

**MODELLING SHIP-SOURCE NOISE IMPACTS ON MARINE MAMMALS  
IN TALLURUTIUP IMANGA NATIONAL MARINE CONSERVATION AREA**

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## Abstract

Climate change has influenced decreases in sea ice extent and thickness in the Arctic and facilitated a subsequent increase in marine traffic across the Canadian Arctic. Tallurutiup Imanga (TI), a unique National Marine Conservation Area (NMCA) which is home to rich wildlife and culture, is located in the heart of the Northwest Passage in the Canadian Arctic and has experienced some of the most rapid increases in vessel traffic in the region over the past two decades. Increases in ship traffic in this fragile and important region have the potential to negatively impact marine mammals that inhabit the area, which was the impetus for protected areas status in the first place. The focus of this thesis research was to examine the potential impacts of underwater noise from ships on marine mammals in the Tallurutiup Imanga NMCA. The approach taken involved: 1) examining historic spatial and temporal vessel traffic trends in the area of interest from 1990 to 2018, using the Canadian Coast Guard ship archive data for the Northern Canada Vessel Traffic Service (NORDREG) Zone, 2) conducting an in-depth analysis of recent traffic trends (2015-18) using spatially precise Automatic Identification System (AIS) vessel traffic data, 3) creating underwater noise profiles using in an acoustic model to produce received level values cumulatively for all vessels and also for all vessels within a single class, 4) identifying behavioural disturbance events as 500 metre cells where the received level was equal to 120 dB, which is the behavioural disturbance threshold for marine mammals defined National Ocean and Atmospheric Administration (NOAA), and 5) overlaying acoustic model outputs with important areas for marine mammals to understand the spatial extent of ship-source underwater noise impacts in TI. Study results revealed that vessel traffic in Tallurutiup Imanga has almost tripled over the past 29 years with bulk carriers and passenger ships travelling the most in 2018. In the most recent years of the study period there were also spikes in vessel traffic; 2018 saw nearly a doubling of bulk carrier traffic to Baffinland Iron Ore Mines Corporation's Mary River Mine site on Baffin Island. From the years 2015 to 2018, there were certain areas where behavioural disturbance events overlapped beluga and narwhal core use areas (50 Percent Volume Contours), as well as observed wildlife areas (based on Inuit and local knowledge). Some areas like Eclipse Sound and Milne Inlet had an increased risk of behavioural disturbance events, especially with cargo vessels and passenger ships. These areas indicated a potential for negative impacts on marine mammals, and areas that have more disturbance events have a higher chance of being affected. The aim of this research was to inform our understanding of potential underwater noise risks to marine mammal, and to support ongoing environmental management and governance efforts that could be used to provide evidence-based decision making for future mitigation of the NMCA.

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# Chapter 1: Introduction

## 1.1 Introduction

Recent reductions in sea ice extent in the Canadian Arctic are a result of global climate change and have influenced an increase in maritime navigability and marine shipping activities (Pizzolato, Howell, Derksen, Dawson, & Copland, 2014; Smith & Stephenson, 2013; Stephenson, Smith, Brigham, & Agnew, 2013). There is already significant interest in the commercial viability of the Northwest Passage (NWP) as evidenced by the recent and historic sailings of cargo vessels such as the Nordic Orion (traversed NWP in 2011), the Nunavik (2014) and also by the non-ice strengthened cruise ship the Crystal Serenity (2016, 2017). The NWP is also attracting a large number of private yachts and research vessels such as the late Paul Allen's the Octopus and the Chinese icebreaker Snow Dragon (2017).

Tallurutiup Imanga (TI; also known as Lancaster Sound) is an important marine area that became a National Marine Conservation Area (NMCA) in the summer of 2019. It spans approximately 110,000 square kilometres and is located at the eastern entrance of the Northwest Passage, exactly where ship traffic has been increasing over the past decade and where future increases are expected (Dawson, Pizzolato, Howell, Copland, & Johnston, 2018; Parks Canada, 2019c). The area is rich in ecological and cultural significance and the protection of Lancaster Sound has been in progress for decades (Parks Canada, 2017). With the official boundaries set in August of 2017, the future protection and management of the new NMCA will be crucial to protecting its integrity.

With this in mind, higher densities of shipping traffic will bring both opportunities and risks to the Arctic and to the NMCA (Dawson, Copland, Johnston, et al., 2017; Fissel, Cross, & Howland, 2013; Huntington et al., 2015; Knol & Arbo, 2014; Miller & Ruiz, 2014; Reeves et al., 2014). In terms of opportunities community re-supply makes up a big portion of the ship traffic in the Canadian Arctic (Dawson et al., 2018) and the deliveries of cargo to each community are essential for local people (Arctic Council, 2009; ITC, 2017), and have lower costs and higher volumes of supplies than air supply (Giguère, Comtois, & Slack, 2017). Furthermore, cruise ships bring in tourists who contribute to the income of communities through participating in guided tours, purchasing carvings and local art, and attending performances (Dawson, Copland, Johnston, et al., 2017; Stewart, Dawson, & Johnston, 2015). Other opportunities include the economic benefits related to fisheries and natural resource development (Afenyo, Lin, Ng, & Jiang, 2019). Despite these opportunities, local communities across Arctic Canada have identified

increased shipping as one of their greatest concerns (Dawson et al., 2020). An increasing number of ships, if not properly managed, could enhance risks related to potential oil and fuel spills and invasive species introduction. One of the greatest concerns among community members in Arctic Canada, and in particular those neighbouring TI NMCA is the impact of underwater noise from ships on marine mammals (see [www.arcticcorridors.ca](http://www.arcticcorridors.ca); Carter, Dawson, & Cook, 2019; Carter, Dawson, Joyce, & Ogilvie, 2017; Carter, Dawson, Joyce, Ogilvie, & Weber, 2018; Carter, Dawson, Knopp, et al., 2018; Carter, Dawson, Parker, Cary, et al., 2018b, 2018c, 2018a; Carter, Dawson, Parker, Joyce, et al., 2018; Carter, Dawson, & Weber, 2019; Greydanus, Provencher, Carter, Dawson, & Kochanowicz, 2018). Inuit are concerned about the health of the animals because hunting animals is part of their cultural identity and plays a role in the overall health and well-being of Inuit (Cunsolo Willox et al., 2013; Donaldson et al., 2010; Meredith et al., 2019). The country food acquired from subsistence hunting is nutritionally beneficial and cost-effective compared to the higher costs of store-bought food that tends to be higher in fats and sugars and can lead to health problems like obesity and diabetes (Andrachuk & Smit, 2012; Donaldson et al., 2010; ITK, 2017; Meredith et al., 2019).

Ship traffic, and related underwater noise from ships is predicted to increase in the Arctic as historic accumulations of thick multi-year sea ice that is now rapidly melting is increasing open water areas and navigability of region (Haas & Howell, 2015; Halliday, Insley, Hilliard, de Jong, & Pine, 2017; Pizzolato, Howell, Dawson, Laliberté, & Copland, 2016; Roth, Hildebrand, Wiggins, & Ross, 2012). Considering the environmental and cultural importance of marine mammals in the TI NMCA, it is vital to understand the effects that increases in ship source noise will have in the region (Southall et al., 2007). Research on the impacts of vessel noise on marine mammals in the Arctic started being documented around the 1980s and is still in development with various studies published on a variety of species (Blackwell et al., 2013, 2017; Erbe, Macgillivray, & Williams, 2012; Halliday et al., 2017; Harris, Miller, & Richardson, 2001; Heide-Jørgensen, Hansen, Westdal, Reeves, & Mosbech, 2013; Pine, Hannay, Insley, Halliday, & Juanes, 2018). Considering that TI is nationally recognized as a vital habitat for marine mammals including narwhals, and belugas (Parks Canada, 2017) research is urgently needed in order to better inform our understanding of potential marine mammal risks and also to support ongoing environmental management and governance efforts that can be used to provide evidence-based decision making through the legal mechanisms that exist within a NMCA framework.

This thesis research responds directly to this knowledge gap and the urgent need to better understand the potential impacts of increased vessel noise from ships in Tallurutiup Imanga. Not only does the

research extend current scientific literature on the spatial extent of underwater noise from ships for marine mammal ranges in the Arctic, but it also contributes new evidence that can be used in the development of the final management plan for the NMCA (Parks Canada, 2017). In August 2019, the Qikiqtani Inuit Association (QIA), Parks Canada and the Government of Nunavut finalized the Inuit Impact Benefit Agreement for the TI NMCA, which includes details about the development of the NMCA and how each organization will work together to see various tasks associated with the NMCA. Next, an interim management plan (IMP) will be finalized and will serve as a temporary management plan until a final management plan is prepared and legally implemented in 2024 (Parks Canada, 2017).

## **1.2 Project Objectives**

The overall aim of this study was to improve the understanding of ship traffic in Tallurutiup Imanga and to model ship-noise impacts on marine mammals. To support this aim, three main research objectives were established including to:

- 1) Quantify historic shipping trends in the Tallurutiup Imanga National Marine Conservation Area from 1990 to 2018 using NORDREG data;
- 2) Assess modelled vessel noise outputs from historic Automatic Identification System (AIS) ship traffic; and
- 3) Identify areas of high risk from noise exposure for marine mammals in the Tallurutiup Imanga National Marine Conservation Area, including marine mammal use distribution areas and observed wildlife areas.

## **1.3 Organization of thesis**

Chapter one introduces the thesis topic and the general outline and objectives of the research. Chapter two includes the key literature for the topic of this study including climate change impacts in the Arctic, environmental risks from vessels and mitigation of vessel noise in marine environments. Chapter three addresses project objective 1 of the thesis by providing an analysis of historic ship traffic in the study area. It is important to have a full understanding of historic traffic trends considering the rapid increase in ship traffic and the need for location specific data (AIS). This chapter was made into a technical report (Kochanowicz, Dawson, & Mussells, 2020; see [www.arcticcorridors.ca/reports](http://www.arcticcorridors.ca/reports)) that was shared with Parks Canada and QIA, and was a deliverable for a Nunavut General Monitoring Program (NGMP) funded project that supported my thesis research. Chapter four is a research article that will be targeted for a peer-reviewed paper and it further addresses project objectives 2 and 3, including both marine

mammal use distribution areas based on western science and observed wildlife areas based on Inuit and local knowledge. The final chapter outlines study contributions and limitations and provides recommendations for future research.

## **1.4 Study Area**

Tallurutiup Imanga is a marine area in Nunavut, in the eastern Canadian Arctic. It covers 110,000 km<sup>2</sup> of the Arctic Ocean, with the Southeastern tip of Ellesmere Island marking its northern limit, and Admiralty Inlet marking its southern limit. As for its longitudinal span Resolute marks its western limit, and its eastern limit extends around 100 km from the coast of Baffin Island into Baffin Bay (see Figure 1). The area also encompasses various bays and inlets such as Admiralty Inlet, Barrow Strait, Eclipse Sound, Maxwell Bay and Arctic Bay. There are five hamlets in and around Tallurutiup Imanga: Arctic Bay, Clyde River, Grise Fiord, Pond Inlet and Resolute. In 2018, the populations were as follows in the communities: 903 in Arctic Bay, 1,149 in Clyde River, 137 in Grise Fiord, 1,773 in Pond Inlet and 211 in Resolute (Government of Nunavut, 2019).

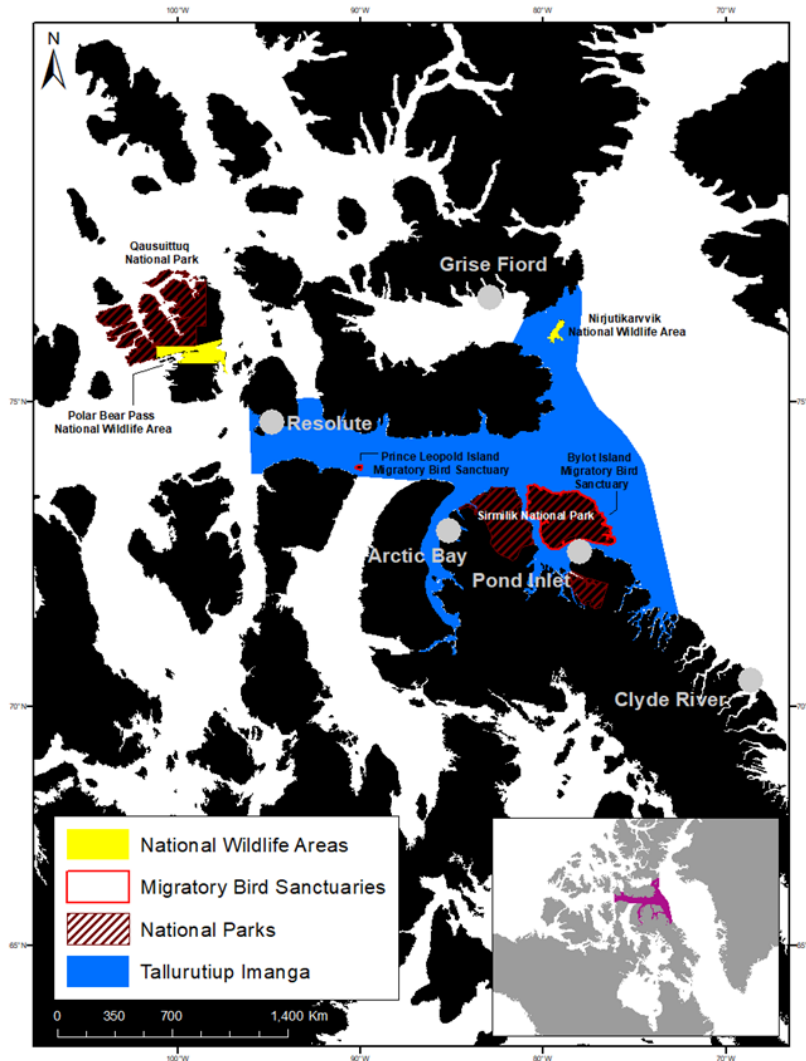


Figure 1. Map of Tallurutiup Imanga in Nunavut, Canada, surrounding communities and protected areas.

Tallurutiup Imanga is one of the most important and unique ecological marine areas in the world and is referred to as the “ecological engine of the entire eastern Canadian Arctic marine ecosystem” (Parks Canada, 2019a). Its polynyas, which are areas of open water that stay ice free year round, have high biological productivity which is key for marine animals who inhabit the area or who migrate there (Parks Canada, 2017; Stirling, 1980). The region is a major migratory corridor for species moving east to west and that links summering and wintering areas for animals like narwhal, beluga, polar bears and seabirds (Parks Canada, 2019a). Not only is this area ecologically important but there is also cultural importance associated with it. Hunting and fishing in the area is part of the traditional lifestyle for Inuit in the surrounding communities; they have a strong connection to the land and wildlife (Parks Canada, 2019a).

Tallurutiup Imanga became a National Marine Conservation Area in 2019 because of its unique cultural and natural seascape. Although there had been interest to legally protect the area since the 1970s, it wasn't until 2009 that the Governments of Canada, Nunavut and the Qikiqtani Inuit Association (QIA) signed a Memorandum of Understanding (MOU) to start a feasibility assessment for the area (Parks Canada, 2017). Resource assessments, community and key stakeholder consultations, and ecological and traditional knowledge studies were conducted over the years 2011 to 2016, which eventually led to an Inuit Impact Benefit Agreement (IIBA) being launched in August, 2017 and signed two years later in August, 2019 (Parks Canada, 2017). Currently an interim management plan is being prepared by the Government of Canada, the Government of Nunavut and the QIA.

## Chapter 2: Background

### 2.1 Climate Change in the Arctic

The Earth's climate has been changing drastically for the past 60+ years which has been attributed mostly to the burning of fossil fuels and the clearing of land (IPCC, 2018, 2019). These changes include raised atmospheric and oceanic temperatures, sea level rise, declining snow and sea ice covers, and increased frequency of extreme weather events such as droughts and heavy precipitation in certain areas (IPCC, 2018, 2019; Meredith et al., 2019). Although climate change is experienced globally these affects are experienced more intensely in the Arctic (Anisimov et al., 2007; IPCC, 2018; Meredith et al., 2019). Notably, the average temperature in the Arctic has increased three times as much as the rest of the world (Bush & Lemmen, 2019). This phenomenon is referred to as "Arctic amplification" and is caused by multiple interacting factors, one of the major ones being the reduction of sea ice (Bush & Lemmen, 2019; Screen & Simmonds, 2010; Simmonds, 2015; Walsh, 2014). Over the last two decades as the climate warmed, Arctic sea ice and the Greenland ice sheet began to lose mass (Meredith et al., 2019). This reduction in the reflective sea ice extent reduces the albedo and allows for the ocean to absorb heat and release it back into the atmosphere, creating a positive ice-temperature feedback that increases the temperature of the atmosphere (Holland & Bitz, 2003; Screen & Simmonds, 2010; Walsh, 2014). The loss of Arctic sea ice has been continuous for the past few decades; notably, from the period of 1979 to 2013 there were negative trends of sea ice in all of the months, seasons and annual averages (Simmonds, 2015). From 2003 to 2018, sea ice volume declined at a rate of 2870 km<sup>3</sup> per decade in winter, and 5130 km<sup>3</sup> per decade in the fall (Kwok, 2018), and it is predicted to keep declining through mid-century (Meredith et al., 2019).

