight into how quantitative and qualitative analyses may be guided by Inuit knowledge, and combined to address community research priorities. Moving forward to develop more comprehensive understandings of the impacts of changing sea ice and ship traffic around KWI will require further research to refine approaches to sea ice analysis, ship traffic analysis, and to expand community monitoring.

We recognize the need to refine our definition of sea ice break-up, to consider both ice melt as well as break-up of thick ice due to winds, currents, or moving ice in the spring. We intend to recalculate our break-up analysis to reflect more dynamic ice conditions, and to more effectively evaluate the timing of break-up that would affect spring migration of caribou onto KWI. This will also aid in refining our analysis of potential interactions between ships and spring sea ice, and the likelihood of shipping impacts on ice deformation or break-up.

Through our shipping analysis there were some years where pleasure crafts were identified as the first vessels to enter caribou crossing areas, while there was still considerable ice in the water. We intend to refine our shipping analysis by looking at relationships between pleasure craft and ice-breaker voyages to see how and where ice-breakers or government vessels may be assisting the smaller vessels.

We are also aware of ongoing wildlife, fish, and harvest monitoring in Uqsuqtuuq (Schott et al. 2020), and evolving approaches to wildlife co-monitoring in other

Kitikmeot communities (Peacock et al. 2020). To really understand the impacts of changing (or variable) sea ice and ship traffic on caribou crossings around KWI more focused partnerships in community, research, and government monitoring would be needed. There is potential to link to existing programs mentioned above, as well as to the Parks Canada Inuit Guardians program established in relation to the nearby Wrecks of HMS Erebus and HMS Terror National Historic Site (Parks Canada 2019). Community-based monitoring, and associated research partnerships, could not only help to improve our collective understanding of caribou behaviour in the region and the importance of sea ice habitat, but could also contribute observations of ship traffic and implications for caribou, other wildlife, and community members.

This research is a starting point, an initial attempt to investigate sea ice as caribou habitat in the context of five specific caribou crossing areas around KWI. There is still much to learn in addressing Uqsuqtuurmiut priorities related to caribou and community well-being, and future efforts must continue to be guided by Uqsuqtuurmiut knowledge. We hope that our collaborative and mixed method approach may encourage other researchers, wildlife managers, and policy makers across disciplines and jurisdictions to consider the interplay of caribou (amongst other wildlife), sea ice, and ship traffic, in assessing the impacts of climate change on sea ice conditions and marine transportation.

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Appendix 1 – Summary of ANOVA analyses

Summary of ANOVA analysis of sea ice freeze-up amongst Subset polygons

Area Set	**p-value**	**f-value**
NW	0.65	0.21
NE	0.92	0.01
S	0.95	0.004
W	0.62	0.25

Summary of ANOVA analysis comparing the timing of sea ice freeze-up between 1983-2018 within polygons delineated by Subset polygons.

Area	**p-value**	**f-value**
NW	0.65	0.21
NE	0.92	0.01
S	0.95	0.00
W	0.62	0.25

Appendix 2 - Certification of Institutional Ethics 08/15/2018 to 08/31/2019

Carleton UNIVERSITY
Canada's Capital University

Office of Research Ethics
5110 Human Computer Interaction Bldg | 1125 Colonel By Drive
Ottawa, Ontario K1S 5B6
613-520-2600 Ext: 2517
ethics@carleton.ca

CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) at Carleton University has renewed ethics approval for the research project detailed below. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Title: Mapping the Journey - Inuit perspectives on the role and value of participatory mapping

Protocol #: 103556

Project Team Members: Dr. Gita Ljubicic (Laidler) (Primary Investigator)
Cheryl Johnson (Project Resource)
Erin Neave (Project Resource)
Emmelie Paquette (Research Assistant)
Alex dePaiva (Researcher)

Department and Institution: Faculty of Arts and Social Sciences\Geography and Environmental Studies (Department of), Carleton University

Funding Source (If applicable):

Awards File No	Title	Status	
100254	Mapping the Journey - Inuit perspectives on the role and value of participatory mapping	Active	CORIS Awards
109200	Community consultation regarding the status of sea ice change and shipping near King William Island and potential impacts on caribou migration routes	Active	CORIS Awards

Effective: **August 15, 2018** Expires: **August 31, 2019**.

Please ensure the study clearance number is prominently placed in all recruitment and consent materials: CUREB-A Clearance # 103556.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and cleared by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

6. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

7. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions.