#### 2.1.1 Impacts of climate change on Arctic marine mammals

Changes in surface air temperature and reductions in sea ice are having significant impacts on marine mammals in Arctic Canada (Descamps et al., 2017; Meredith et al., 2019). Shifts in species distribution are already being observed, for example Atlantic mackerel have shifted 1650 km westward and 400 km northward of their summer distributions from 1997 to 2016 and their stock expanded from 0.4 to 2.5 millions km<sup>2</sup> (Meredith et al., 2019). Marine mammals like seals and polar bears that rely on ice and snow for their breeding, denning and feeding activities, are using more energy to find food sources, to find less densely populated areas for breeding (Descamps et al., 2017; Stirling & Derocher, 2012), as well as swimming further to find suitable ice (Meredith et al., 2019; Pilfold, McCall, Derocher, Lunn, &

Richardson, 2017). Declines in summer sea ice have also been linked to reduced growth and survival of polar bears (Bromaghin et al., 2015). Furthermore, persistent organic pollutants that can impair the reproductive and endocrine systems of marine mammals have been found in beluga whale blubber (Desforges, Ross, & Loseto, 2012). Toxic mercury released by anthropogenic emissions have also been found in high levels in belugas whales and impact the immune system of these mammals as well as any predators eating them, such as polar bears (Frouin, Loseto, Stern, Haulena, & Ross, 2012; Loseto et al., 2008).

### **2.1.2 Impacts on northern communities**

The impacts of climate change in the Arctic have effects on society as well (Meredith et al., 2019). The lives and livelihoods of Inuit in Arctic communities are being impacted by changes to the biophysical environment (Andrachuk & Smit, 2012; Ford, 2012; Ford et al., 2012; Pearce, Ford, Willox, & Smit, 2015). Changes in sea ice dynamics are already restricting traditional food access for indigenous communities that hunt animals on the ice (Carter, Dawson, Joyce, et al., 2018; Ford, 2012). Hunters rely on adequate ice conditions for travelling, ice fishing and hunting marine mammals (such as seals, narwhals and polar bears) and it is becoming challenging to monitor these rapid changes in ice, snow and wind conditions as the climate changes (Andrachuk & Smit, 2012; Berkes & Jolly, 2001; Ford et al., 2012; Ford, Smit, & Wandel, 2006; Ford & Pearce, 2012; ITK, 2017; Meredith et al., 2019). Furthermore, the restricted access to quality country food that communities hunt and gather carries implications for nutrition and well-being as communities start to rely more on Western diets (Ford, 2012; Meredith et al., 2019).

## **2.2 Climate Change and Shipping in the Arctic**

Recent reductions in sea ice extent in the Arctic ocean have been attributed to climate change and are projected to continue declining in the coming decades (Meredith et al., 2019; Simmonds, 2015; Stephenson et al., 2013). From 1990 to 2013 the ice extent in the Arctic retracted, the melt season length extended, and shipping activities increased (Pizzolato et al., 2016, 2014). Furthermore, projections show that new areas of the Arctic might become accessible and could lead to increased shipping in the Arctic in the 21st century (Melia, Haines, & Hawkins, 2016; Stephenson et al., 2013).

Moreover, the Arctic sea routes (NWP and Northeast Passage which is north of Siberia) are shorter paths between Asia and Europe compared to the classic Panama or Suez Canal routes (Khon, Mokhov, Latif, Semenov, & Park, 2010; Lasserre & Pelletier, 2011). Although they are not predicted to replace the traditional routes through mid-latitude oceans, the Arctic routes are expected to become more widely

used as the summer sea ice melts and access to the Arctic via these routes increases (Lasserre & Pelletier, 2011; Stephenson, Smith, & Agnew, 2011; Stephenson et al., 2013).

It is important to note that declining sea ice due to climate change is not the only factor that will influence the future trends of vessel traffic in the Arctic. Non-environmental factors such as the pressure of economic development, mining, tourism, community re-supply and resource exploration also influence the vessel traffic in the Arctic (Dawson et al., 2018; Pizzolato et al., 2016, 2014). For example more cargo vessels are expected to travel through the Canadian Arctic due to future growth in demographic and construction demands (Pelletier & Guy, 2015); cruise and yacht tourism has been one of the fastest growing sectors and is expected to continue increasing (Dawson, Johnston, & Stewart, 2014; Halliday, Têtu, Dawson, Insley, & Hilliard, 2018; Johnston, Dawson, De Souza, & Stewart, 2017); and, oil and mineral exploration is of international interest for countries like China and Russia due to huge areas of undiscovered resources (Farré et al., 2014). Although the interest in Arctic shipping and transportation will increase, factors such as lack of infrastructure and modern bathymetry charts, harsh weather conditions, remoteness and lack of broadband communications will still limit the potential for long-term growth of shipping in the Canadian Arctic (Farré et al., 2014; Smith & Stephenson, 2013).

### **2.3 Arctic Shipping Trends in Canada**

The total annual distance travelled in kilometres in the Canadian Arctic by all vessel types tripled between 1990 to 2018 (Figure 2). Vessels have always been concentrated in the southerly and easterly Arctic areas (Dawson, Copland, Johnston, et al., 2017); furthermore, bulk carriers, passenger ships and pleasure crafts had the biggest increases in distance travelled from 1990 to 2015 (Dawson et al., 2018).

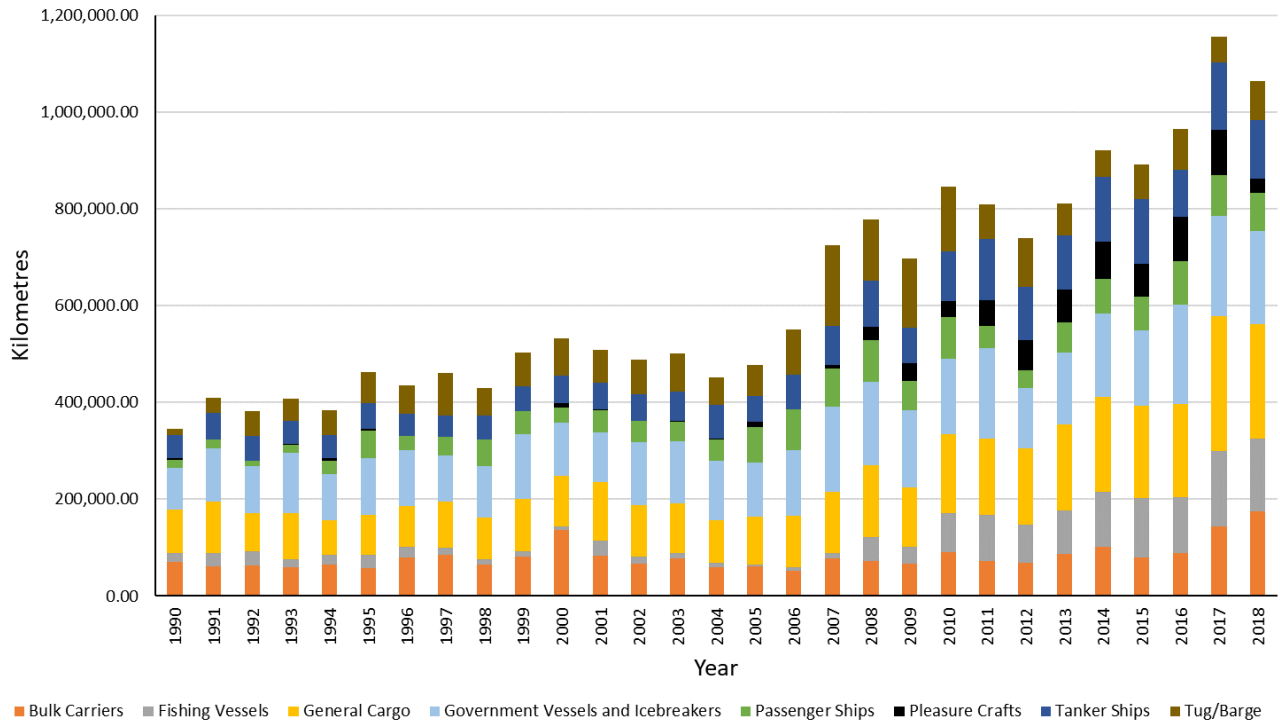


Figure 2. Total kilometres travelled annually by all vessel types in the Canadian Arctic.

In terms of vessel activity around northern Canadian communities, most have experienced notable increases in shipping within 50 km; Pond Inlet, Baker Lake, Cambridge Bay and Chesterfield have seen the largest increases (Dawson et al., 2018). Because of the challenges with long-term predictions of socio-economic factors, accurate predictions for shipping trends in the Canadian Arctic are hard to achieve. Short-term predictions suggest that there will be an overall increase of traffic volume and the only vessel type that will experience rapid increases are pleasure crafts (Dawson, Copland, Johnston, et al., 2017). Vessels are also anticipated to increase on the northeast coasts of Labrador, Newfoundland and Quebec because of resource development (Dawson, Copland, Johnston, et al., 2017). Resource vessels are also expected to increase around Baffin Bay and the Hudson Strait due to the operations at Mary River Mine (Dawson, Copland, Johnston, et al., 2017).

## 2.4 Environmental Risks from Vessels

Shipping in the Arctic will continue to gain national and international attention and navigations will occur more frequently in the coming years (Arctic Council, 2009; Stephenson et al., 2013). With increases in shipping frequency, there are consequently social, environmental, cultural and economic

impacts, associated with these trends (Arctic Council, 2009; Huntington et al., 2015). Focusing in on the environmental impacts, Table 1 from Arctic Council Working Groups outlines a comprehensive list of the range of environmental risks associated with marine shipping in the Arctic; the same environmental risks were mentioned in a study done by Huntington et al (2015).

*Table 1. Environmental impacts associated with marine shipping in the Arctic. Source: AMAP/CAFF/SDWG (2013).*

Category	Activities/pressures	Impacts
Pollution	Accidental discharge of oil and toxic chemicals	Physical oiling and death of birds and fur-bearing mammals due to impaired thermal insulation Toxicological effects
	Regular discharges to water (including garbage and illegal discharges)	Oiling (primarily from illegal discharges) Entanglement of whales and other wildlife (ropes, nets and other garbage) Ingestion of plastics by birds and mammals
	Emissions to air	Climate change (carbon dioxide and other greenhouse gases) Ozone and haze (nitrogen oxides) Decrease in local air quality Deterioration in ice conditions (black carbon; 'soot')
Disturbance	Sound and noise disturbance	Disruption of feeding, breeding or other vital activities for birds and mammals Interference with communication among whales
	Ice breakers and disturbance	Effects on behavior and communication between mammals Disturbance of wintering, migrating or staging birds and mammals in leads and polynyas Disruption of migration routes for terrestrial mammals crossing sea ice (e.g., caribou) Ice entrapment of whales in artificial leads
	Vessel strikes	Injury and death of whales by collision
	Light disturbance	Injury and death of birds attracted to lighted ships
Introductions	Introduction of invasive species through ballast water, hull fouling and cargo	Various biological and ecological effects including detrimental changes to food webs and displacement and potential loss of native species. Impacts on breeding birds by introduced predators, notably 'rat spills' associated with ship accidents on islands

## 2.5 Risks from Underwater Noise in the Arctic

Since the focus of this thesis is on impacts of noise disturbance in the Arctic region, the characteristics of underwater noise in the Arctic will be explored in more detail in this section, including sources of sound and impacts of underwater noise on marine mammals.

### 2.5.1 Natural noise sources

Natural sources of noise in the ocean can come from biotic or abiotic sources (Bradley & Stern, 2008). Abiotic sources come from processes like earthquakes, eruptions of underwater volcanoes, waves and rainfall (Bradley & Stern, 2008; Hildebrand, 2009). One of the most dominating forces throughout all of

the oceans is wind (National Research Council, 2003). Winds act on the surface of the ocean and create wave activity; therefore, wind speed is what determines the intensity of the waves that create this sound (National Research Council, 2003). These forces are also present in the Arctic ocean and contribute to the addition of ambient noise, especially during periods when there is no ice covering the water (Insley, Halliday, & De Jong, 2017; Roth et al., 2012). Another important natural force that modifies ambient noise levels is sea ice (National Research Council, 2003). The ice cover in the Arctic can have two effects on ambient noise: dampening of sound and emission of sound pulses due to cracking (National Research Council, 2003). Sounds become dampened by ice because the ice isolates the water column from the effects of wind (Insley et al., 2017; National Research Council, 2003; Roth et al., 2012). Furthermore, changes in air temperature cause thermal stresses that crack the ice, as well as movements of ice blocks which cause mechanically-induced stresses (Kinda et al., 2015; National Research Council, 2003).

Biotic sources of sound are also present in the Arctic. Marine species use sound over light to communicate and navigate in the oceans because of sound's effective ability to travel through water (National Research Council, 2005). Some examples of noise produced by animals include fish that move in the water or rub skeletal parts of their body together to make noises (Bradley & Stern, 2008); shrimp that produce a loud snap by the rapid closure of their claw (Versluis, Schmitz, von der Heydt, & Lohse, 2000); and, marine mammals like seals and walrus that use their larynx and high pressure air to generate noises for communication, breeding and navigation of their environments (Bradley & Stern, 2008; National Research Council, 2003).

### **2.5.2 Anthropogenic noise sources**

Sources of noise in the ocean that are produced by humans, called anthropogenic sources are powerful noises that drastically increase the ambient noise of the oceans (Hildebrand, 2009). Overtime humans have filled the oceans with noise from activities like transportation, commerce, defense and exploring and exploiting resources, and these activities are expected to keep increasing with the economic pressures for shipping remaining strong (Moore et al., 2012; National Research Council, 2003; Reeves, Rosa, George, Sheffield, & Moore, 2012). The Arctic is specifically expected to see increased shipping due to increased accessibility from less ice buildup (Huntington et al., 2015; Pizzolato et al., 2014).

Shipping and geophysical exploration are the two main anthropogenic sounds produced in oceans all over the world, including the Arctic (Klinck et al., 2012; Roth et al., 2012; Stafford, Castellote, Guerra, & Berchok, 2017). Vessel traffic is responsible for low frequency sounds in the oceans produced by

propeller noises and high frequency sounds produced by the main engine and diesel generators (Stafford et al., 2017; Veirs, Veirs, & Wood, 2016). Propeller cavitation, specifically, is part of the ships mechanics that produces the most noise underwater and is caused by air bubbles forming from the propeller which rupture (Ross, 1976; Veirs et al., 2016). Seismic exploration involves the use of low frequency airgun rays that pulse high pressure air into the water to produce geo-acoustic profiles of the seabed (Barger & Hamblen, 1980; Madsen et al., 2006).

Other sources of anthropogenic noise do not contribute to ambient noise greatly, but are still sounds that can be disruptive to the marine environment because of their temporal and spatial releases and intensity (Hildebrand, 2009). These sources include chemical explosives, sonars, offshore drilling and construction pile driving (Blackwell et al., 2013, 2017; Heide-Jørgensen et al., 2013; Hildebrand, 2009).

### **2.5.3. Impacts of underwater noise on marine mammals**

As has been noted, anthropogenic noises have been increasing the ambient noise in oceans, and marine mammals that are exposed to these noises may experience a range of effects. The amount of physical and psychological stress to the mammal depends on parameters like the spatial range of the animal to the sources, the sensitivity of the animal and the exposure level (Southall et al., 2007).

One type of impact that anthropogenic noise can have on marine mammals is to disturb their behaviour, which can range from changes in breathing patterns, to altering vocalization, to escaping regions with the noise disturbance (Gomez et al., 2016; National Research Council, 2003). The type of behavioural response that a marine mammal will generate can also depend on if the animal has prior experience to hearing a sound, their current activity and if they have motivation to stay in that area or not, as well as conditioning to the noise (Ellison, Southall, Clark, & Frankel, 2012; Southall et al., 2007).

In fact, bowhead whales have been shown to react to seismic airgun noise by avoiding the areas with increased sound levels (Richardson, Würsig, & Greene, 1986). They also have been recorded changing their calling rates (Blackwell et al., 2013) and blow intervals and dive times due to airgun noise produced in seismic surveying (Gailey, Würsig, & McDonald, 2007). Contrastingly, pinnipeds including ringed seals, bearded seals and spotted seals show greater tolerance to sounds like seismic surveying and pipe-driving and do not show behavioural reactions (Blackwell, Lawson, & Williams, 2004; Harris et al., 2001). Some avoidance behaviour of seals was observed during seismic surveying, but only when airgun levels were at their highest, and even then the seals' reaction was to move away a short distance (Harris et al., 2001).

Noise further has the potential to diminish the ability for the receiver of sound to detect or even recognize a noise, which is called communication masking (Erbe & Farmer, 2000; Erbe, Reichmuth, Cunningham, Lucke, & Dooling, 2016). One study predicted beluga whale's communication to be masked within a 14-71 km range from icebreaker vessels (Erbe & Farmer, 2000). More broadly, acoustic masking as a whole should also be considered and includes the masking of other biologically significant sounds such as echolocation for foraging and for detection of predators, and for the detection of abiotic sound cues like earthquakes (Clark et al., 2009). Certain marine mammals are able to alter the characteristics of their vocalizations so that their sounds are not compensated by a masking signal (Erbe et al., 2016). However, masking is still an important factor to consider especially since the largest contributing factor for marine mammal masking is commercial shipping which has seen positive trends over the past few decades, especially in the Arctic (Dawson et al., 2018; Pizzolato et al., 2016).

Marine mammals that are exposed to sound with sufficient intensity and duration may experience an increased hearing threshold, meaning that they lose some hearing sensitivity (Finneran, 2016; Southall et al., 2007). If the hearing threshold of the mammal eventually returns back to normal this effect is called temporary threshold shift (TTS); however, if this shift does not return to the original threshold, it is called a permanent threshold shift (PTS) (Finneran, 2016). Some effects of PTS are the irreparable damage to sensory hair cells or changing the chemical composition in the inner ear fluids (Southall et al., 2007). Specifically in the Arctic Ocean, beluga whale studies have shown that TTS can occur when icebreaker vessels are within 1-4 km of the whales for at least 20 minutes (Erbe & Farmer, 2000).

## **2.6 Mitigation of Vessel Noise in Marine Environments**

The increase of anthropogenic noise in the ocean over the last century has affected the acoustic habitats of various marine mammals; therefore, methods are needed to conserve and manage coastal and marine ecosystems (Hatch et al., 2016). Some of the first policies for noise mitigation were focused to "not exceed" a certain amplitude of sound that was known to have an effect on marine mammals (Southall et al., 2007). More recently, the management of marine areas has moved from animal-centered management to more habitat-centered management (Hatch & Fristrup, 2009; Williams, Erbe, Ashe, & Clark, 2015). For example, it has evolved into ecosystem-based management, which emphasizes the protection of the whole ecosystem structure and considers a range of activities that are affecting it (Hatch & Fristrup, 2009; Hatch et al., 2016).

### **2.6.1 Spatial management**

Current national and international efforts to include marine mammals into spatial planning include the incorporation of noise disturbance or the designation of critical habitats into regions like Marine Protected Areas (MPAs) (Williams et al., 2015; Wright, Deak, & Parsons, 2011). MPAs are established in coastal areas where human activities are concentrated and are at risk of effecting the ecosystem (Wright et al., 2011). One study highlights the importance of including acoustic buffer zones in these areas because of the acoustic footprint that could extend past the MPA where mammal populations will still be present (Wright et al., 2011).

Prioritizing areas for marine management are another factor to consider in spatial management. A common method is to conduct a risk assessment by integrating multiple data sets, such as high noise levels created by anthropogenic sources and high-value target species (Hatch et al., 2016). This type of risk assessment prioritizes areas where there are already species that are vulnerable to the effects of increased noises from human activities (Erbe, Williams, Sandilands, & Ashe, 2014; Rolland et al., 2012). Alternatively, Williams et al. (2015) and Hatch & Fristrup (2009) support the increased protection and management of quiet marine areas. These areas contain high densities of marine mammals but experience low levels of anthropogenic noise (Williams et al., 2015). Those studies claim that the quiet areas are most vulnerable to noise intrusions because very little noise is required to lower the acoustic quality of the environment since its usual noise levels are low (Hatch & Fristrup, 2009).

### **2.6.2 Speed limits and rerouting**

Other methods to mitigate vessel noise impacts in marine environments include rerouting the vessels to avoid ecologically sensitive areas as well as slowing down vessel speeds when in these areas (Cominelli et al., 2018; IMO, 2014). According to a recent study (McWhinnie, Halliday, Insley, Hilliard, & Canessa, 2018) out of these two methods, speed restrictions would be more feasible for the Arctic because due to the geographical limitations and navigational hazards, avoiding areas might not be possible. McWhinnie et al. (2018) also suggest that management should be a combination of spatial (e.g., exclusion zones, rerouting), vessel (e.g., speed reduction, pilotage), monitoring (e.g., AIS, marine mammal visual observations) and outreach (e.g., to general public, to stakeholder) methods to have a comprehensive and complete management of the vessels.

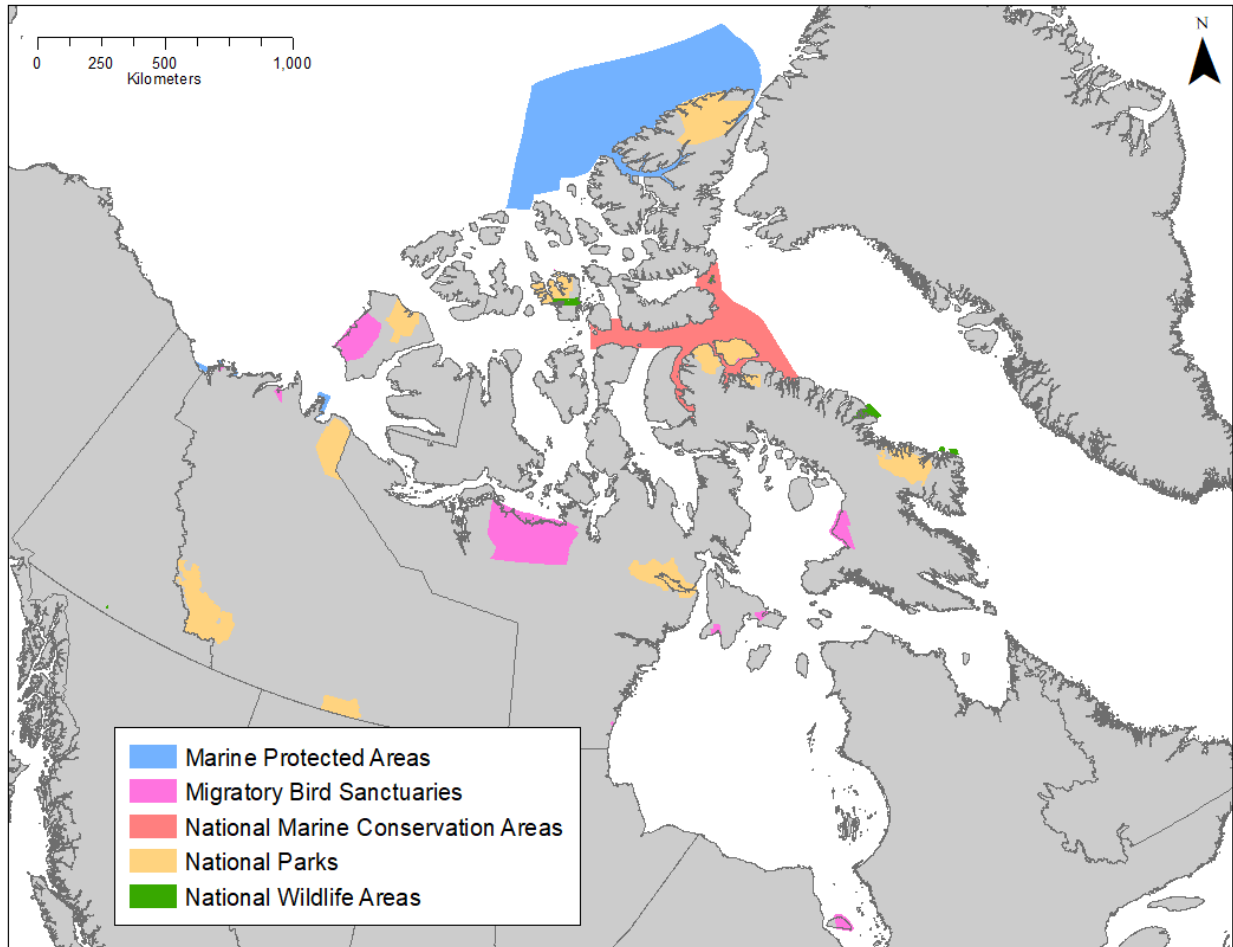
### **2.6.3 Machinery modifications**

Finally, another method to help reduce the impact of anthropogenic noise, specifically from ships, is the maintenance of hulls and propellers and the incorporation of new designs to quiet vessel (Clear Seas, 2018; DFO, 2017). The maintenance of the hull and propeller will reduce cavitation (Clear Seas, 2018), while selecting the design of a ship to have noise reducing characteristics, such as hull design and propeller diameter and pitch (IMO, 2014) are also ways for vessel owners and operators to reduce ship noise to the environment.

## **2.7 Arctic Marine Governance and Protected Areas Management**

In order to implement any of the above noise mitigating management strategies, effective policy has to be developed within appropriate governance structures. Although there are various international and national governing bodies for marine policies, this section will focus on Protected Areas.

Canada's Ocean Strategy is described by the Government of Canada's policy statement that aims to "...ensure healthy, safe and prosperous oceans for the benefit of current and future generations of Canadians" (DFO, 2002). As part of its contribution to fulfil this overarching goal, the Federal Marine Protected Areas Strategy (FMPAS) is a key contribution. The FMPAS, coordinated by the minister of the DFO, is a network of three federal departments and agencies: Fisheries and Oceans Canada (DFO), Parks Canada (PC) and Environment and Climate Change Canada (ECCC). The mandates of these departments and agencies is to establish and manage marine protected areas through three main programs: Oceans Act Marine Protected Areas (established by DFO), National Wildlife Areas with marine focuses (established by ECCC), and National Marine Conservation Areas (established by PC) (DFO, 2005). Furthermore, Migratory Bird Sanctuaries and National Parks with marine components are also considered contributions to the marine protected areas network (Fisheries and Oceans Canada (DFO), 2005). See Figure 3 for a map showing the various types of marine protected areas within the FMPAS, in the Canadian Arctic.



*Figure 3. Map of Canada and the different types of components in the marine protected areas network in the Canadian Arctic.*

Marine Protected Areas (MPA) are sections of the ocean that are legally protected and managed to ensure the long-term conservation of nature throughout the area (DFO, 2018a). MPAs are established through the Oceans Act and are chosen based on their ecological/biophysical, social, cultural and economic benefits (DFO, 2018a). There are currently three MPAs in the Arctic: Tarium Niryutait MPA in the Mackenzie River Delta and estuary in the Beaufort Sea; Anguniaqvia niqiqyuam MPA in the Inuvialuit Settlement Region; and, Tuvaijittuq MPA off the northwest coast of Ellesmere Island.

National Wildlife Areas (NWA) are terrestrial and marine regions that are managed to ensure the conservation of wildlife and for the purpose of research and interpretation (ECCC, 2020). There are currently 54 NWAs across Canada; 5 of which are in the Arctic and all of them contain marine habitats (ECCC, 2020).

A National Marine Conservation Area (NMCA) is a marine area established to protect and conserve main marine ecosystems and their key features, while ensuring the use of marine resources in an ecologically sustainable way (DFO, 2015). Activities like undersea mining, oil and gas exploration and development and ocean dumping are prohibited in these areas and include the water column and the seabed beneath it (DFO, 2015). There is now currently one NMCA in the Arctic, the one of which this thesis is focused on: Tallurutiup Imanga.

# Chapter 3: Analysis of historic ship traffic in Tallurutiup

## Imanga

### 3.1 Introduction

There are a variety of different vessels that have historically transited the Tallurutiup Imanga borders including; government vessels and icebreakers, container ships, general cargo, bulk carriers, tanker ships, passenger ships, pleasure craft, tub/barge, fishing vessels, and oil and gas exploration vessels (see Pizzolato et al. (2014) for a table of vessel types and typical operations). Within the Tallurutiup Imanga region, the shipping season lengthened between 1990 and 2013 (Dawson, Copland, Johnston, et al., 2017; Pizzolato et al., 2014) and there were increases in kilometres travelled by almost all sectors of vessel traffic between 1990 and 2015 (Dawson et al., 2018). Higher densities of marine shipping traffic have significant impacts on the flora and fauna in the Arctic through various vectors, such as invasive species from ballast water, noise pollution and risks related of oil and fuel spills (Dawson, Copland, Johnston, et al., 2017; Ghosh & Rubly, 2015). This chapter summarizes the specific temporal and spatial shipping trends in Tallurutiup Imanga from 1990 to 2018 and fulfills the first objective of the overall research objectives

### 3.2 Methodology

The database used for this study was created using Canadian Coast Guard non-spatial NORDREG ship archive data from 1990 to 2018. For further details on the process of constructing the database see: Pizzolato et al. (2014; 2016); Dawson, Copland, Johnston, et al. (2017); Dawson, Copland, Mussells, & Carter, (2017); and Dawson et al. (2018).

The model used for developing the shipping trends and tracks database has certain limitations that should be acknowledged considering it is based on modelled ship tracks and not actual satellite-based locations. The modelled ship tracks were derived using a least cost path approach that considers a variety of different geophysical properties such as bathymetry, distance to land, and sea ice cover (see Pizzolato et al., 2016). The model algorithm used was validated and was found to perform reasonably well but can sometimes overestimate kilometers traveled or can estimate ships tracks to be further from shore than in reality. Automatic Identification System (AIS) data which is based on satellite information is more geographically precise but this data does not capture ships prior to 2012 nor does it capture

small vessels. Therefore, the modelled data was chosen in order to understand historic trends since 1990. Note that AIS data was used to achieve Objectives 2 & 3 of this study considering the importance of spatial precision in understanding potential ship-source noise.

### 3.3 Temporal Trends (1990-2018)

The total annual kilometres travelled by all vessel types in Tallurutiup Imanga in the past 29 years has more than doubled. In 1990 the total kilometres travelled by vessels was 51,584 km and 142,111 km in 2018 (Figure 4). The year with the highest number of kilometres travelled within this record was in 2017. Since 1990, the average vessel traffic has increased with some variation from year to year, including a drop between the years 1999 and 2004 (Figure 4).

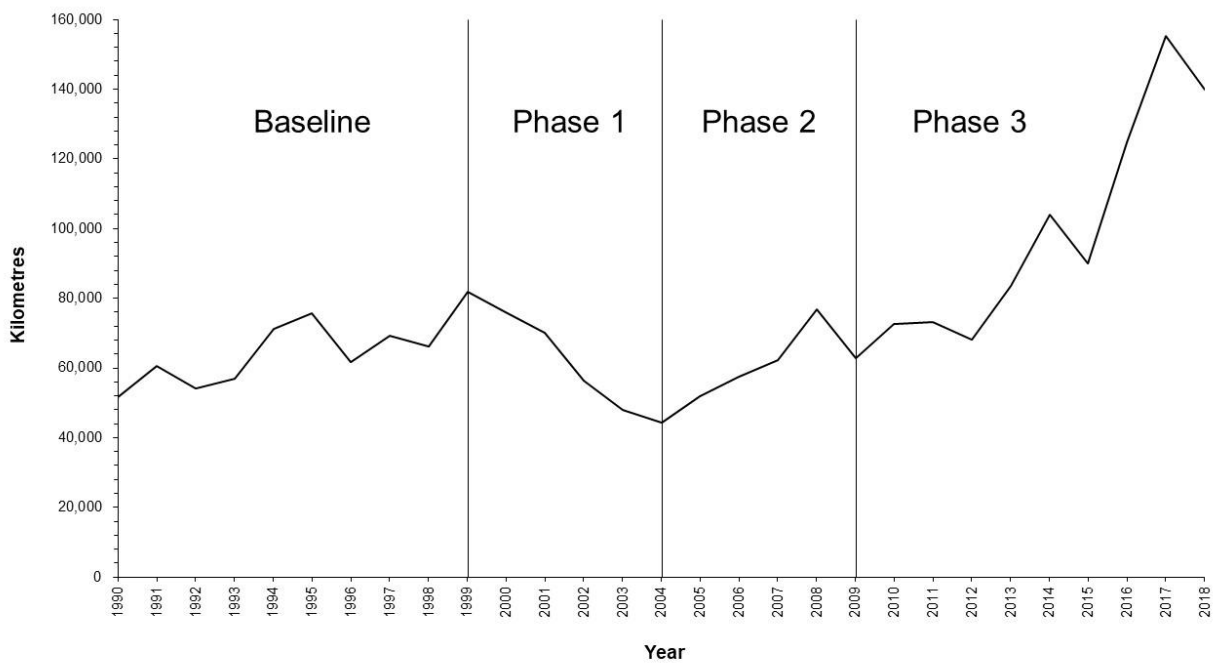


Figure 4. Total annual kilometres travelled by all vessel types in Tallurutiup Imanga from 1990-2018.