CLEARED BY: **Date: August 15, 2018**

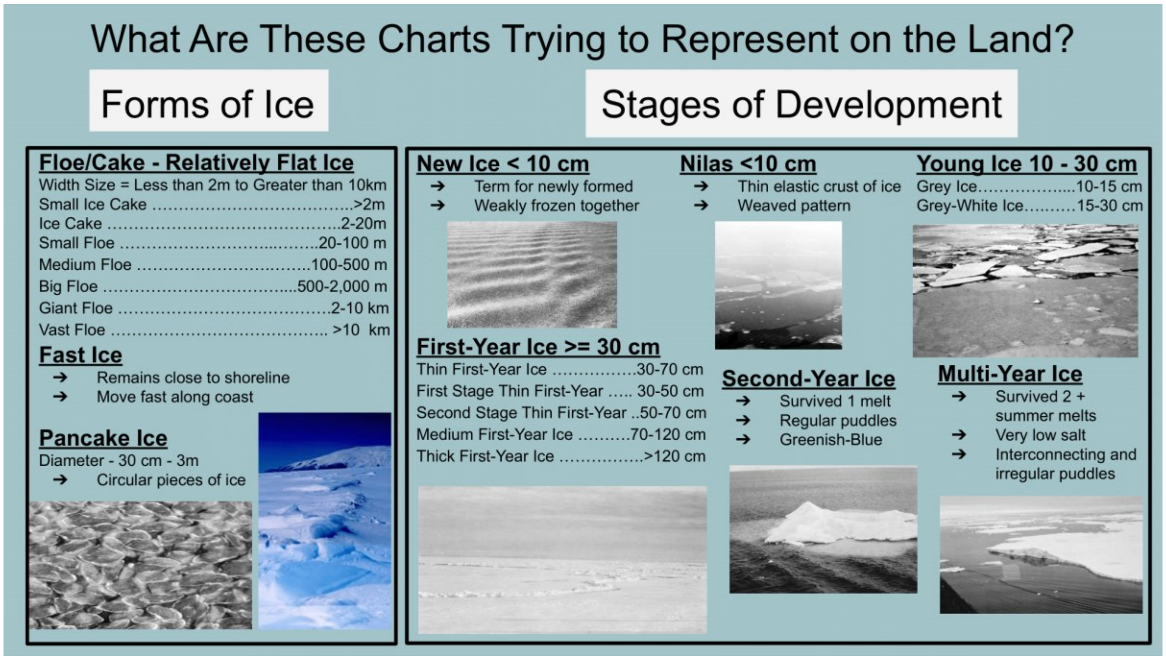
B Campbell

Bernadette Campbell, PhD, Chair, CUREB-A

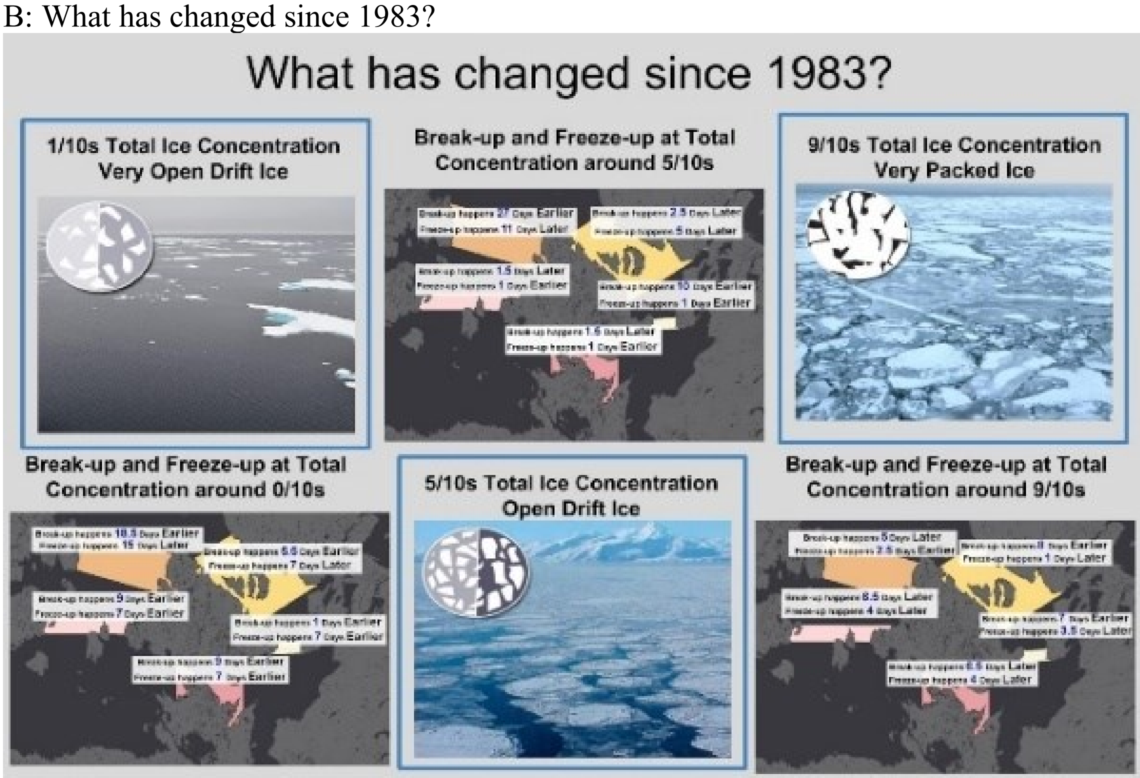
Andy Adler, PhD, Vice-Chair, CUREB-A

Appendix 3 - Workshop posters

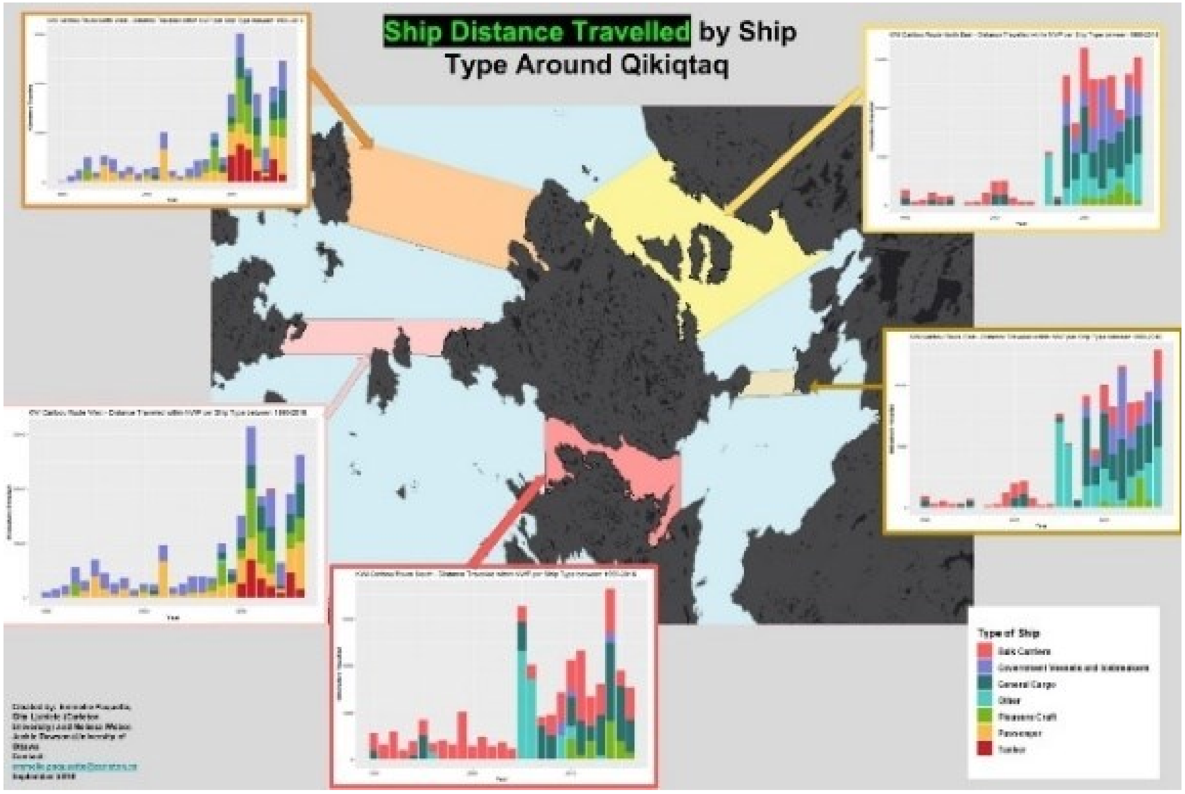
A: What do these numbers on sea ice charts look like on the ice?



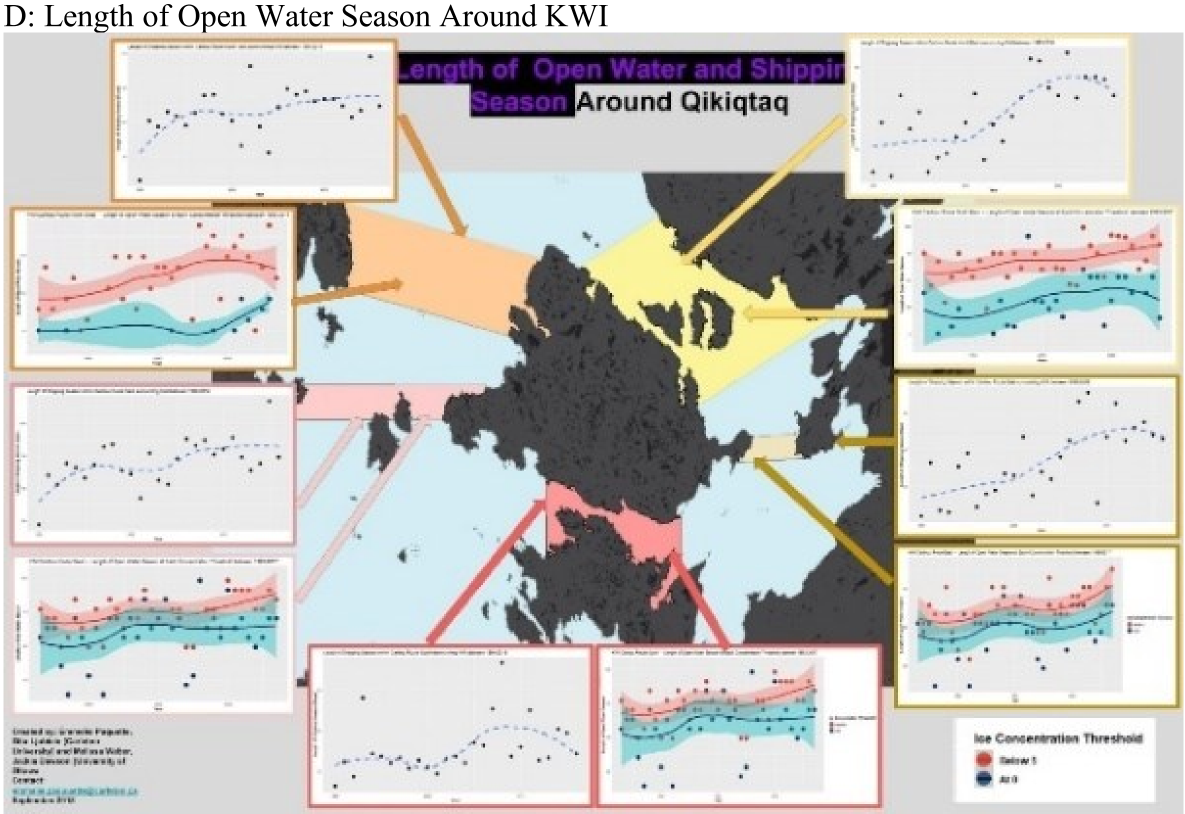
B: What has changed since 1983?