To better understand the temporal changes in ship traffic, the study period (1990-2018) was divided into four separate stages: i) baseline (1990-1999), representing a relatively stable period with limited growth; ii) phase 1 (2000-2004), a period of minor decline; iii) phase 2 (2005-2009), a period of rapid growth; and iv) phase 3 (2010-2018), a period of continued growth and development.

During the baseline period of 1990 to 1999 ship traffic remained relatively stable, fluctuating between 51,584 km and 81,969 km travelled yearly with an average of 64,916 km. During phase 1 the total annual distance travelled in Tallurutiup Imanga started to decrease with the lowest distance travelled in 2004 at 44,416 km and the phase 1 average at 59,009 km. The annual average travelled in phase 2 was 62,257 km, which was higher than phase 1 but lower than the baseline period. The distances travelled in phase 2 ranged from 51,999 km to 76,753 km per year. The final phase 3 had the highest annual averaged distance travelled with 101,793 km and ranging from 68,160 km and 157,820 km.

Figure 5 separates the total number of kilometres travelled by vessel type for the whole study period. Government vessels and icebreakers travel the greatest distances, almost every year. General cargo was relatively stable for the baseline and phase 1, but started to decline partway through phase 1 and incline again at a low rate in phases 2 and 3. Bulk carriers had some of the highest annual averages in between the years 1990 and 2002 (for example 20,849 km in 1992 and 18,693 km in 1999) but saw a big drop from the year 2003 to 2014 and have again increased in 2015, 2016, 2017 and 2018 (with a maximum of 51,184 km in 2018). This was a notable change in the trends because between 2003 and 2014 bulk carriers were one of the classes with the lowest kilometres travelled and jumped to being one of the vessel classes with the highest kilometres travelled in 2016, 2017 and 2018. Passenger ships have been on a steady increase since 1990, with the biggest increases occurring from 2017 to 2018 of 393,412 km. They were also one of the highest vessel types in the latest half of phase 3. Tanker ships and pleasure crafts had relatively low annual averages of kilometres travelled from 1990 to the middle of phase 2 and have increased substantially in phase 3. Tugs and barges had relatively low averages, never going any higher than 8,758 km per year, while fishing vessels and oil/gas exploration had minimal data with only 8 and 3 years collected, respectively, which each had low values of kilometres travelled.

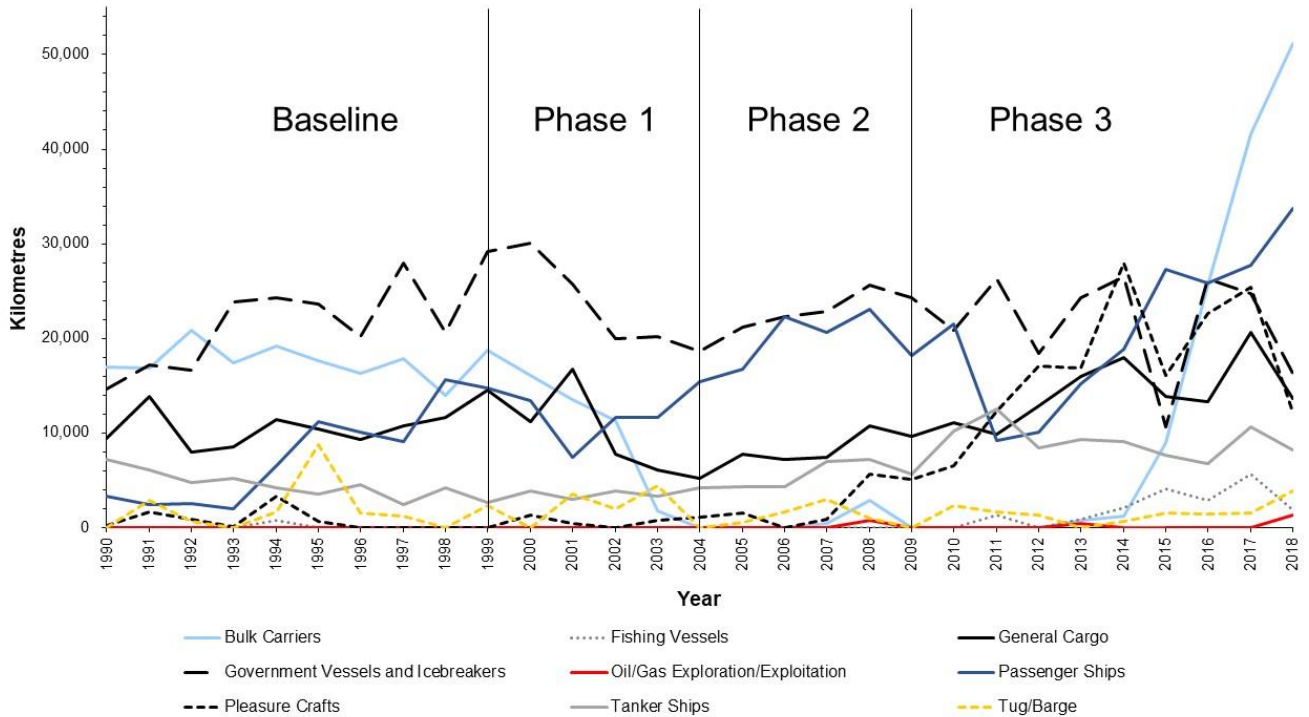


Figure 5. Total Annual Kilometres Travelled in Tallurutiup Imanga, by Vessel Type, from 1990-2018.

### 3.4 Spatial Trends (1990-2018)

Figure 6 provides the spatial distribution of kilometres travelled by all vessel types in Tallurutiup Imanga during the baseline period, and the change in activity from the baseline to phases 1, 2 and 3. In the baseline period of 1990 to 1999 the vessel traffic was concentrated in the middle of Parry Passage, with other high traffic routes going to Resolute and to Admiralty Inlet. In phase 1, from 2000 to 2004, total vessel traffic decreased in the western region near Resolute and increased on the eastern side of Bylot Island, up north to Coburg Island, as well as in Admiralty Inlet. There was intensification in vessel traffic in phase 2 (2005 - 2009). Vessel traffic increases were experienced in western Parry Passage and again in Admiralty Inlet and going north to Coburg Island. There was also an increase in traffic on the eastern side of Bylot Island and in Eclipse Sound, and to the small inlets on Devon Island. Phase 3 (2010-2018) experienced the most significant intensification of traffic. The vessel traffic increased the most in Eclipse Sound, due to the Mary River Mine which is located on Baffin Island, starting operations in 2014 (Baffinland Iron Mines Corporation, 2019). Increases were also present in Parry Passage, in small inlets on Devon Island, and northward to Coburg Island.

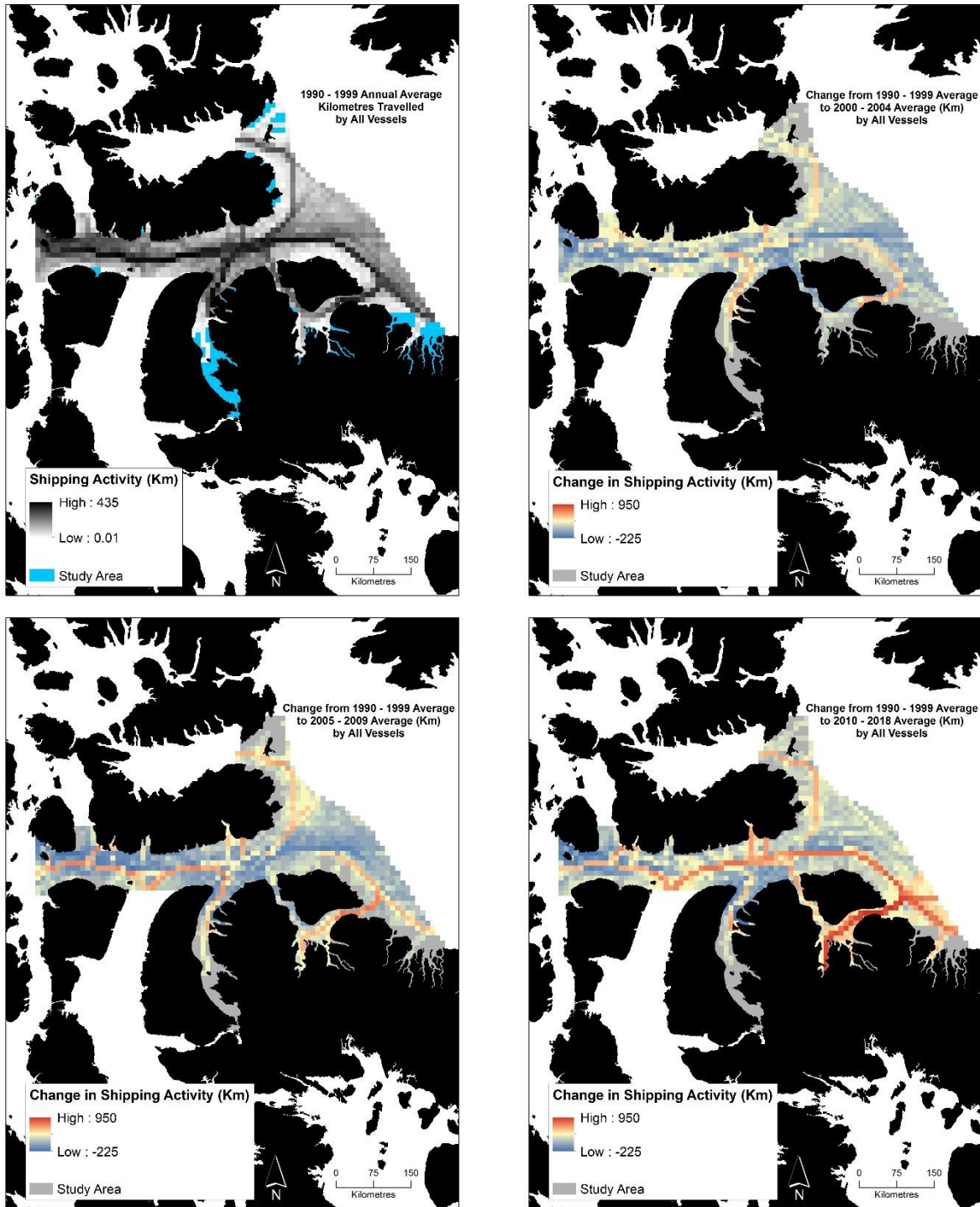


Figure 6. Annual average kilometres travelled by all vessel types (Baseline: 1990-1999) (top left); Change in annual average kilometres travelled between Baseline and Phase 1 (2000-2004) (top right); Change in annual average kilometres travelled between Baseline and Phase 2 (2005-2009) (bottom left); Change in annual average kilometres travelled between Baseline and Phase 3 (2010-2018) (bottom right).

### **3.5 Spatial Trends by Vessel Type**

#### **Bulk carriers**

Bulk carriers are vessels that carry either oil or loose or dry cargo (but not simultaneously) like timber and ore. As seen in Figure 7, during the baseline period, bulk carriers were spread across the whole region of Tallurutiup Imanga, with higher shipping activity to and from Little Cornwallis Island (near Resolute) and Nanisivik (Near Arctic Bay) likely because of the Polaris zinc mine and Nanisivik mines, respectively. During phases 1 and 2 bulk carriers decreased in concentration and spatial extent, likely due to the closures of the Polaris and Nanisivik mines (Bowes, Richards, & McGee, 2009). In phase 3 bulk carriers were still limited in their spatial extent compared to the baseline; however, they were more concentrated on the southeastern side of Bylot Island towards Pond Inlet and Milne Inlet where there is access to the Mary River Mine on Baffin Island (which started operations in 2014); most of the vessels in this area are mine operation-related vessels (Baffinland Iron Mines Corporation, 2019).

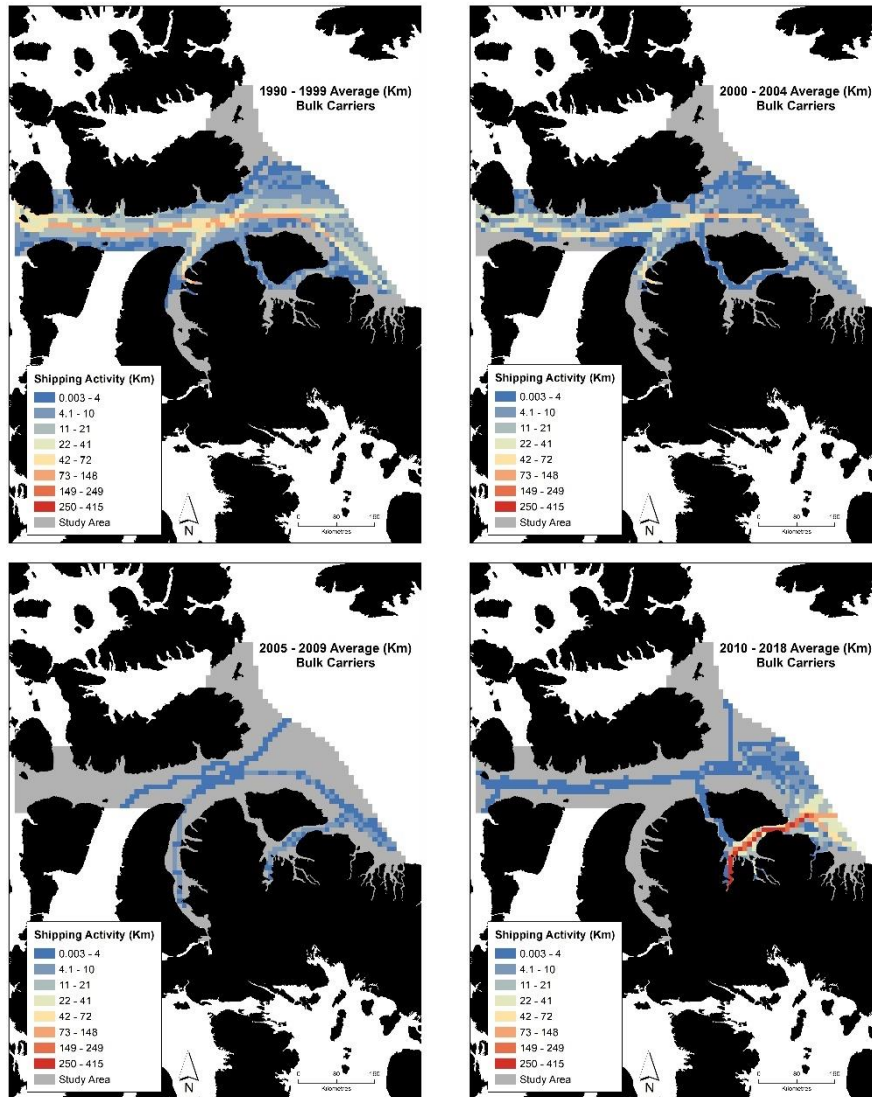


Figure 7. Annual average kilometres travelled by bulk carriers; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### Fishing vessels

Fishing vessels are boats that are used for commercial fishing activities and are generally small vessels from 30 to 100 metres in length; these boats include trawlers, whaling boats and fish-processing boats. Fishing vessels were one of the vessel types with the lowest shipping activity, as seen in Figure 8. Since fishing vessels were only recorded in the years 1994, 2011, and 2013 to 2018, only the baseline period and phase 3 period could be analyzed. In the baseline there was only one fishing vessel that travelled along the central route in Tallurutiup Imanga. In phase 3, there was more distribution of fishing vessels, with some going up to Jones Sound, Resolute and down to Arctic Bay. Most of the ships recorded in

Phase 3 were vessels from Baffin Fisheries and the Arctic Fishery Alliance LP, which fish for Greenland halibut (turbot) and shrimp (Arctic Fishery Alliance, 2018; Baffin Fisheries, 2020; Government of Nunavut, 2016). A possibility for the increases in Phase 3 could be the addition of a second vessel from the Arctic Fishery Alliance in 2013 and an increase to their quota of turbot in the same year (Arctic Fishery Alliance, 2018).

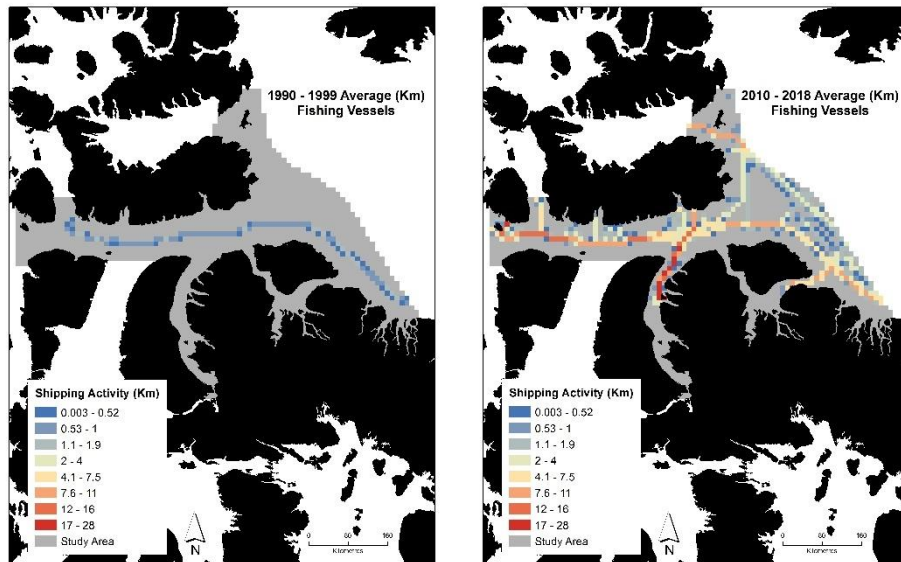


Figure 8. Annual average kilometres travelled by fishing vessels; Baseline Period (left), Phase 3 (right).

### General cargo

General cargo refers to vessels that carry numerous types of cargo such as community re-supply and roll on/off cargo. As seen in Figure 9 general cargo in the baseline was spatially distributed more than any of the other phases; however, in the most recent phase 3 there was a substantial increase in shipping activity along the northern and eastern edges of Bylot Island all the way to Pond Inlet. General cargo trends were consistently present in all of the time periods because most of the cargo traffic refers to community re-supply which happens yearly. The increases of ship traffic in Phase 3 were likely due to two main rises in demand: mining activities requiring machinery and equipment, as well as rapid population growth in Nunavut requiring materials for increased infrastructure, utilities and public services (Pelletier & Guy, 2015).

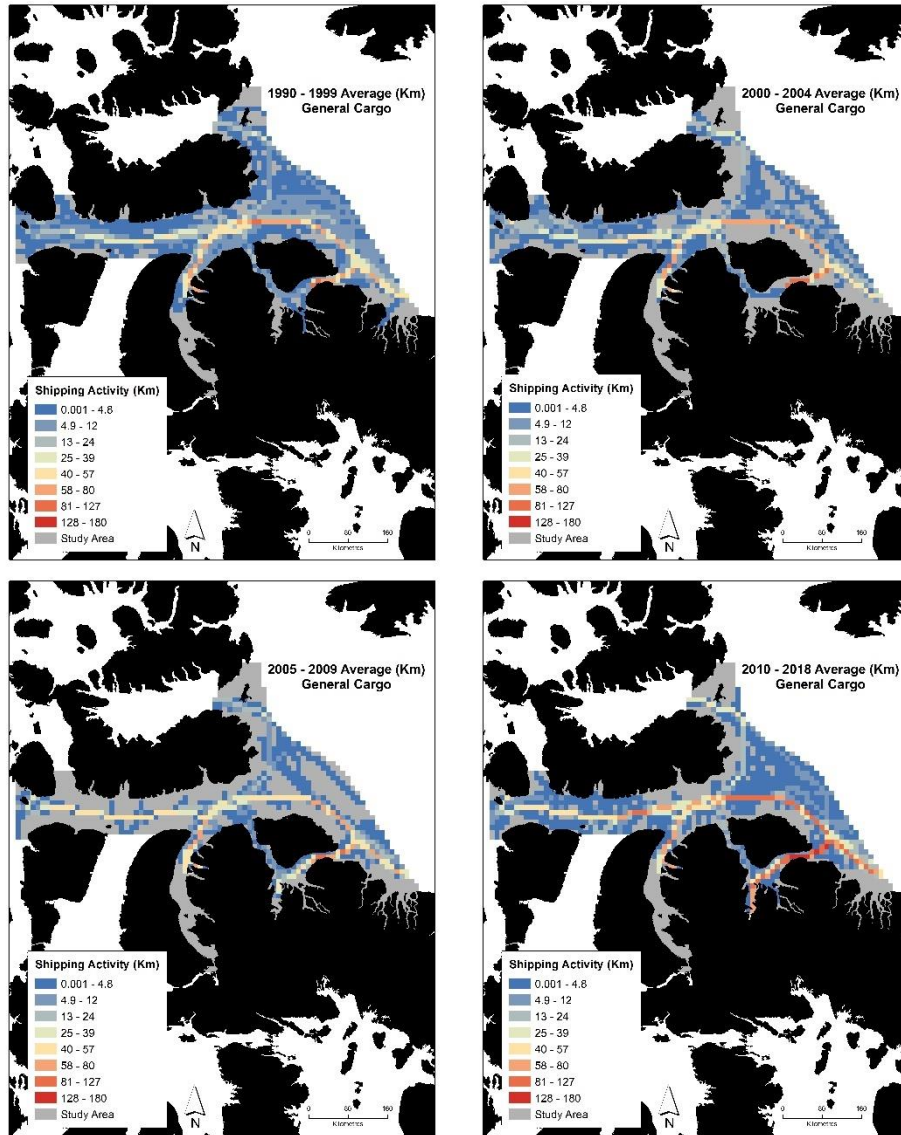


Figure 9. Annual average kilometres travelled by general cargo; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### Government vessels and icebreakers

Government vessels and icebreakers include all Canadian Coast Guard vessels, research vessels and private, research and government icebreakers. Government vessels and icebreaker trends in Tallurutiup Imanga are shown in Figure 10 and have consistently high shipping activity throughout the baseline and the three phases. They have the highest shipping activity in this region. All four periods show high concentration of vessel traffic throughout the central region as well as the locations near the communities. Canadian Coast Guard vessels are present in the Canadian Arctic for various reasons: to

provide support in icebreaking; to provide ice routing advice and information; to support Arctic sovereignty; to re-supply Northern communities when commercial services are not available; and, to work with the Department of National Defence to respond to marine Search and Rescue cases (Canadian Coast Guard, 2017). The Canadian Coast Guard fleet also includes the Amundsen which is a research icebreaker that began scientific missions in 2003 and since has hosted a variety of organizations including ArcticNet and multiple universities to perform research in the Arctic (Amundsen Science, 2020).

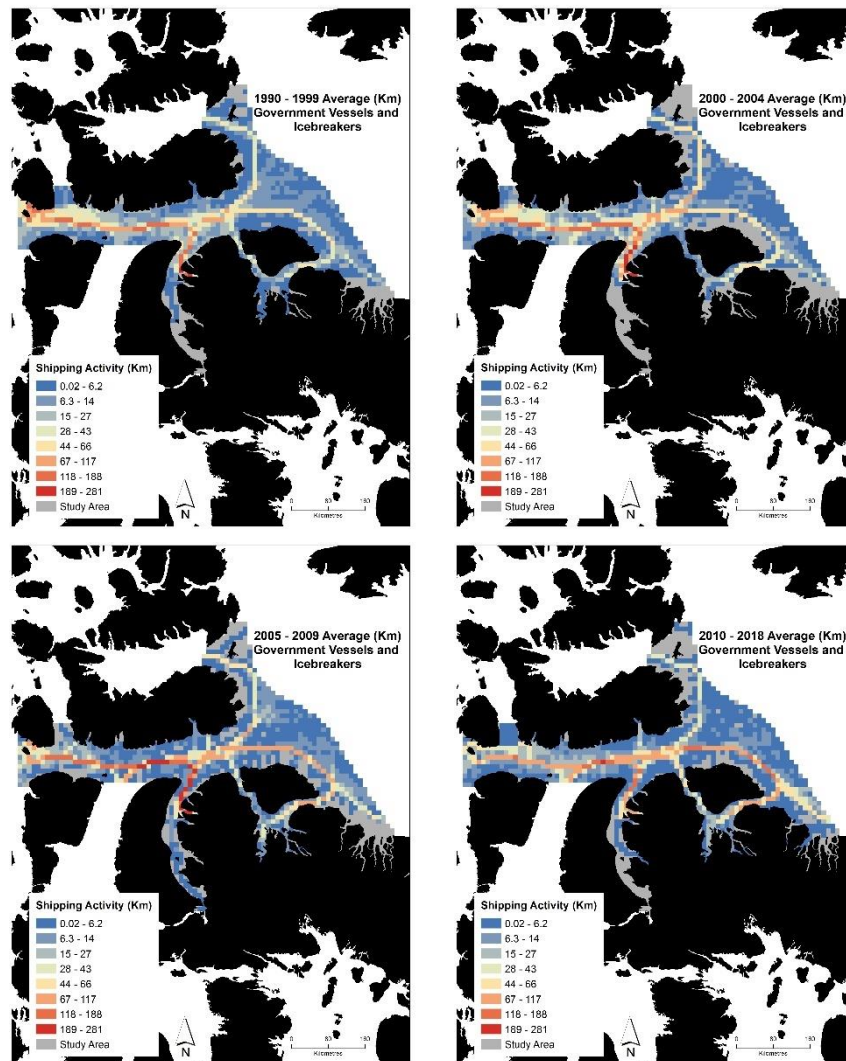


Figure 10. Annual average kilometres travelled by government vessels and icebreaker; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

## Oil/gas exploration vessels

Oil and gas exploration and exploitation vessels include vessels for seismic, oceanic and hydrographic surveys, oil drilling and storage, offshore re-supply and portable oil platform vessels. Oil and gas vessels have the lowest shipping activity in Tallurutiup Imanga, as seen in Figure 11. In phase 2, there was only one ship that travelled in the year 2008, the Hudson CSS which travelled to the south-east of Devon Island. While in phase 3 there was also only one ship present, that travelled in the middle of Parry Channel and to the south of Bylot Island towards Eclipse Sound. This vessel was present there only in 2018 and is owned by a fuel supply company named Coastal Shipping Limited (Coastal Shipping Limited, 2018). Although these vessel types were limited in the study period, other vessel types like bulk carriers and tankers are also involved in oil and gas operations so the lack of oil/gas exploration vessels here does not represent the total oil and gas operations in the region.

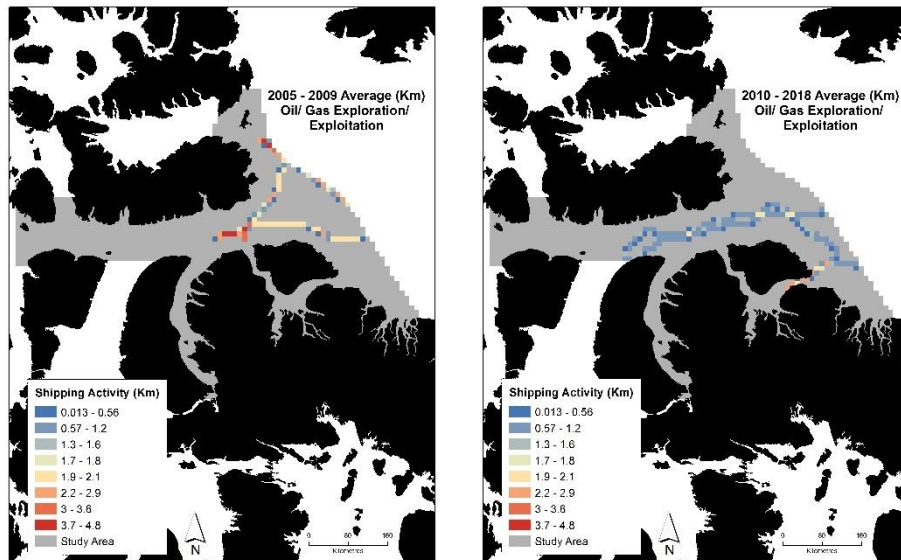


Figure 11. Annual average kilometres travelled by oil/gas exploration/exploitation vessels; Phase 2 (left), Phase 3 (right).

## **Passenger ships**

Passenger ships are vessels that carry passengers for remuneration and include vessels like cruise ships. Passenger ships have seen a steady increase all throughout Tallurutiup Imanga, as shown in Figure 12. They are one of the vessel types with the highest shipping activity in this region. Shipping activity was high in Parry Channel as well as near tourist attractions such as the northern community of Pond Inlet and Beechy Island on Devon Island, where graves of members of the ill-fated John Franklin expedition remain. There was also some notable activity going to the small inlets on Devon Island where there are higher chances of seeing wildlife, and by Coburg Island near the Nirjutiqavvik National Wildlife Area. Passenger ships tend to be smaller vessels that hold from 90 to 200 passengers and similar numbers of crew; however, some larger ships like the *Crystal Serenity* (2016, 2017) can hold around 1000 passengers. The trends for passenger ships were higher in more recent years likely because of reduction in sea ice extent that have opened up previously inaccessible regions (Dawson et al., 2014; Dawson, Stewart, Johnston, & Lemieux, 2016).

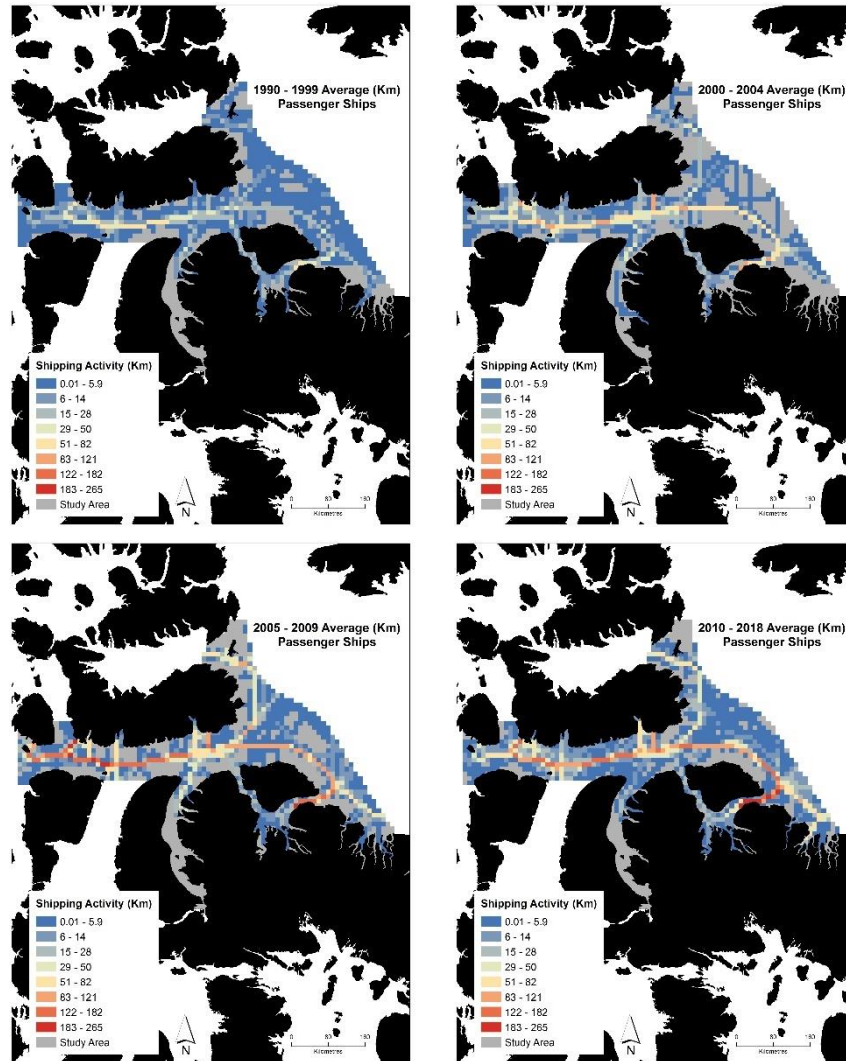


Figure 12. Annual average kilometres travelled by passenger ships; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### Pleasure crafts

Pleasure crafts are vessels that are non-commercial such as motor yachts, sailboats and rowboats. As seen in Figure 13 from the baseline to phase 2, pleasure crafts had low shipping activity and were only concentrated in the central channel and towards the communities. In phase 3, the shipping activity increased significantly in kilometres travelled and in spatial distribution, with the annual average in phase 3 increasing to 18,086 km from 2,867 km in phase 2. Areas of high activity include Beechy Island, Pond Inlet and some inlets on the southern side of Devon Island. Recent increased trends are most likely due to attraction of travelling through the Northwest Passage, greater accessibility due to less sea ice

extend, and wanting to see the pristine Arctic landscape before it is altered by climate change (Dawson, Copland, Johnston, et al., 2017; Dawson et al., 2018; Johnston et al., 2017).