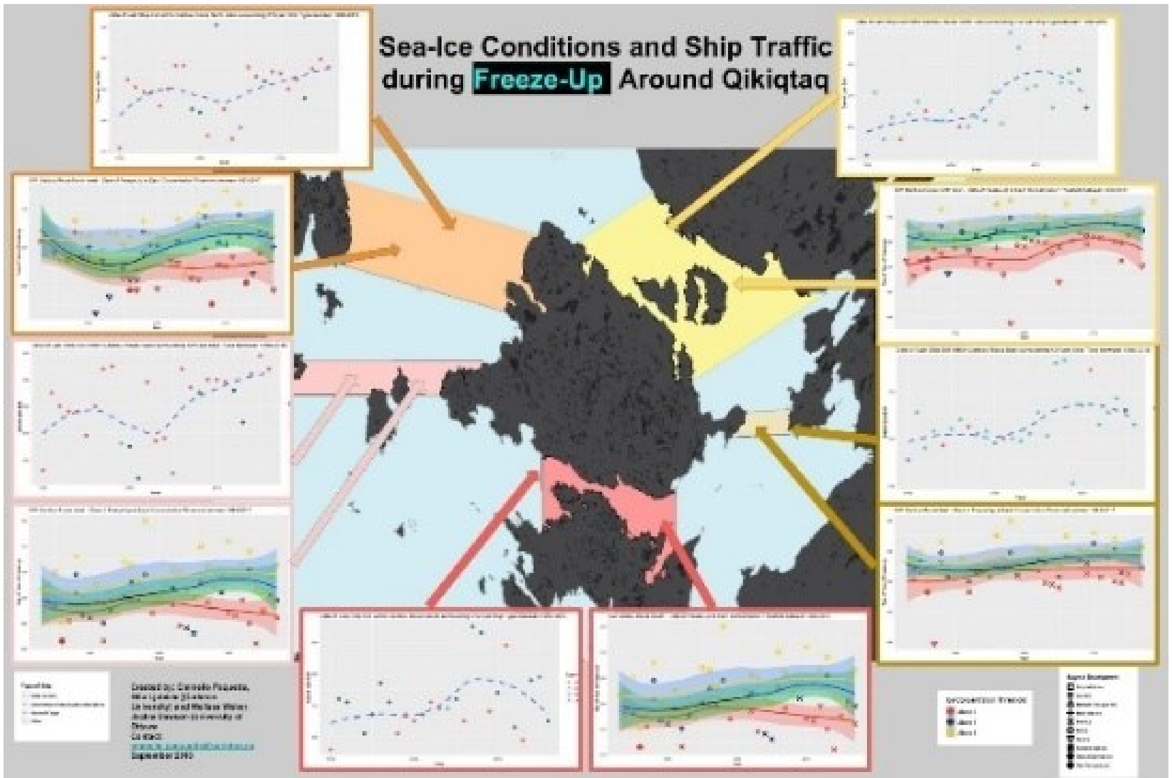
C: Ship Distance Travelled by Ship Type Around KWI



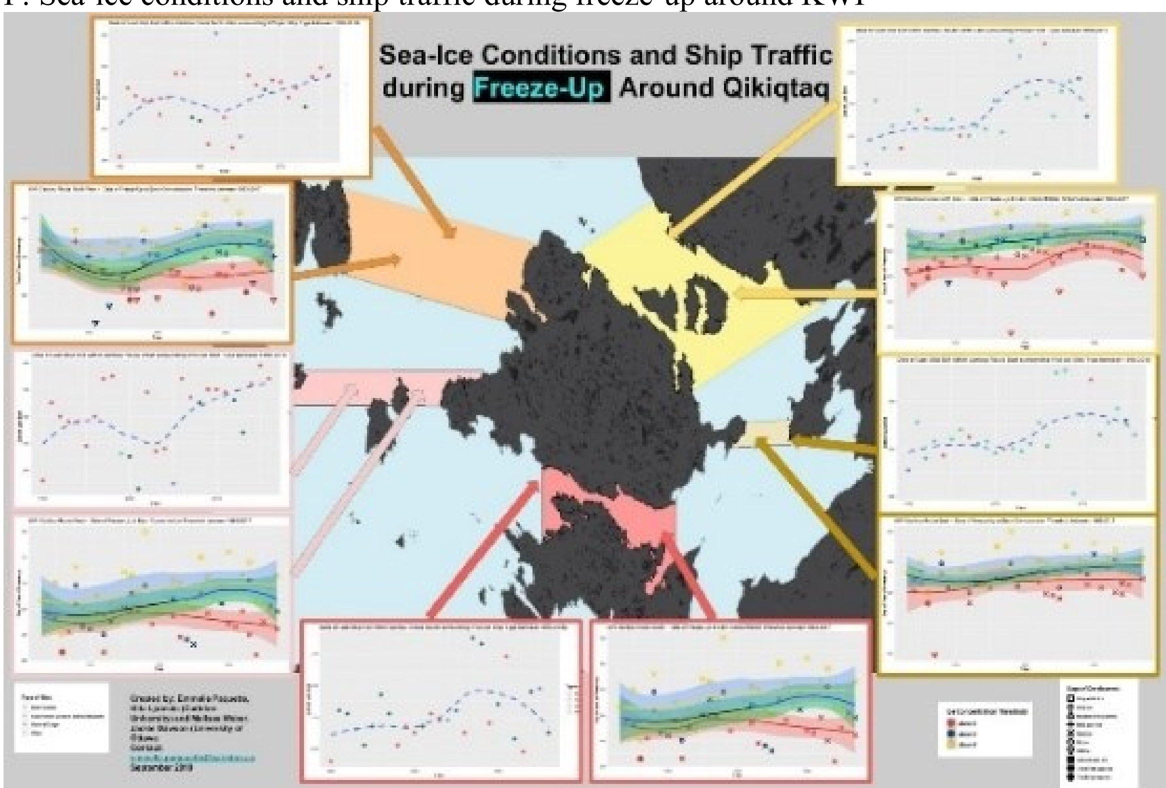
D: Length of Open Water Season Around KWI



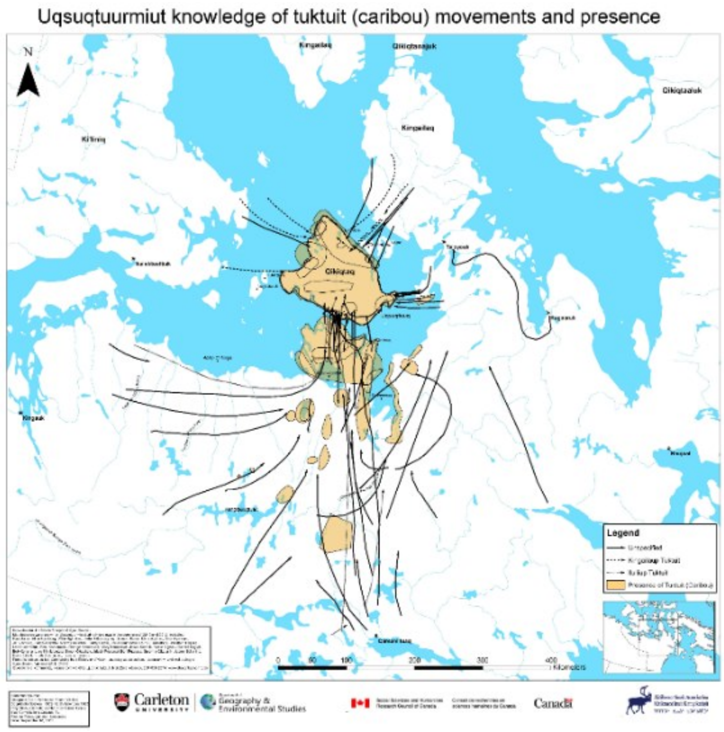
E: Sea-Ice Conditions and Ship Traffic during Freeze-up around KWI



F: Sea-ice conditions and ship traffic during freeze-up around KWI



G: Uqsuqtuurmiut knowledge of caribou (caribou) movements and presence



H: Inuit knowledge of caribou on and near King William Island, NU

Appendix 4 - Workshop Consent Form -Uqsuqtuuq, September 2018

Carleton UNIVERSITY

WORKSHOP CONSENT FORM

Mapping the journey: Inuit perspectives on the role and value of participatory mapping

We have been informed that this workshop builds on earlier caribou research in our community, conducted by Gita Ljubicic and collaborators (2011-2016). We understand that this workshop is part of the process to verify and build on earlier mapping of caribou crossings, and we agree to provide input on the effects of sea ice and shipping changes on caribou movement and health in the region. We also understand that we will be asked to provide input on the role and value of participatory mapping. We have been informed of what it means to participate in this project, and we are willing to participate in the workshop in support of this project. We understand that by participating in project activities we may be **photographed** and **recorded by audio or video**. Our contributions can be used in the project under the following conditions.

Identification
We remain the owner of the information and opinions we have contributed, but for the publication of project results and sharing this information with others we have indicated how we wish to be identified at the end of this form.

Sharing of information
We understand that information and opinions we share will be used to compile and communicate the results of this project in **reports, publications**, or **related project outputs** (e.g. posters, videos, presentations, news items, website postings on the Internet). Therefore, we understand that the results of this project will be publicly available to a broad range of people within Gjoa Haven, across Nunavut, and within and outside Canada. **Results of this project may only be used for non-commercial or educational purposes**.

In addition, we agree to have original audio, video, or photo recordings stored and accessible for future use in *(check all that apply)*:

- ☐ **a local community repository** (e.g. High School, Hamlet Office, or Heritage Centre)
  - for community use (i.e. the local centre would approve other external uses)
- ☐ **a regional or Nunavut archive** (e.g. Kitikmeot Heritage Society, Prince of Wales Heritage Centre)
  - for public use (i.e. the centre would approve external uses based on their heritage/research mandate)
- ☐ **with the StraightUpNorth research group** at Carleton University
  - for educational and research use (i.e. Gita Ljubicic would approve involvement of future students or researchers based on their interest in furthering project priorities)
- ☐ **none of the above**, I want original recordings used only in this project, not for any future uses

We understand that we may change our individual levels of consent, and/or that we may individually withdraw from participating in this project, **within two months** of reviewing our contributions and/or initial results. For any changes or withdrawal we understand that we need to contact the local workshop facilitator (________________________) or the Project Leader (Gita Ljubicic) directly. All contact details are included on the reverse page.

We have asked any questions we have, we understand the levels of consent provided here, and we freely agree to participate in the project as outlined above.

Workshop Participants:

Full Name	Use Name in Project Materials?	Verbal Consent	P.O. Box	Phone/email
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________
______________________	Yes No	☐	_________	_________________________

Researcher Consent:

As you agree to participate in this project, I, _____________________ promise to respect the context of the knowledge and opinions you contribute to this project, and the terms of this consent form.

If you have any questions or concerns about this project, or the consent you have provided, please contact the researchers involved, the local research coordinator, the Nunavut Research Institute, or the Carleton Ethics Committee:

Project Leader
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Carleton University Research Ethics Board
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Workshop Date: ______________________

Workshop recording file name(s): ____

Notes:

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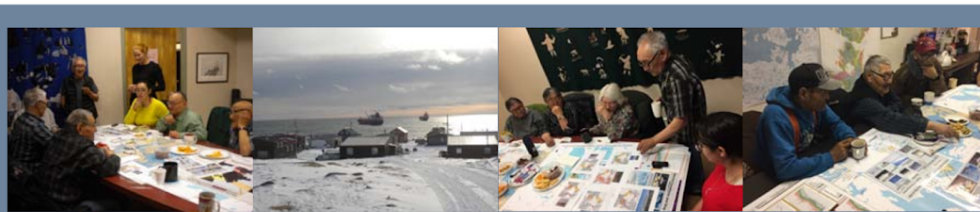
Appendix 5 - Gjoa Haven Trip Report (September 23-28, 2018)



Gjoa Haven Trip Report (September 23 - 28, 2018)

***Emmelie Paquette**, MSc Student, Dept. of Geography and Environmental Studies, Carleton University*
***Gita Ljubicic**, Associate Professor, Dept. of Geography and Environmental Studies, Carleton University*

Purpose of the trip:

- Gita Ljubicic and Simon Okpakok have been working with Elders, hunters, and youth in Gjoa Haven since 2010 to learn about the connections between caribou, community, and well-being.
- With the help of Sean Robertson and Rebecca Mearns, this earlier project included interviews, participatory mapping, and land camps over three summers (2011 - 2013), verification workshops in 2013 and 2016, and ongoing communication with local researchers, planning committee members, and local organizations.
- This visit in September 2018 was to continue building on the earlier project, and to respond to concerns raised by the Hunters and Trappers Association about potential impacts of changing sea sea ice on caribou movements.
  - Following on these concerns, Emmelie Paquette has been working to analyze sea ice and shipping data to see if there have been changes over time.
- Our goal for this visit was to for Gita and Emmelie to facilitate workshops to continue learning from Elders and hunters about:
  - Sea ice as caribou habitat
  - Local concerns of ship traffic for caribou movement
  - Changes in timing and conditions of sea ice break-up/freeze-up
  - Feedback on early sea ice and ship traffic analysis results
  - Feedback on maps of caribou crossing areas
- Cheryl Johnson and Erin Neave of Environment and Climate Change Canada were also travelling with Gita and Emmelie, and were observers at the workshops to learn from Uqsuqtuurmiut knowledge.

Activities during this trip:

Workshops discussing caribou, sea ice, and shipping

Over three days we held four workshops with 21 Elders, active hunters and members of the Hunters and Trappers Association, including with: Miriam Aglukkaq, Peter Akkikungnaq, Mary Aqilriaq, Saul Aqslaluq, Willie Aquptanguak, Simon Hiqiniq Sr., Alisa Kammimalik, Paul Kammimalik, Jacob Keanik, Simon Komangat, George Konana, Susie Konana, Uriash Puqiqnak, Wayne Puqiqnak, Ben Putuguq, Salomie Qitsualik, Ruth Qiqqut, Jimmy Qiqqut, David Siksik, Tommy Tavalok, Adam Ukuqtunnuaq.

Meeting with Ikaarvik

During our stay we also joined one morning of the Ikaarvik meeting that was happening in the community at the same time. We shared our work on the caribou project, and they shared their work testing the SIKU app for community use. We met Shelly Elverum, Gibson Porter, Sammy Kogvik, Betty Kogvik, Nicole Kunuaq, and Sarah Rosengard.

Key points from workshops:

Sea ice as caribou habitat

- Uqsuqtuurmiut knowledge of sea ice conditions and caribou is passed from ancestors.
- Fresh water ice and sea ice are different, freshwater is more brittle and cracks often, while sea ice is more flexible.
- Sea ice conditions are different around the island, they are influenced by many things like water currents, water body size, and geography.
- Caribou can walk on thinner and younger ice than humans (2-3 inches of sea ice)
- Caribou do not move in straight lines or trails during migration, but move within a larger area to rest and feed throughout.
- Caribou use solid and unmoving sea ice for travel (although some will swim).

Carleton University
Questions? Comments?
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Local concerns of shipping traffic for caribou movement

- Grounding of nearby tanker ships can potentially pollute vital waters.
- Icebreakers can disturb sea ice conditions of important caribou crossing areas.

Shared spaces between Inuit, caribou and other wildlife in Arctic facing climate change

- Timing of break-up/freeze-up varies significantly between years, making predicting sea ice conditions and preparing for travel difficult and dangerous.
- However, an active hunter observed significant changes in annual freeze-up since the 1980s - sea ice was safe for travel around September, but in recent years, it was not safe until November.
- More animals, including caribou predators like grizzly bears, wolverines and wolves, are coming to the island, following the caribou along the same routes.
- A rise in both predators and diseases among caribou are a concern for many in the community, with the problem starting in the 1990s.

Feedback on caribou crossing area maps:

- Some active hunters noted their use of the narrow southern passage between King William Island and Adelaide Peninsula for hunting travel, and the use of the same route by their ancestors.
- During the summertime, the cows and calves congregate to the northern side of the island, and there are very few bulls on the island.

Community Updates:

- Between the workshops, Gita met with the following organizations to provide updates and leave copies of project materials:
  - **Lorraine Puqiknaq at Qikirtaq High School** (copies of reports, maps, and posters for use in the school)
  - **Helen Tungilik and Susie Ikkutisluk with the Kitikmeot Inuit Association** (copies of reports)
  - **Hamlet Council members** (copies of reports, plaque of caribou seasonal diagram)
  - **Wayne Puqiknaq with the Hunters and Trappers Association** (copies of reports, maps, and posters)
  - **Barbara Okpik and Jennifer Ullulaq with the Gjoa Haven Film Society** (copies of land camp video)
  - **Jacob Keanik with the Nattilik Heritage Society** (copies of reports, maps, posters, Rebecca Mearns' Master's thesis, copies of all interview audio files and land camp video files)

Next Steps:

- We do not have more funding for this project, but we will continue to work on finalizing and sharing our results.
- We are also interested in ongoing work with the community if there is local interest to develop new projects together based on community priorities.
- By spring of 2018, we aim to complete the following:
  - Work with meeting transcripts
  - Complete Master's thesis (Emmelie Paquette)
  - Reports and photos updated on the project website (www.straightupnorth.ca)
  - Start writing several journal articles to be submitted for publication

Thank you:
We would like to thank the community of Gjoa Haven for the warm welcome that we received. Qujanaqqutit to all who participated in the workshops, and for generously sharing your time and knowledge. Many thanks to Simon Okpakok for his help organizing the workshops, and his thorough and patient translation helping everyone communicate. We are grateful to Susie Ikkutisluk for helping with meeting planning and communications, and to the Nattilik Heritage Centre and Hunters and Trappers Association for the use of their boardroom meeting space. Thanks to CAP Enterprises for providing rental accommodations.