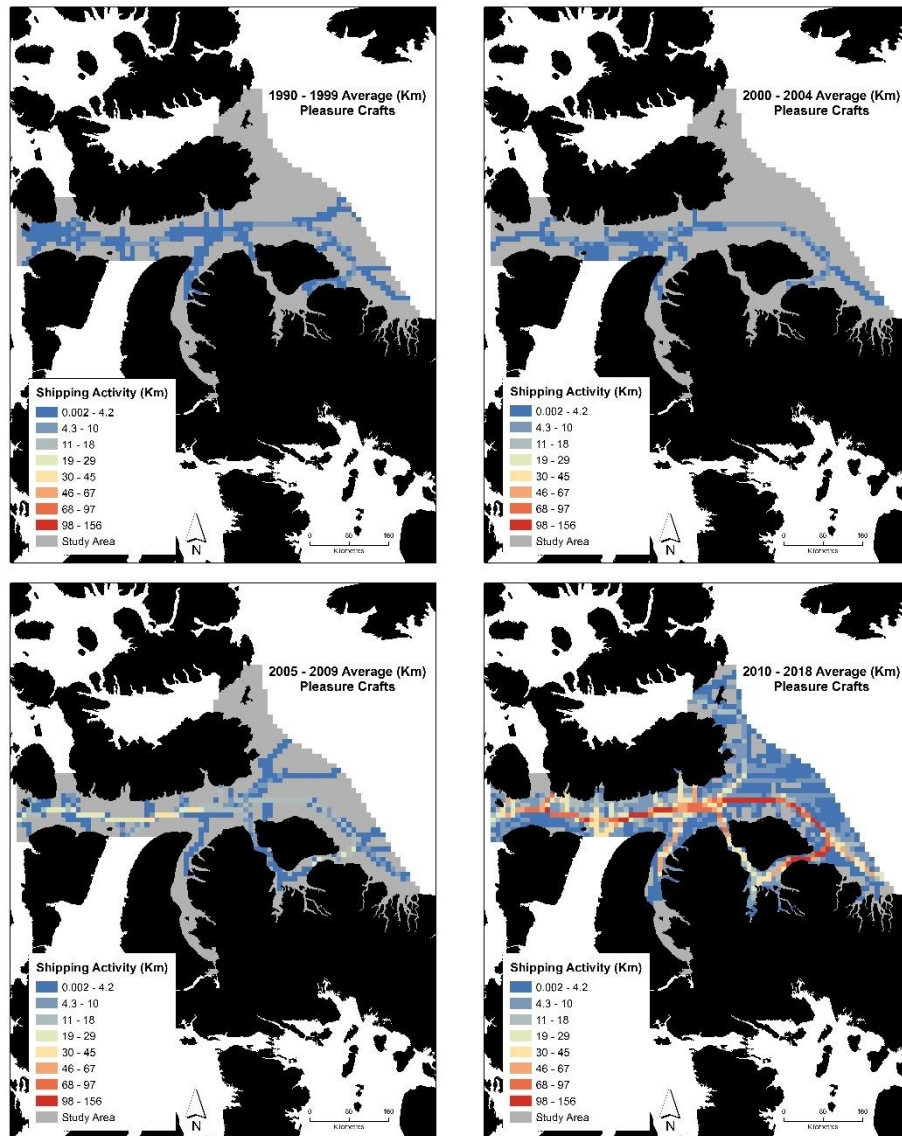


Figure 13. Annual average kilometres travelled by pleasure crafts; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### Tanker Ships

Tanker ships carry bulk liquids or compressed gases. Tanker ships were widely spread throughout Tallurutiup Imanga during the baseline period (Figure 14), likely due to the active years of Polaris and Nanisivik mines on Little Cornwallis Island and Baffin Island, respectively. Spatial distribution slightly decreased in phases 1, 2, by decreasing in the Parry Channel, likely due to the closures of Polaris and

Nanisivik mines in 2002. Shipping traffic started to increase in phase 2 and 3, being concentrated around Bylot Island, down to Arctic Bay which is likely due to the early stages of the Mary River Mine and then the beginning of operations in 2014. Higher trends were also present going to the communities because of the annual re-supply.

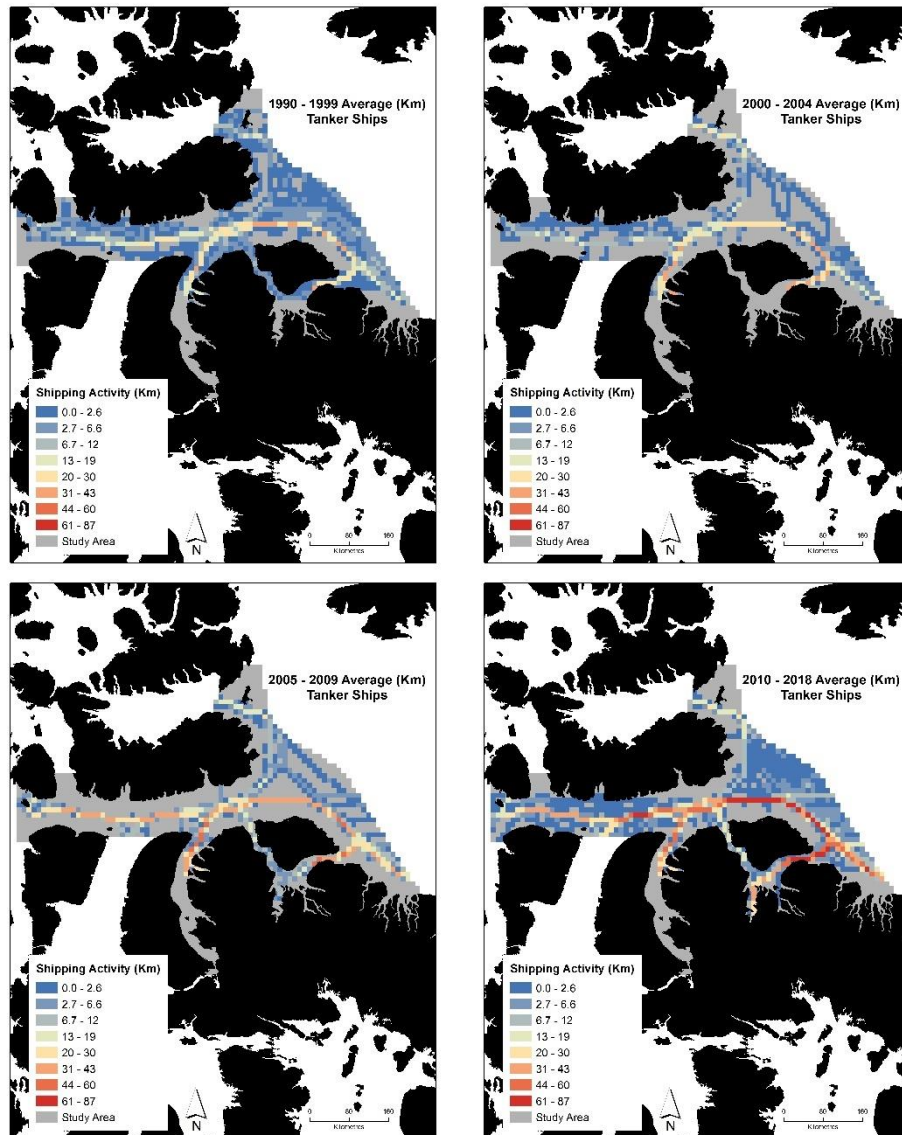


Figure 14. Annual average kilometres travelled by tanker ships; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### Tug/barge

Tugs and barges support cargo ships; tugs are designed for towing and pushing while barges are designed for carrying bulk or mixed cargo; this is why the trends are highest near communities. As

shown in Figure 15, tugs and barges were one of the vessel types with low shipping activity. They were the most spatially distributed in the baseline period and the most concentrated in kilometres travelled in phase 1 around Bylot Island. Spatial distribution and general shipping activity decreased in phases 2 and 3.

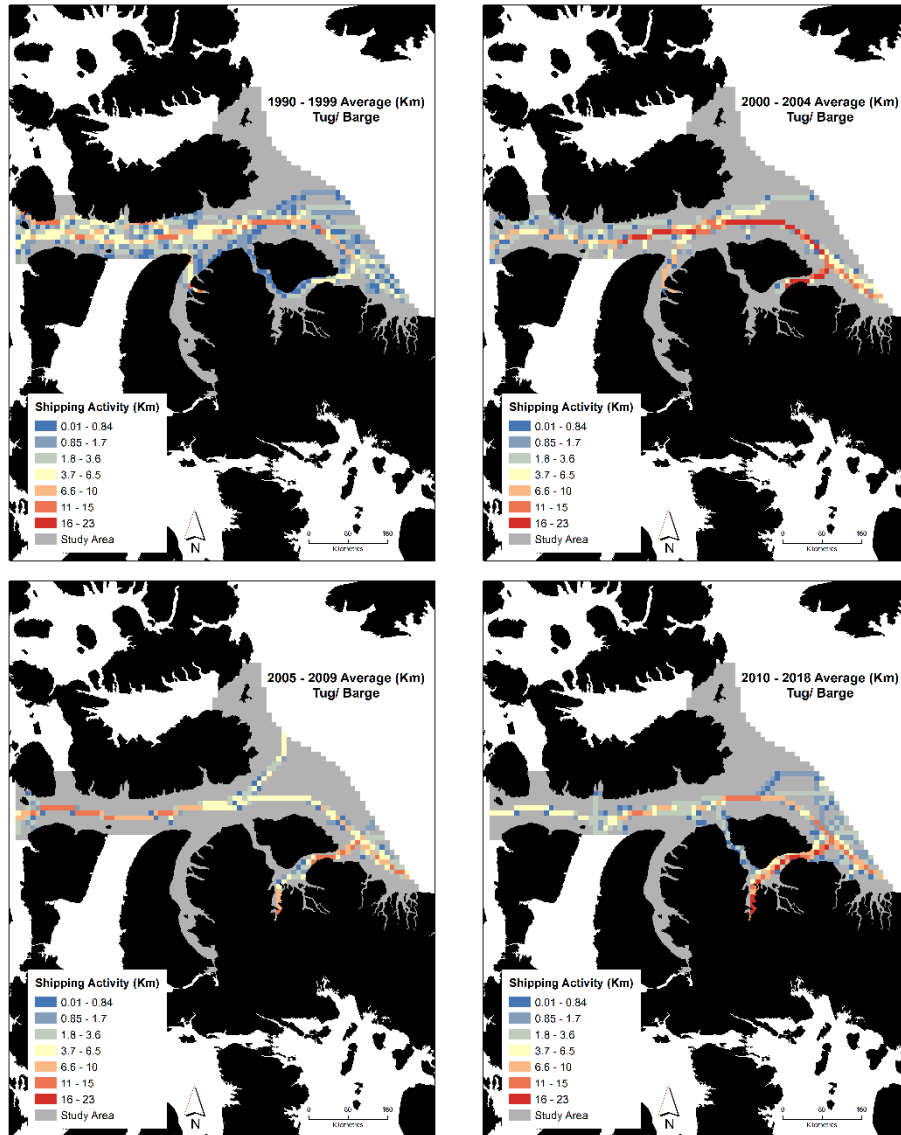


Figure 15. Annual average kilometres travelled by tugs/barges; Baseline Period (top left), Phase 1 (top right), Phase 2 (bottom left), Phase 3 (bottom right).

### 3.6 Vessel Traffic Near Communities Around Tallurutiup Imanga

Figure 16 shows the overall spatial change in vessel traffic from the baseline period (1990-1999) to phase 3 (2010-2018). It also displays the proportional changes in vessel traffic encountered within 50 kilometres of each community near Tallurutiup Imanga. The dots that are royal blue and light blue represent communities where the change in shipping activity decreased. Resolute and Arctic Bay respectively show decreases of ship traffic from the baseline to phase 3 which is likely due to the closure of the Polaris and Nanisivik mines in 2002. The yellow, orange and red dots represent the communities that experienced an increase in shipping activity (Grise Fiord, Clyde River and Pond Inlet respectively). Pond Inlet has experienced the greatest increase in shipping activity in Tallurutiup Imanga and in the whole Canadian Arctic, most likely attributed to increases: in tourism, where passenger vessels travelled four times as much kilometres in phase 3 than in the baseline period, and pleasure craft increased by sixty times as much kilometres travelled; bulk carriers and tanker traffic associated with mining in the Mary River Mine that started operation in 2014 (of which bulk carriers had thirteen times as many kilometres travelled in phase 3 than in the baseline period, and tankers had three times as many); and cargo increased almost twice as much in kilometres travelled from the baseline to phase 3.

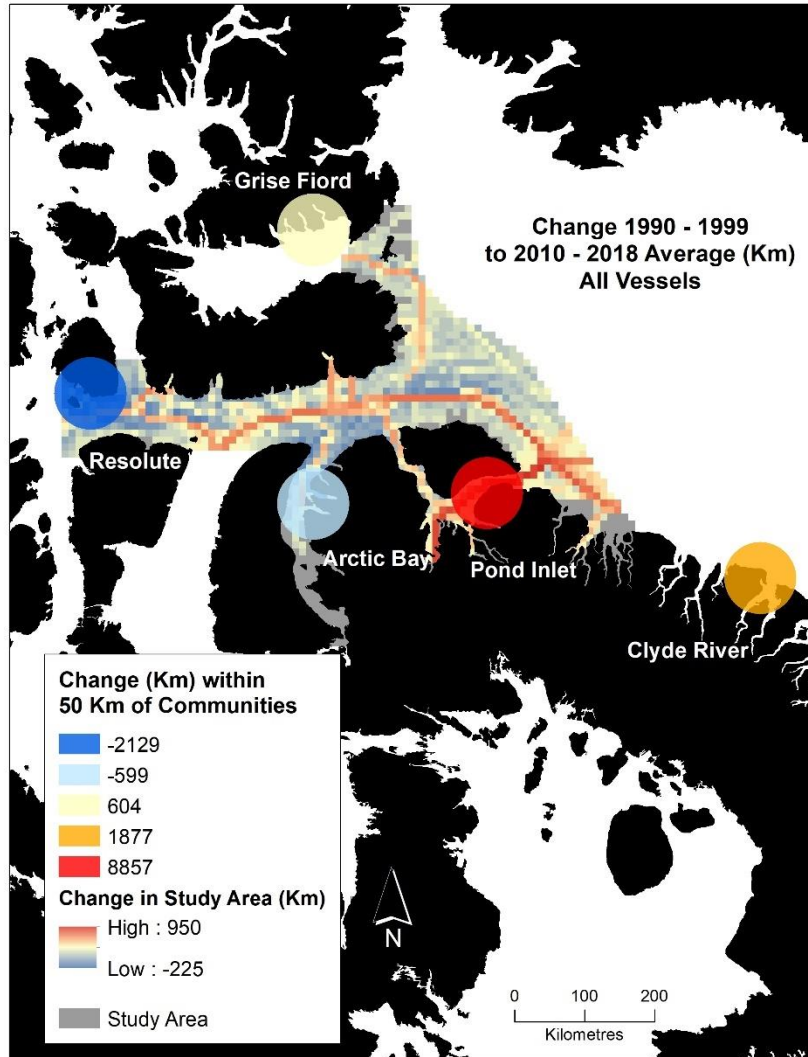


Figure 16. Change in Vessel Traffic (Km) within 50 Km of Communities, from 1990-1999 Average to 2010-2018 Average and Changes in Overall Vessel Traffic During the Same Period.

### **3.7 Conclusion**

This chapter summarized the temporal and spatial trends in ship traffic in Tallurutiup Imanga, Nunavut, Canada from 1990 to 2018. The chapter results were made available to Parks Canada and QIA as a technical report and were a deliverable that was part of a Nunavut General Monitoring Program (NGMP) funded project that supported my thesis research. Overall, the total annual kilometres travelled by ships in the region has increased 90,528 km over the 29-year time period. The types of vessels that have consistently made up the greatest portion of traffic in the region were government vessels and icebreakers, passenger ships and general cargo. Over the last 10 years of the study period, pleasure craft vessels have increased at the greatest rate in terms of total proportions of overall vessel traffic in the region. Bulk carriers experienced decreases in total kilometres travelled around 2003 but have since increased over the last 4 years (2015-2018). Other vessel types, such as oil and gas exploration vessels as well as fishing vessels and tugs and barges have remained relatively low throughout the time period and into recent years.

The spatial distribution of the vessel traffic in Tallurutiup Imanga has been relatively consistent. Most vessels stay in the middle of Parry Passage. Vessel types like passenger ships, pleasure crafts, tankers and general cargo are concentrated around communities. Pleasure crafts and passenger ships also tend to visit inlets on the southern coast of Devon Island.