Report Date: December 12, 2018

Carleton UNIVERSITY

Questions? Comments?

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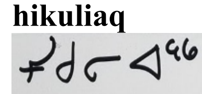
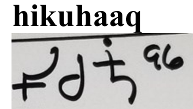
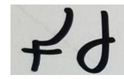
Appendix 6 – Canadian Ice Service ice chart Egg Code descriptions - Stage of Development

Egg Code Value	Description (Government of Canada 2016b)	Thickness	Definition (Government of Canada 2016a)	Uqsuqtuuq Inuktitut (when known)
1	New ice	<10 cm	"A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are a float."	**qinu** ᕿᓄ
2	Nilas, ice rind	<10 cm	"A thin elastic crust of ice, easily bending on waves and swell and under pressure growing in a pattern of interlocking "fingers" (finger rafting). Nilas has a matte surface and is up to 10 cm in thickness and may be subdivided into dark nilas and light nilas."	**hikuliaq** 
3	Young ice	10-30 cm	"Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into grey ice and grey-white ice."	**hikuhaaq** 
4	Grey ice	10-15 cm	"Young ice 10-15 cm thick, less elastic than nilas and breaks on swell. It usually rafts under pressure."	

5	Grey-white ice	15-30 cm	“Young ice 15-30 cm thick. Under pressure it is more likely to ridge than to raft.”	
6	First-year ice	>=30 cm	“Sea ice of not more than one winter’s growth, developing from young ice; 30 cm or greater. It may be subdivided into thin first-year ice – sometimes referred to as white ice –, medium first-year ice and thick first-year ice.”	**hiku** 
7	Thin first-year ice	30-70 cm	-	
8	First stage thin first-year ice	30-50 cm	-	
9	Second stage thin-first-year	50-70 cm	-	
1.	Medium first-year ice	70-120 cm	-	
4.	Thick first-year ice	>120 cm	-	
7.	Old ice	-	“Sea ice which has survived at least one summer’s melt. Topographic features generally are smoother than first-year ice. It may be subdivided into second-year ice and multiyear ice.”	
8.	Second-year ice	-	“Old ice which has survived only one summer’s melt. Thicker than first-year ice, it stands higher out of the water. In contrast to	

			multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.”	
9.	Multi-year ice		“Old ice which has survived at least two summer’s melt. Hummocks are smoother than on second-year ice and the ice is almost salt-free. Where bare, this ice is usually blue in colour. The melt pattern consists of large interconnecting, irregular puddles and a well developed drainage system.”	**hikutuqaq** ᓯᑯᑐᖃᖅ
▲·	Ice of land origin	-	“Ice formed on land or in an ice shelf, found floating in water.”	
X.	Undetermined or unknown	-		

Appendix 7 – Canadian Ice Service ice chart Egg Code descriptions - Form of Ice

Egg Code Value	Description(Government of Canada 2016b)	Width	Definition (Government of Canada 2016a)	Uqsuqtuuq Inuktitut (where known)
0	Pancake Ice	-	"Predominantly circular pieces of ice 30 cm to 3 m in diameter, up to 10 cm in thickness, with raised rims due to the pieces striking against one another. It may form on a slight swell from grease ice, shuga or slush or as a result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice. It also sometimes forms at some depth at an interface between water bodies of different physical characteristics where it floats to the surface. It may rapidly form over wide areas of water."	
1	Small ice cake, brash ice, agglomerated brash	< 2 m	"(Brash ice) Accumulation of floating ice made up of fragments not more than 2 m across, the wreckage of other forms of ice." "(Small ice cake) An ice cake less than 2 m across."	

2	Ice cake	2-20 m	“Any relatively flat piece of ice less than 20 m across.”	
3	Small floe	20-100 m	-	
4	Medium floe	100-500 m	-	
5	Big floe	500-2,000 m	-	
6	Vast floe	2-10 km	-	
7	Giant floe	> 10 km	-	
8	Fast ice	-	“Ice which forms and remains fast along the coast. It may be attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. It may be formed “in-situ” from water or by freezing of floating ice of any age to shore and can extend a few metres or several hundred	**Hiku** 

			kilometres from the coast. It may be more than one year old in which case it may be prefixed with the appropriate age category (old, second-year or multi-year). If higher than 2 m above sea level, it is called an ice shelf.”	
9	Icebergs, growlers, floebergs	-	“A massive piece of ice of greatly varying shape, protruding 5 m or more above sea level, which has broken away from a glacier and which may be afloat or aground. They may be described as tabular, domed, pinnacled, wedged, dry docked or blocky. Sizes of icebergs are classed as small, medium, large and very large.”	
x	Undetermined, unknown or no form	-		

Appendix 8 - Adapted code from Benoit MontPetit (ECCC) to extract Egg code values from CIS ice charts

```
import os, arcpy, csv, time
from os import listdir
from os.path import join, isfile, isdir, basename, splitext
from arcpy import env
from shutil import rmtree


### Options / Paths ############################################################

# URGENT: These options / paths should be changed to suit the project at hand

# The full project folder
BASE_PATH = 'C:\Users\emmel\Desktop\Feb2019_SeaIceAnalysis'

# A temporary folder for files as needed
TEMP_DIR = 'Temp_Folder'

# Location of the source .e00 files
E00_DIR = 'E00_Charts\Trial'

# Location of a .csv file containing the output information
CSV_FILE = 'Sea_Ice_Outputs\West\Trial_Output.csv'

# Location of a projection file for coordinate remapping
PROJECTION_FILE = 'BenCodePack\IceConcProj.prj'

# A shape file containing the area of interest (AOI)
SHAPE_FILE = 'Route_Shapefiles\C_R_West\Block\C_R_West_ArcFiles\C_R_West.shp'

# Toggle these booleans to turn column checking on/off

# Concentration checks
CHECK_CT = True
CHECK_CA = True
CHECK_CB = True
CHECK_CC = True

# Form of ice checks
CHECK_FA = True
CHECK_FB = True
CHECK_FC = True

# Stage of development checks
CHECK_SA = True
CHECK_SB = True
CHECK_SC = True

### Function definitions ########################################################

logfile = open(join(BASE_PATH, 'logfile.txt'), 'a')

def list_folder(in_dir):
```

```
    # List all files in a folder

    # parameters
    # in_dir: a path to a directory to list the contents of
    filenames = [f for f in listdir(in_dir) if isfile(join(in_dir, f))]

    return filenames

def conv_e00(filename, in_dir, out_dir):
    # Convert .e00 files to .shp

    # parameters
    # filename: the .e00 file being converted
    # in_dir: direcrtory containing the .e00 files
    # out_dir: directory to write the .shp file to
    if not isdir(join(out_dir, (splitext(filename)[0])[8:16])):
        arcpy.ImportFromE00_conversion(join(in_dir, filename), out_dir, (splitext(filename)[0])[8:16] )


def is_float(s):
    # Returns "True" if the STRING s is a float (error handling helper function)

    # parameters
    # s: a string to test if a float can be parsed without a value error
    try:
        float(s)
        return True
    except ValueError:
        return False

def clean():
    # clean the build environment, potentially incomplete
    rmtree(join(BASE_PATH, TEMP_DIR))
    open(join(BASE_PATH, CSV_FILE), 'w').close()
    os.makedirs(join(BASE_PATH, TEMP_DIR))

def spatial_avg(area, x):
    return area * x

def LOG(msg):
    logfile.write(msg+'\n')

################################################################################

# Set the path that arcpy is using
env.workspace = BASE_PATH

# absolute path to the source .e00 files directory
in_dir = join(BASE_PATH, E00_DIR)

# absolute path to the exported .shp files directory
out_dir = join(BASE_PATH, TEMP_DIR)
```

```
# a copy of the SpatialReference for this current projection file
sr = arcpy.SpatialReference(join(BASE_PATH, PROJECTION_FILE))

# a polygon for CLIPPING (binary intersection) using the currecnt ShapeFile
clip_feature = join(BASE_PATH, SHAPE_FILE)

# tolerance for the min distance for points to be equal, left balnk to use
# the map's default settings
tolerance = ""

# Clean the build before beginning
clean()

# Creates a list of all the .e00 files
filenames = list_folder(in_dir)

# Creates a spreadsheet in .csv format in which the data will be saved in
with open(join(BASE_PATH, CSV_FILE), 'a') as csvfile:

  # Creates a CSVWriter
  output = csv.writer(csvfile, delimiter=' ')

  # Writes the column headers of the .csv file
  output.writerow(['Year', 'Month', 'Day', 'CT', 'CA', 'CB', 'CC', 'FA', 'FB', 'FC', 'SA', 'SB', 'SC'])

  # for all the source .e00 files
  for e00_file in filenames:

    # Creates a temporary file
    temp = (os.path.splitext(e00_file)[0])[8:16]

    #Converts the .e00 file
    conv_e00(e00_file, in_dir, out_dir)

    # Reprojects the chart to the standard projection
    arcpy.DefineProjection_management(join(out_dir, temp), sr)

    # 5 SECOND DELAY
    # This is one of the only ways around ARC not crashing when
    # processing and also seems to be a stanard way to avoid such
    # issues. Normally awful things should never be in a loop.
    time.sleep(5)

    # Creates a new attribute to compute the area of the polygons
    arcpy.AddField_management(join(out_dir, temp, "polygon"), "AREA2", "Double")

    # Same for the perimeter
    arcpy.AddField_management(join(out_dir, temp, "polygon"), "PERIMETER2", "Double")

    # Use the resulting shape from clipping
    clip_result = join(out_dir, '.'.join([temp,"shp"]))
```

```
        # Get the mode of the categorical column containing form of ice type
        for i in range(3):
            max_of_form = max(form_frequency[i])
            form_frequency[i] = form_frequency[i].index(max_of_form)


        # Get the mode of the categorical column containing the symbol for
        # stage of development
        LOG("S* PRE MAX: " + str(stage_of_dev))
        max_stages = []
        for i in range(3):
            if len(stage_of_dev[i].values()) ==0:
                max_stages.append('-1')
                continue
            max_value = max(stage_of_dev[i].values())  # maximum value
            max_keys = [k for k, v in stage_of_dev[i].items() if v == max_value]

            # Only one value gets written
            max_stages.append(max_keys[0])
        LOG("S* POST MAX: " + str(max_stages))

        # Writes the year, month, day and total ice concentration of the
        # polygon, and the form of ice type in the .csv file
        # (temp[0:4], temp[4:6], temp[6:8]) is the date of the chart
        output.writerow([temp[0:4], temp[4:6], temp[6:8],
                    concentration['CT'], concentration['CA'],
                    concentration['CB'], concentration['CC'],
                    form_frequency[0], form_frequency[1], form_frequency[2],
                    max_stages[0], max_stages[1], max_stages[2]])
logfile.close()
```

Appendix 9 - Carleton University - University of Ottawa research agreement between Dr. Gita Ljubicic and Dr. Jackie Dawson

Proposed collaboration in support of Emmelie Paquette's MSc thesis research on:

Potential impacts of sea ice change and shipping traffic on caribou migratory routes surrounding King William Island, Nunavut

Overview:

Emmelie Paquette began her MSc program at Carleton in September 2017, and is working with Gita Ljubicic to build on earlier work to learn about Inuit knowledge of caribou in Gjoa Haven, Nunavut. This earlier work was part of a SSHRC Project "Connecting Inuit Elders and Youth: Learning about caribou, community, and well-being in Gjoa Haven, Nunavut" that ran from 2011 to 2016 (http://www.straightupnorth.ca/Sikuliriji/GH-SummReports.html). The importance of sea ice as habitat came up during interviews in Gjoa Haven (2012-2013), as well as more recently in discussions with the HTA (winter and spring of 2018). Emmelie is developing her MSc research to investigate any trends in sea ice changes around King William Island (KWI), and to evaluate the potential implications of these changes for four key caribou crossings on and off KWI (based on participatory mapping results from the SSHRC project). During HTA discussions, there were also a number of concerns raised around shipping activity in the region, the impacts of ships on ice conditions, and the timing of shipping activities during shoulder seasons (freeze-up and break-up times). In particular, these concerns related to shipping involved questions around the implications for caribou, in terms of affecting ice integrity or creating other disturbance that affects caribou crossing to and from KWI. Through Emmelie's investigations, our goal is to improve our understanding of the interplay between any trends in sea ice change, shipping traffic, and sea ice as habitat for caribou.

We are collaborating with Cheryl Johnson and Erin Neave at Environment and Climate Change Canada in Ottawa, who can support some of the sea ice and habitat assessments. Gita's past work with Elders and hunters in Gjoa Haven, and planned upcoming community workshops in September will enable local feedback and consideration of Inuit knowledge in assessing sea ice and shipping implications for caribou. However, within our team, we do not have the expertise related to shipping trends and assessment, and we are reaching out to Jackie Dawson and her research team to invite collaboration on this front.

What we are requesting:

- support from a member of Dawson's research team to analyze the shipping database previously compiled, to provide numbers and identify trends related to:
    1. spatial locations of shipping routes around KWI, and a comparison of numbers of transits and types of ships between the eastern and western routes around KWI over time (between 1985 – 2018) (SEE SHAPE FILE)

2. a time series analysis of ship tracks intersecting with key caribou crossings at freeze-up and break-up times (between DATES and DATES), trying to identify if there are trends towards ships beginning transits earlier in the season, or extending later into the season (in general, and in relation to sea ice change analysis that Emmelie is conducting with CIS ice charts)
3. work with us to create appropriate spatial and graphic visualizations that represent the results, in a way that is most conducive to receiving community feedback in September, and after any necessary revisions based on this feedback, maps or figures that can be used in publications

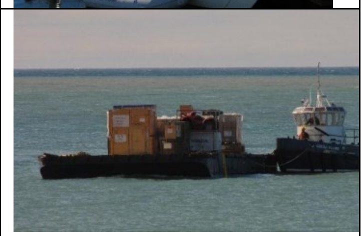
Proposed timeline:

- **August 2018** – Emmelie and Jackie's student to meet and review plans, and clarify data and methods
- **Early September 2018** – Emmelie, Gita, Jackie, and Jackie's student to meet to review preliminary results, and finalize maps or graphics to bring to the community workshops
- **October – December 2018** – Emmelie and Jackie's student work to refine analyses and link shipping, sea ice, and community workshop results
- **January – April 2019** – Emmelie writing and revising her thesis
- **May – August 2019** – Emmelie defending her thesis, and working with Gita, Jackie, and Jackie's student to develop her thesis for publication

This agreement represents a commitment by Gita Ljubicic (Carleton University) and Jackie Dawson (University of Ottawa), and their students involved, to work together to link shipping and sea ice change analysis around King William Island. Outcomes of these analyses will contribute to Emmelie Paquette's MSc thesis research. Any publications resulting from this work that include the results of the ship traffic analysis provided by Dawson and students, will involve co-authorship roles for all involved.

Appendix 10 - Descriptions and images of vessel types within NORDREG Zone used in analysis.

Classification	Description	Examples	
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	
General Cargo	• Carries various types and forms of cargo	• Community re-suppl • 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	

Source: Pizzolato et al. 2014; Dawson et al. 201

Appendix 11 - Summary of sea ice trend analyses

A. Summary of changes in the timing of sea ice freeze-up between 1983-2018 within caribou crossing areas.

Area	**p-value**	**sen's slope**	**z-value**
NW	0.28	0	1.08
NE	0.58	0	0.55
E	0.55	0	0.61
S	1	0	0
W	0.15	0	1.44

B. Summary of changes in the timing of sea ice break-up between 1983-2018 within caribou crossing areas.

Area	**p-value**	**sen's slope**	**z-value**
NW	0.28	0	1.08
NE	0.58	0	0.55
E	0.50	0	0.61
S	1	0	0
W	0.15	0	1.44

C. Summary of Mann-Kendall trend analysis of the annual length of open water season between 1983-2018 within *caribou* crossing areas.