# Chapter 4: Modelling ship-source noise exposure for marine mammals in the Tallurutiup Imanga National Marine Conservation Area

Abstract:

Tallurutiup Imanga (Lancaster Sound) is a National Marine Conservation Area (NMCA) in Nunavut, Canada, that was established in the summer of 2019. It spans approximately 110,000 square kilometers and is located at the eastern entrance of the Northwest Passage. The area is rich in ecological and cultural significance and provides core use areas for marine mammals such as narwhals and belugas. The region has experienced an increase in vessel traffic in the most recent three decades and shifts in the types of vessel that transit its waters. The aim of this study was to examine the potential impacts of underwater noise from ships on marine mammals in Tallurutiup Imanga. Among many impacts to the wildlife in the region, underwater noise from ships is known to disturb various marine mammals and vessel-source noise especially poses a risk to marine mammals. The results of this study indicate that in the years 2015 to 2018, ships transited through the areas of use of three important species of marine mammals (belugas, bowheads and narwhals). The noise footprints of these vessels revealed that some parts of the estimated beluga and narwhal core use areas (50 Percent Volume Contours) and of the observed wildlife areas (based on Inuit and local knowledge) exceeded the 120 dB behavioural threshold for marine mammals multiple times throughout the shipping season, mostly in Eclipse Sound and Milne Inlet, near the Mary River Mine on Baffin Island. Belugas core use areas in the waters northeast of Devon Island were also overlapped by ships that surpassed the threshold, but by fewer ships than in the narwhal core use areas. With the operationalization of the NMCA beginning soon, an interim management plan is currently being prepared by the Governments of Nunavut, Canada and the Qikiqtani Inuit Association (QIA) and the results of this study could be used to inform decision and policy makers about the potential impacts of vessels in Tallurutiup Imanga.

Keywords: *Canadian Arctic; vessel traffic; underwater noise; marine mammal*

## 4.1 Introduction

Marine shipping activities in the Canadian Arctic have been increasing due to global climate change and the consequential reductions in sea ice extent and thickness (Pizzolato et al., 2014; Smith & Stephenson, 2013; Stephenson et al., 2013). There is already significant interest in the commercial viability of the Northwest Passage (NWP) as evidenced by the recent and historic sailings of cargo vessels such as the Nordic Orion (traversed NWP in 2011), the Nunavik (2014) and also by the non-ice strengthened cruise ship the Crystal Serenity (2016, 2017). The NWP is also attracting a large number of private yachts and research vessels such as the Chinese icebreaker Snow Dragon (2017).

Tallurutiup Imanga (TI) is a marine area in Nunavut that became a National Marine Conservation Area (NMCA) in August 2019 (Parks Canada, 2019b). It is located at the eastern entrance of the Northwest Passage, exactly where ship traffic has been increasing at higher than average rates over the past decade and where future increases are expected (Dawson, Copland, Johnston, et al., 2017; Dawson et al., 2018; Parks Canada, 2019c). The area contains two large polynyas (the Lancaster Sound Polynya and the Bylot Island Polynya), which are recurring areas of open water in the Arctic, which means that many parts of TI have areas of open water in periods where other areas are completely frozen solid (Barber & Massom, 2007; Melthofte, 2013). The areas open up around December and February and close in October, so they are not open throughout the whole winter; however, because they stay ice free longer than other areas, they are regions of high productivity which attract various species of seabirds and marine mammals (Barber & Massom, 2007; Melthofte, 2013; Parks Canada, 2019a). Furthermore, it is because of this area's rich ecological and cultural significance that the protection of Lancaster Sound has been in progress for decades (Parks Canada, 2017).

With the official boundaries set in August of 2017, the future protection and management of the new NMCA will be crucial to protecting its integrity, especially as commercial shipping continues to increase in this area. Local communities in the Canadian Arctic have expressed their concerns over multiple risks associated with shipping, and have identified the impacts of shipping on marine mammals to be one of the biggest concerns (Dawson et al., 2020; ITK, 2017). They are concerned about the health of the animals they are eating when, for example waste is being dumped into oceans by ships (ITK, 2017). They have also identified ship noise disturbances as a big concern because of the scarcity of some marine mammals when they are scared off by ships (Dawson et al., 2020; ITK, 2017). By having such a close relationship to their land and waters, Inuit have noticed increases in shipping activity in the Arctic (ITK, 2017). The livelihood of hunters is threatened when the animals that they hunt are being scared away

by ships. More importantly, the food security of these communities is threatened with the restricted access to country food that communities hunt for, which carries implications for nutrition and well-being as well (Carter, Dawson, Parker, Cary, et al., 2018c; Donaldson et al., 2010; Ford, 2012; Meredith et al., 2019). Historic accumulations of multi-year sea ice in the Arctic Ocean that used to prevent high numbers of vessels transiting through the Arctic are now rapidly melting, and with the increased vessel traffic it is predicted that there will be rises in underwater noise pollution in the future that could pose a threat to marine mammals (PAME, 2019).

With the increases of shipping traffic in the Arctic in recent years and the predictions of continued increases in the future, it is especially important to understand the effects of ship noise on the marine mammals in the region (McWhinnie et al., 2018; Southall et al., 2007). The topic of the impacts of vessel noise on marine mammals in the Arctic is still in development, with only a few published studies that have mainly focused on the western Canadian Arctic (PAME, 2019). Although Finley, Miller, Davis, & Greene (1990) did find that narwhals and belugas had distant reactions to icebreakers in the TI NMCA, there have not been any recent studies completed on ship-source noise and its potential impact on marine mammals in the TI area. This is alarming, considering that TI is nationally recognized as a vital habitat for marine mammals, including bowhead whales, narwhals and belugas (Parks Canada, 2017). Thus, there is an urgent need to better understand the potential impacts of increased vessel noise on these marine mammals in TI, which is what this study explores.

The overall aim of this study was to model the potential impact of ship-source underwater noise on marine mammals in Tallurutiup Imanga from 2015 to 2018. To achieve this, the three main objectives were to:

1. Examine the spatial and temporal trends in vessel traffic and underwater noise from marine traffic in the region using AIS satellite data (addressing overall research objective 2);
2. Identify the overlap between important areas for marine mammals and vessel traffic in the region (addressing overall research objective 3);
3. Analyse potential impacts of vessel traffic on marine mammals and propose management options to influence policy makers and encourage mitigation strategies (addressing overall research objective 3).

## 4.2 Data and methodology

### Study Area

Tallurutiup Imanga is located in the eastern Canadian Arctic, within the territory of Nunavut, and spans an area of around 110,000 km<sup>2</sup> between Devon Island and Baffin Island. It is roughly 714 km long with areas extending into Baffin Bay, Admiralty Inlet and several adjacent inlets (see Figure 17).

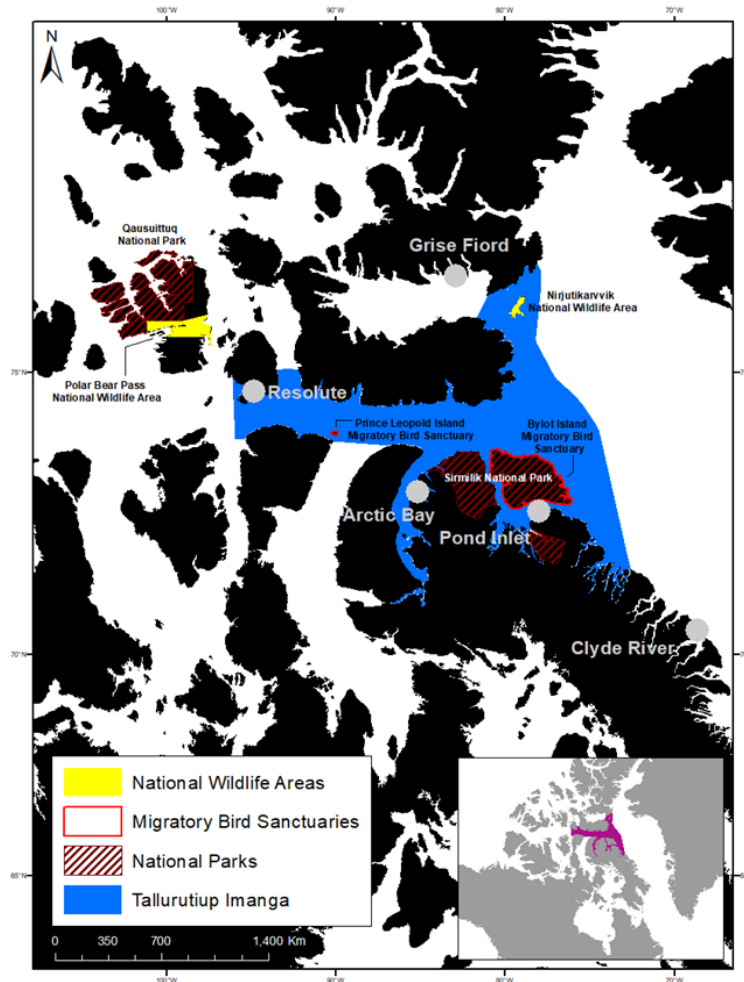


Figure 17. Map of Tallurutiup Imanga in Nunavut, Canada, surrounding communities and protected areas.

On August 1, 2019 the Governments of Canada and Nunavut, and the Qikiqtani Inuit Association (QIA) signed an Inuit Impact Benefit Agreement (IIBA) to officially established TI as a National Marine Conservation Area (Parks Canada, 2019b). TI was first proposed as a NMCA because of its ecological and

cultural significance due to its unique characteristic of containing polynyas (Parks Canada, 2017). TI also provides food, shelter, material and tools for Inuit who call the NMCA home and rely on its cultural importance (Parks Canada, 2017). Furthermore, the NMCA contributes to the government of Canada’s marine conservation target to protect 10% of marine and coastal areas by the year 2020 (DFO, 2019b). New Marine Protected Areas will also be established under the Oceans Act to help contribute to the protection of Canada’s waters and shores (DFO, 2019a).

There are five communities in and around Tallurutiup Imanga: Arctic Bay, Clyde River, Grise Fiord, Pond Inlet and Resolute, as well as various protected areas in and around Tallurutiup Imanga: two National Parks, two Migratory Bird Sanctuaries and two National Wildlife Areas (Figure 17). There is also an iron ore mine located on Baffinland Island, the Mary River Mine. It contains one of the world’s richest iron ore deposits and began to be explored and developed in 1986 and began operations in 2014 (Baffinland Iron Mines Corporation, 2020).

## Research Steps

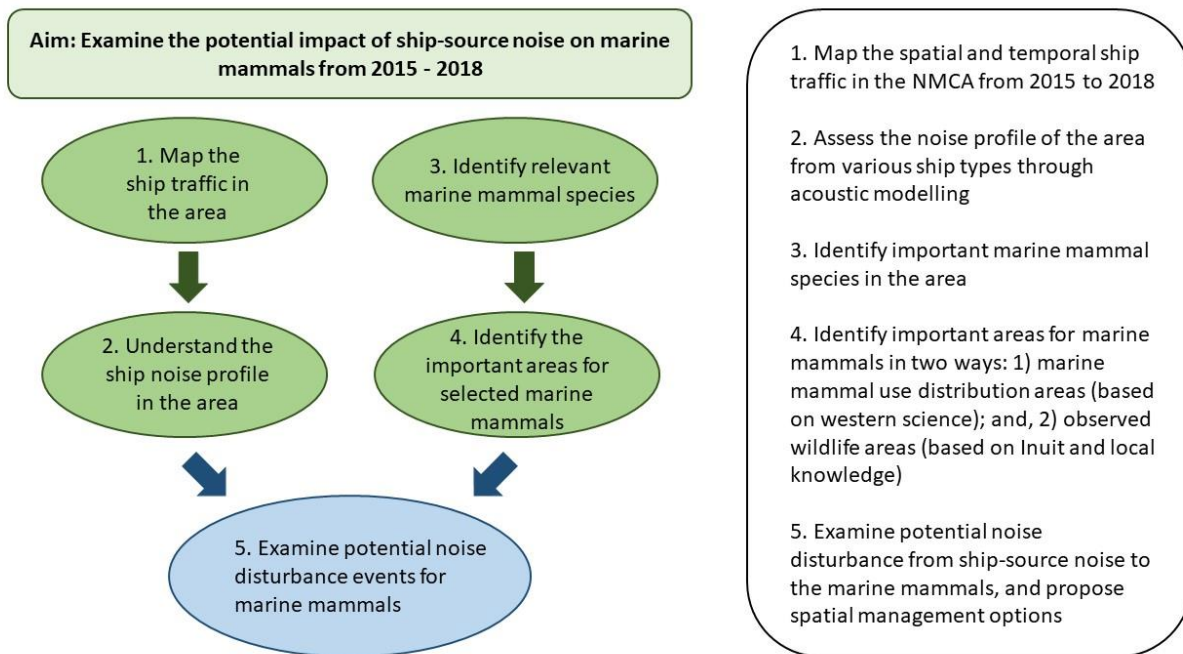


Figure 18. Diagram outlining the steps of the study.

By following the 5-step process in Figure 18, the three objectives of the study were fulfilled. The next section will discuss in detail which data sources were used to complete the steps.

## Traffic Analysis

### Automatic Identification System Data

One of the objectives of this study was to model the potential underwater noise exposure for marine mammals in the TI NMCA from 2015 to 2018. This was done through five main research steps that can be seen in Figure 16. The first step was to understand the shipping traffic in the area from 2015 to 2018 and this was done through the use of Satellite Automatic Identification System (AIS) data. AIS allows managers (i.e. Coast Guard, Transport Canada) and researchers to track vessel movements and is essential to maritime safety. In the beginning of its implementation, satellite AIS quality was less reliable and incomplete due to a poor coverage by satellites equipped to detect AIS signals, but has improved more in recent years as the constellation of satellites has improved (Felski & Jaskolski, 2013). Raw AIS data from exactEarth and provided by MEOPAR was processed using Python to build ship track lines with properly formatted time stamps. The original data contained multiple points per day, per ship. In 2015 exactEarth merged with the Harris Corporation to have better global AIS coverage through the use of more constellations; this is why the data used in this study is only from 2015 and on (exactEarth, 2015). The types of messages received from transponders included in the analysis were ITU 1 to 3 (Class A vessels), ITU 18 (Class B vessels), and ITU 19 (Class B vessels). In some cases, there were gaps in a vessel track line which were either due to a lack of satellite coverage, or they were produced from the Python code which had a maximum distance and time threshold between points of 300 minutes or 50 nautical miles. The track was fixed manually where gaps existed, by ensuring the MMSI number of the two lines surrounding the gap were the same and connecting the two lines in a straight line that followed the rest of the ship traffic in that region. The data was also reclassified from the original AIS ship types into 8 main categories, sorted roughly by similarity in type and size of vessels (Table 2). It is to be noted that cargo vessels in AIS data also include bulk carriers. The vessel traffic trends of the AIS data were analyzed in 100 km<sup>2</sup> cells. Finally, the data was limited to the shipping season, which in this study was defined as being between July 19 and October 10 (84 days in total), which is the first and last day that ships were recorded in each year between 2015 and 2018 (excluding some outliers for the end of the season).

Table 2. Raw AIS data from exactEarth and MEOPAR classified into 8 vessel categories.

AIS ship type name	Vessel category
Cargo	Cargo vessels
Passenger	Cruise ships
Fishing	Fishing vessels
Icebreaker, Research, SAR	Government and icebreakers
Military	Military vessels
Local, Pleasure Craft, Sailing	Recreational vessels
Tanker	Tankers
Tug, Tug/Port, Dredger	Tugs

Analyses of the processed AIS data were conducted using ArcMap 10.6.1 software (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute) to produce spatial and temporal trends of the shipping in the region.

## Acoustic Modeling of Ship Traffic

After the vessel traffic was analyzed and mapped in TI, the next research step was to define the noise profile in the area. This process was done through acoustic modelling, which takes into account various factors of noise and how noise moves from the source to the listener.

### Transmission Loss

To be able to model the noise emitted by a ship, the transmission loss was first taken into consideration. Transmission loss is when sound travelling away from a source loses energy (gets quieter) as it gets farther away. The transmission loss of underwater noise was calculated using the software dBSea 2.0 (Irwin Carr Consulting, Northern Ireland). Transmission loss depends on four main factors: the source level of the noise, the sound speed profile of the region, bottom sediment type and bathymetry.

Median vessel source levels in 1/3 octave bands were obtained from the Port of Vancouver’s listening station (ECHO Program) for the following ship categories: bulk carrier, cruise ship, government and icebreaker vessel, tanker, and tug (see Table 3). Average broadband source levels for military, recreational, and fishing vessels were obtained from Veirs, Veirs, & Wood (2016) (Table 3), but were not used for the detailed acoustic propagation modeling.

Table 3. Median vessel source level data details.

Source of data	Vessel category	N	Source level (dB re 1 $\mu$ Pa @ 1 m)
ECHO Program	Cargo vessels	1,728	188
ECHO Program	Cruise ships	81	180
ECHO Program	Tankers	292	187
ECHO Program	Tugs	582	181
ECHO Program	Government and icebreakers	12	192
Veirs, Veirs & Wood (2016)	Fishing	65	164
Veirs, Veirs & Wood (2016)	Military	113	161
Veirs, Veirs & Wood (2016)	Recreational	41	159

The average sound speed profile for the study region was calculated based on conductivity-temperature-depth (CTD) measurements taken by the research vessel CCGS Amundsen. The mean CTD and sound speed values at each metre of depth were calculated from the data from 22 different CTD casts aboard the Amundsen in 2014 (See Appendix A for map showing locations of casts).