Area	**p-value**	**sen's slope**	**z-value**
NW	0.423	0	-0.801
NE	0.115	0	0.909
E	0.613	0	0.506
S	0.88	0	-0.156
W	0.425	0	0.671

Appendix 12 - Statistical summary of ship voyages entering and exiting each crossing area

A. Summary of trend analysis representing changes in the timing of last ship exit in each caribou crossing area (by ship type) between 1990-2016

Area	Ship Type	P-value	Sen's slope	Z-value
NW	GVIB	0.095	0.667	1.67
NW	GC	**0.015**	3.5	2.425
NW	PC	0.169	1.73	1.375
NW	PS	**0.033**	0.612	2.13
NW	TK	**0.015**	3.5	2.425
NW	TB	**0.012**	0.718	2.49
NE	GVIB	0.122	0.5	1.545
NE	GC	0.343	0.633	0.948
NE	PC	0.107	0.861	1.612
NE	PS	0.085	2	1.723
NE	TK	0.343	0.633	0.948
NE	TB	**0.007**	0.5	2.697
E	GVIB	0.452	0.3	0.751
E	GC	0.142	0.708	1.467
E	PC	0.114	0.923	1.579
E	PS	0.085	0.0845	1.723
E	TK	0.142	0.708	1.468
E	TB	0.013	0.5	2.498
S	GVIB	0.233	0.3125	1.192
S	GC	0.296	-27	-1.045
S	PC	0.097	2.472	1.661
S	PS	0.452	5	0.752
S	TK	0.296	-27	-1.045
S	TB	0.073	-0.714	-1.791
W	GVIB	**0.0003**	1.611	3.678
W	GC	0.178	1.556	1.347
W	PC	**0.002**	3	3.086
W	PS	**0.012**	-1.225	-2.505

W	TK	0.178	1.556	1.347
W	TB	0.169	1.353	1.377

B. Summary of trend analysis representing changes in the timing of first ship entry in each caribou crossing area (by ship type) between 1990-2016 (bolded values in tables represent statistically significant trends ($p<0.05$)).

Area	Ship Type	P-value	Sen's slope	Z-value
NW	GVIB	**0.03**	-0.79	-2.13
NW	GC	0.12	-0.8	-1.56
NW	PC	0.17	-1.46	-1.38
NW	PS	**0.01**	1	2.66
NW	TK	0.12	-0.8	-1.56
NW	TB	0.43	-0.8	0.79
NE	GVIB	**0.01**	-0.48	-2.73
NE	GC	0.76	-0.58	-0.31
NE	PC	0.23	-0.48	-1.20
NE	PS	0.31	1	1.02
NE	TK	0.75	-0.58	-0.31
NE	TB	0.79	-0.11	-0.27
E	GVIB	**0.00**	-0.77	-3.25
E	GC	0.75	-0.58	-0.31
E	PC	0.06	-0.67	-1.86
E	PS	0.39	0.33	0.87
E	TK	0.75	-0.58	-0.31
E	TB	0.63	-0.12	-0.49
S	GVIB	0.23	0.33	1.19
S	GC	0.3	7	1.05
S	PC	0.73	0.17	0.35
S	PS	1	0.5	0
S	TK	0.3	7	1.05
S	TB	0.93	0	-0.09
W	GVIB	**0.01**	-1.5	-2.67
W	GC	0.18	-0.5	-1.35

W	PC	0.45	1.08	0.76
W	PS	0.23	0.27	1.19
W	TK	0.18	-0.5	-1.35

Appendix 13 – Sea ice conditions as ships enter and exit caribou crossing areas

A. Form and stage of ice ships encounter as they exit each caribou crossing area between 1990-2016.

Route	**Year**	**Ship**	**FA**	**SA**
NW	1990	GVIB	Big Floe	Old Ice
NW	1991	GVIB	Small Floe	Old Ice
NW	1992	TB	Medium Floe	Old Ice
NW	1993	PS	Small Floe	Old Ice
NW	1994	PS	Vast Floe	Thick First-year Ice
NW	1995	PS	Fast Ice	Thick First-year Ice
NW	1996	PS	Big Floe	Old Ice
NW	1997	PS	Medium Floe	Thick First-year Ice
NW	1998	PS	Big Floe	Old Ice
NW	1999	GVIB	Vast Floe	Old Ice
NW	2000	GVIB	Big Floe	Thick First-year Ice
NW	2001	PS	Big Floe	Thick First-year Ice
NW	2002	PS	Big Floe	Thick First-year Ice
NW	2003	TB	Vast Floe	Thick First-year Ice
NW	2004	GVIB	Vast Floe	Old Ice
NW	2005	PC	Fast Ice	Thick First-year Ice
NW	2006	GVIB	Vast Floe	Old Ice
NW	2007	GVIB	Vast Floe	Thick First-year Ice
NW	2008	GVIB	Fast Ice	Thick First-year Ice
NW	2009	GVIB	Big Floe	Thick First-year Ice
NW	2010	PS	Medium Floe	Thick First-year Ice
NW	2011	GVIB	Big Floe	Thick First-year Ice
NW	2012	GVIB	Vast Floe	Thick First-year Ice
NW	2013	GVIB	Vast Floe	Thick First-year Ice
NW	2014	GVIB	Big Floe	Thick First-year Ice
NW	2015	PC	Big Floe	Old Ice
NW	2016	PC	Medium Floe	Old Ice
NE	1990	GVIB	Medium Floe	Old Ice

NE	1991	GVIB	Medium Floe	Old Ice
NE	1992	TB	Big Floe	Thick First-year Ice
NE	1993	PC	Small Floe	Thick First-year Ice
NE	1994	PC	Medium Floe	Old Ice
NE	1995	PC	Medium Floe	Thick First-year Ice
NE	1996	TB	Pancake Ice	Old Ice
NE	1997	TB	Medium Floe	Old Ice
NE	1998	TB	Big Floe	Old Ice
NE	1999	GVIB	Small Floe	Old Ice
NE	2000	TB	Big Floe	Thick First-year Ice
NE	2001	PC		Open Water
NE	2002	GVIB	Small Floe	Thick First-year Ice
NE	2003	GVIB	Small Floe	Thick First-year Ice
NE	2004	GVIB	Big Floe	Thick First-year Ice
NE	2005	PS	Big Floe	Old Ice
NE	2006	PS	Vast Floe	Thick First-year Ice
NE	2007	PC		Open Water
NE	2008	PC	Big Floe	Thick First-year Ice
NE	2009	GC	Medium Floe	Thick First-year Ice
NE	2010	PC	Big Floe	Old Ice
NE	2011	PC	Medium Floe	Thick First-year Ice
NE	2012	PC	Medium Floe	Thick First-year Ice
NE	2013	GVIB	Big Floe	Thick First-year Ice
NE	2014	PC	Medium Floe	Thick First-year Ice
NE	2015	PC	Medium Floe	Thick First-year Ice
NE	2016	PC	Medium Floe	Old Ice
E	1990	PC		Open Water
E	1991	GVIB		Open Water
E	1992	GVIB	Medium Floe	Thick First-year Ice
E	1993	GVIB		Open Water
E	1994	PC		Open Water
E	1995	PC	Big Floe	Thick First-year Ice

E	1996	TB		Open Water
E	1997	TB		Open Water
E	1998	TB		Open Water
E	1999	GVIB		Open Water
E	2000	TB		Open Water
E	2001	PC		Open Water
E	2002	GVIB		Open Water
E	2003	GVIB		Open Water
E	2004	GVIB		Open Water
E	2005	PS	Big Floe	Old Ice
E	2006	PS		Open Water
E	2007	PC		Open Water
E	2008	GVIB	Big Floe	Thick First-year Ice
E	2009	PC	Pancake Ice	Thick First-year Ice
E	2010	PC		Open Water
E	2011	PC		Open Water
E	2012	PC		Open Water
E	2013	GVIB		Open Water
E	2014	PC	Medium Floe	Thick First-year Ice
E	2015	PC		Open Water
E	2016	PC		Open W
S	1990	GVIB	Pancake Ice	Old Ice
S	1991	GVIB		Open Water
S	1992	GVIB	Medium Floe	Old Ice
S	1993	TB	Small Floe	Thick First-year Ice
S	1994	TB		Open Water
S	1995	PC	Pancake Ice	Thick First-year Ice
S	1996	PS		Open Water
S	1997	GVIB		Open Water
S	1998	GVIB		Open Water
S	1999	GVIB		Open Water
S	2000	GVIB		Open Water

S	2001	GVIB		Open Water
S	2002	GVIB		Open Water
S	2003	GVIB		Open Water
S	2004	GVIB	Big Floe	Thick First-year Ice
S	2005	PC	Medium Floe	Thick First-year Ice
S	2006	PS		Open Water
S	2007	GVIB		Open Water
S	2008	TB	Fast Ice	Thick First-year Ice
S	2009	GC	Medium Floe	Thick First-year Ice
S	2010	GC		Open Water
S	2011	TB		Open Water
S	2012	TK		Open Water
S	2013	PC		Open Water
S	2014	TK		Open Water
S	2015	TK	Big Floe	Thick First-year Ice
S	2016	TK		Open Water
W	1990	GVIB		Open Water
W	1991	GVIB	Small Floe	Old Ice
W	1992	TB	Big Floe	Thick First-year Ice
W	1993	PC	Small Floe	Old Ice
W	1994	TB	Small Floe	Thick First-year Ice
W	1995	TB	Vast Floe	Thick First-year Ice
W	1996	TB	Big Floe	Old Ice
W	1997	TB		Open Water
W	1998	TB	Big Floe	Old Ice
W	1999	PS	Big Floe	Thick First-year Ice
W	2000	PS	Big Floe	Thick First-year Ice
W	2001	TB	Big Floe	Thick First-year Ice
W	2002	TB	Big Floe	Thick First-year Ice
W	2003	GVIB	Vast Floe	Thick First-year Ice
W	2004	GVIB	Medium Floe	Thick First-year Ice
W	2005	PC	Big Floe	Old Ice

W	2006	GVIB	Big Floe	Old Ice
W	2007	GVIB	Fast Ice	Thick First-year Ice
W	2008	GVIB	Fast Ice	Thick First-year Ice
W	2009	GVIB	Big Floe	Thick First-year Ice
W	2010	PS	Medium Floe	Thick First-year Ice
W	2011	GVIB	Big Floe	Thick First-year Ice
W	2012	GVIB	Big Floe	Thick First-year Ice
W	2013	GVIB	Vast Floe	Thick First-year Ice
W	2014	GVIB	Medium Floe	Thick First-year Ice
W	2015	PC	Big Floe	Old Ice
W	2016	PC	Medium Floe	Thick First-year Ice

B. Form and stage of ice ships encounter as they exit each caribou crossing area between 1990-2016.

Route	Year	Ship	FA	SA
NW	1990	GVIB	Small Floe	Old Ice
NW	1991	TB	Small Floe	Old Ice
NW	1992	TB	Medium Floe	Old Ice
NW	1993	PS	Small Floe	Old Ice
NW	1994	PS	Big Floe	Old Ice
NW	1995	PS	Medium Floe	Old Ice
NW	1996	PS	Big Floe	Old Ice
NW	1997	PS	Small Floe	Old Ice
NW	1998	PS	Medium Floe	Old Ice
NW	1999	PS	Vast Floe	Thick First-year Ice
NW	2000	PS	Medium Floe	Old Ice
NW	2001	PS	Big Floe	Thick First-year Ice
NW	2002	TB		Open Water
NW	2003	PS	Big Floe	Thick First-year Ice
NW	2004	PS	Vast Floe	Old Ice
NW	2005	PC	Medium Floe	Old Ice
NW	2006	PS	Pancake Ice	Old Ice
NW	2007	PC	Medium Floe	Old Ice
NW	2008	PC	Medium Floe	Thick First-year Ice
NW	2009	PC	Medium Floe	Old Ice
NW	2010	PC	Big Floe	Old Ice
NW	2011	PC	Pancake Ice	Thick First-year Ice
NW	2012	PS	Small Floe	Old Ice
NW	2013	PS		Open Water
NW	2014	GC	Medium Floe	Thick First-year Ice
NW	2015	PC	Big Floe	Old Ice
NW	2016	PC	Big Floe	Old Ice
NE	1990	GVIB	Medium Floe	Old Ice
NE	1991	GVIB	Medium Floe	Old Ice
NE	1992	GVIB	Big Floe	Thick First-year Ice

NE	1993	PC	Medium Floe	Old Ice
NE	1994	PC	Medium Floe	Old Ice
NE	1995	PC	Small Floe	Thick First-year Ice
NE	1996	TB		Open Water
NE	1997	TB	Vast Floe	Old Ice
NE	1998	GVIB	Pancake Ice	Old Ice
NE	1999	GVIB		Open Water
NE	2000	PC	Small Floe	Old Ice
NE	2001	PC	Medium Floe	Thick First-year Ice
NE	2002	GVIB		Open Water
NE	2003	GVIB	Small Floe	Thick First-year Ice
NE	2004	GVIB	Big Floe	Thick First-year Ice
NE	2005	PS	Big Floe	Old Ice
NE	2006	PS	Medium Floe	Old Ice
NE	2007	PC		Open Water
NE	2008	PC		Open Water
NE	2009	PC	Big Floe	Thick First-year Ice
NE	2010	PC	Small Floe	Old Ice
NE	2011	PC		Open Water
NE	2012	GVIB	Medium Floe	Thick First-year Ice
NE	2013	PC		Open Water
NE	2014	PS	Medium Floe	Thick First-year Ice
NE	2015	PC	Big Floe	Old Ice
NE	2016	PC		Open Water
E	1990	GVIB		Open Water
E	1991	GVIB		Open Water
E	1992	GVIB	Medium Floe	Thick First-year Ice
E	1993	GVIB		Open Water
E	1994	PC		Open Water
E	1995	PC	Pancake Ice	Thick First-year Ice
E	1996	TB		Open Water
E	1997	TB		Open Water

E	1998	GVIB		Open Water
E	1999	GVIB		Open Water
E	2000	PC		Open Water
E	2001	PC		Open Water
E	2002	GVIB		Open Water
E	2003	GVIB		Open Water
E	2004	GVIB		Open Water
E	2005	PS	Big Floe	Old Ice
E	2006	PS		Open Water
E	2007	PC		Open Water
E	2008	GVIB		Open Water
E	2009	GVIB		Open Water
E	2010	PC		Open Water
E	2011	PC		Open Water
E	2012	GVIB		Open Water
E	2013	PC		Open Water
E	2014	PS		Open Water
E	2015	PC		Open Water
E	2016	PC		Open Water
S	1990	PC		Open Water
S	1991	GVIB		Open Water
S	1992	GVIB		Open Water
S	1993	GVIB		Open Water
S	1994	PC		Open Water
S	1995	PC		Open Water
S	1996	GVIB		Open Water
S	1997	GVIB		Open Water
S	1998	TB		Open Water
S	1999	TB		Open Water
S	2000	TB		Open Water
S	2001	GVIB		Open Water
S	2002	TB		Open Water

S	2003	TB		Open Water
S	2004	GVIB		Open Water
S	2005	PS	Medium Floe	Old Ice
S	2006	PS		Open Water
S	2007	GVIB		Open Water
S	2008	TB		Open Water
S	2009	TB		Open Water
S	2010	GC		Open Water
S	2011	TK		Open Water
S	2012	TB		Open Water
S	2013	TB		Open Water
S	2014	GC		Open Water
S	2015	TK		Open Water
S	2016	TK		Open Water
W	1990	GVIB		Open Water
W	1991	GVIB	Medium Floe	Old Ice
W	1992	TB	Medium Floe	Old Ice
W	1993	PC	Small Floe	Old Ice
W	1994	TB	Small Floe	Old Ice
W	1995	GVIB		Open Water
W	1996	TB		Open Water
W	1997	TB	Small Floe	Thick First-year Ice
W	1998	TB	Pancake Ice	Old Ice
W	1999	TB	Big Floe	Thick First-year Ice
W	2000	PC	Pancake Ice	Old Ice
W	2001	TB	Big Floe	Thick First-year Ice
W	2002	GVIB		Open Water
W	2003	TB		Open Water
W	2004	TB	Vast Floe	Thick First-year Ice
W	2005	PC	Pancake Ice	Old Ice
W	2006	PS	Pancake Ice	Old Ice
W	2007	PC	Small Floe	Thick First-year Ice

W	2008	PC		Open Water
W	2009	PC	Medium Floe	Thick First-year Ice
W	2010	PC	Medium Floe	Old Ice
W	2011	PC		Open Water
W	2012	PS		Open Water
W	2013	PS		Open Water
W	2014	GC	Medium Floe	Thick First-year Ice
W	2015	PS		Open Water
W	2016	TK	Big Floe	Old Ice