For the bottom sediment type, one single sediment value was used for the entire region. Letaïef et al. took sediment samples across the Canadian Arctic Archipelago, aboard the Amundsen in 2014. The samples were collected at specific spatial points and further interpolated; the average sediment type of Tallurutiup Imanga was identified as silt (Letaïef, 2019; Letaïef, St-Onge, & Montero-Serrano, 2018).

Bathymetric data was obtained from the International Bathymetric Chart of the Arctic Ocean at a 500 metre spatial resolution (Jakobsson et al., 2012). These data were the most recent and most accurate data currently available for the Arctic.

Using the four inputs mentioned above, sound propagation was modelled using vessel positions along major routes in the region (identified using AIS data). Vessels positions were placed between 20 and 50 kilometres apart from each other while also ensuring that the bathymetric characteristics were included. The model calculates received levels every 500 m away from the source of noise along 8 radial slices (which equal to 45° separation) and 10 metre depth increments. The modeling accounted for frequency-dependent attenuation and propagation of sound by modelling each 1/3 octave band, and used two different models to calculate propagation: normal modes for low frequency noise sources (12.5 Hz to 1.2 kHz) and ray tracing for high frequencies (1.6 kHz to 32 kHz). Transmission loss values were produced

and then averaged across the radial slices for each source position, and then grouped together in different areas based on their average transmission losses (see Table 4). Locations of each transmission loss group can be seen in Figure 19.

*Table 4. Transmission loss values in decibels (log10) calculated in dBSea.*

<b>Location</b>	<b>Bulk Carrier</b>	<b>Cruise Ship</b>	<b>Government Vessel</b>	<b>Tug Boat</b>
Baffin Bay	19.1	17.2	17.9	17.4
Parry Passage	19	17.5	18.2	17.5
Eclipse Sound - East	18.8	17.3	18.2	17.3
Eclipse Sound – Milne Inlet	19.8	18	18.8	18
Eclipse Sound – North	18.8	18.5	19.4	18.1
Admiralty Inlet	19	17.4	18.2	17.3
Nanisivik	20	20	20	19.7
Arctic Bay	20	20	20	19.7
Resolute Bay	17.6	17.3	18.2	16.9
Maxwell Bay	17.8	17.5	18.4	17.1
Craker Bay	19.6	19.3	20	18.8
Grise Fjord	19.1	17.5	18.2	17.4
Barrow Strait	18	16.9	17.6	16.8
Devon Island Bays	19.6	19.3	20	18.8
Admiralty Inlet Bays	20	20	20	19.7

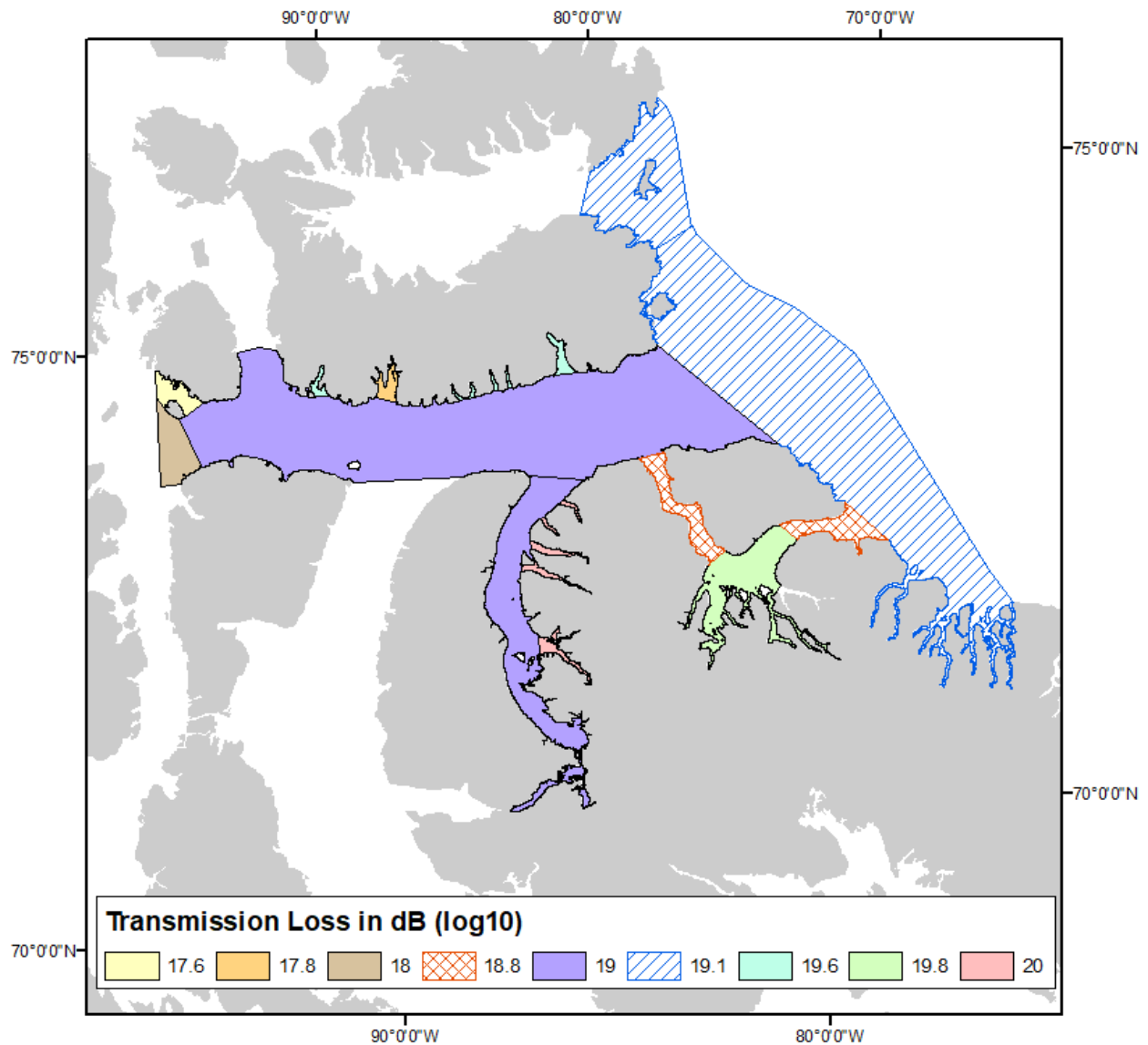


Figure 19. Locations of transmission loss values of bulk carriers in Tallurutiup Imanga, Nunavut, Canada. Refer to Table 4 for more details.

### Vessel noise footprint

Following the estimation of each zone’s transmission loss, vessel noise footprints were produced for each vessel track for each ship, within each month of each year from 2015 to 2018, during the designated shipping season using ArcMap 10.4 software. The monthly results were combined for every year; this method was chosen because the computation time for modelling more precisely (i.e. every

day) would take too long for the timeline of this research. A noise footprint is an estimation of the received level of a ship along the entire vessel track, and shows the propagation of noise perpendicular to the vessel track. First, a grid of distance values was calculated around each vessel track using 500 m cell size, and each cell was assigned a specific transmission loss value depending on the class of the vessel and the location of the cell (see Table 4). The received level in each cell was then calculated using the standard received level calculation:

$$RL = SL - TL * Distance \quad (1)$$

where RL is received level, SL is the broadband source level for a given vessel class, TL is the transmission loss calculated for different areas in the study region and Distance is the distance grid.

The received level grid was then converted into a binary raster variable, with a one assigned to any cell where received level was  $\geq 120$  dB re 1  $\mu$ Pa, and a zero assigned to all cells with received level  $< 120$  dB (Figure 20). 120 dB is the behavioural disturbance threshold for marine mammals as defined by the National Ocean and Atmospheric Administration (NOAA, 2016). Binary rasters were then summed for all vessels within a year to estimate the number of times that each 500 m cell exceeded the 120 dB noise threshold within each year; this was done cumulatively for all vessels, and also for all vessels within a single class.

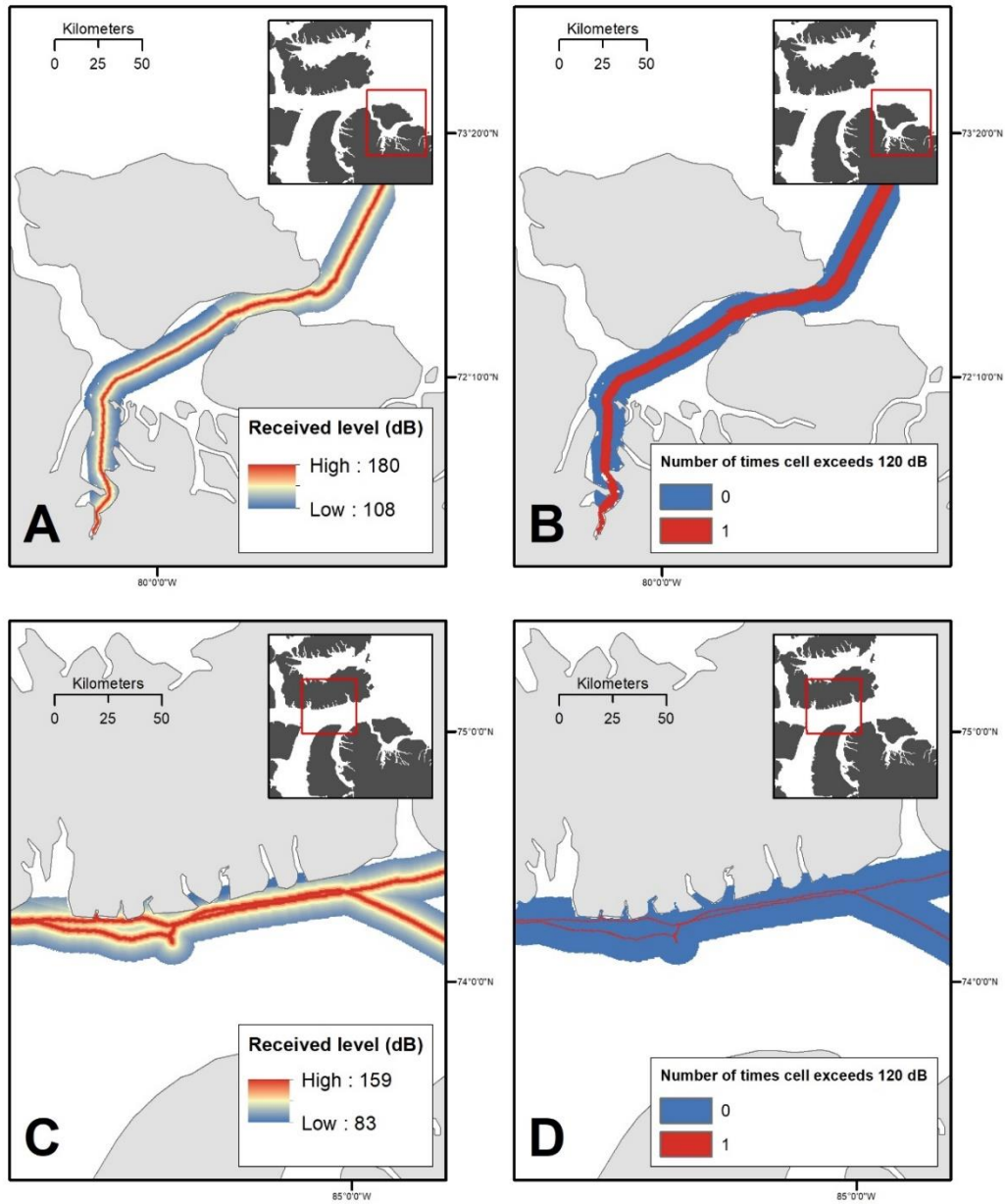


Figure 20. Example of converting the received level grid (A and C) into a binary raster variable (B and D), where A and B are one single, unique tanker ship track, and C and D are one single, unique recreational ship track.

## Identifying Important Marine Mammal Areas

### Marine mammal use distribution areas (based on western science)

The third step of the study was to identify the key marine mammals in the region. The three main marine mammal species were chosen based on the most common in Tallurutiup Imanga and the

availability of data: beluga whales (*Delphinapterus leucas*), narwhals (*Monodon monoceros*), and bowhead whales (*Balaena mysticetus*). Walrus (*Odobenus rosmarus*) and ringed seals (*Pusa hispida*) are also common in this area, but were lacking in spatial data for this region. Harbour seal (*Phoca vitulina*) data was also available but given that this species is sub-Arctic, there was no data available in the Tallurutiup Imanga area (AMAP/CAFF/SDWG, 2013; Yurkowski et al., 2018). Polar bears (*Ursus maritimus*) are also a key marine mammal of the Arctic ecosystem, but the data was not included in this study because there are currently no studies showing the impacts of underwater ship noise on polar bears.

The fourth step of the study was to estimate the area used most often by each of these marine mammal species. This was done first with marine mammal telemetry data (as seen in this section), then with Inuit and local knowledge (as seen in the following section). The marine mammal data for the region was acquired from a compilation of satellite telemetry data put together by Yurkowski et al. (2018) and was processed in a state-space model to produce one average location estimate per day, per individual (Yurkowski et al., 2018). Additional bowhead whale data which is part of the same population that are in Tallurutiup Imanga, were provided by Mads Peter Heide-Jørgensen (Chambault et al., 2018). The data were also modelled using state-space models, but this data had multiple points per day; therefore, to make it similar to the data provided by Yurkowski et al. (2018) only the first point in each day was chosen as the estimated position of each individual. All the marine mammal data was in the form of spatial points. See Table 5 for details of all data that were used.

The marine mammal data was then used to calculate kernel density estimations (KDE). KDE is a common approach used for assessing ranges of terrestrial and aquatic species (Lees, Guerin, & Masden, 2016; Rayment et al., 2009; Sprogis, Raudino, & Rankin, 2016; Tumenta et al., 2013); in other words, it is the space that is used by an animal (Fieberg & Kochanny, 2005; Worton, 1989). For this study KDEs were calculated for each of the five marine mammal species in R Studio using the *ks* package (Duong, 2007) with the default bandwidth plug-in to estimate the smoothing parameter. The KDEs were calculated using the combined telemetry data, but restricted between July and October to ensure an accurate estimation of the marine mammals present during the shipping season. Furthermore, only data that were from populations of marine mammals that overlapped with the NMCA were included. For beluga whales the data was narrowed down to only include the Eastern High Arctic – Baffin Bay population (COSEWIC, 2004), and for bowhead whales, only whales in the East Canada-West Greenland population were included.

Further, percent volume contours (PVCs) can be identified within KDEs to represent the core use areas of species (Sprogis et al., 2016; Tumenta et al., 2013). PVCs are probability contours that measure the extent of animals' home ranges and represent the probability that an individual can be found in an area (Kern, McDonald, Amstrup, Durner, & Erickson, 2003). PVCs can be represented in various probabilities, with 50% and 95% being the most common. 95% PVCs represent the minimum area where an individual has a 95% possibility of being found, so this value is more of an estimated of the specie's range, whereas, the 50% PVC is more representative of the high use areas of a species, also known as the "core use area". In this study, 50% and 95% PVCs were calculated in R Studio using the ks package, for all three marine mammal species. Only 50% and 95% PVCs that occurred within the NMCA were used for analysis to estimate the core use areas and total species ranges, respectively. Hereinafter, the PVCs will also be referred to as the marine mammal use distribution areas.

*Table 5. Marine mammal telemetry data details.*

<b>Source</b>	<b>Species</b>	<b>Date range</b>
Yurkowski et al. (2018)	Bowhead	July 13, 2006 – October 31, 2016
Heide-Jørgensen et al. (2017)	Bowhead	July 1, 2002 – July 21, 2011
Yurkowski et al. (2018)	Beluga	September 12, 1995 – October 31, 2001
Yurkowski et al. (2018)	Narwhal	August 21, 1993 – October 31, 2017

### **Observed wildlife areas (base on Inuit and local knowledge)**

Furthermore, the second part of research step 4 was to complete another analysis for the important areas of the three key marine mammals, but by using Inuit and local knowledge data made available from the Arctic Corridors and Northern Voices (ACNV) project (arcticcorridors.ca). The ACNV project was "established in 2014 in direct response to the vital need to consider local and Indigenous knowledge of culturally significant marine areas in the low impact corridors across Arctic Canada consider" (Dawson et al., 2020, p. 20). The data from ACNV project was collected in 14 Arctic communities; however, the data used in this project was only taken from Resolute and Pond Inlet since they are the communities in closest proximity to TI. Workshops for the project took place in April 2016 for Pond Inlet and March 2019 for Resolute. Research participants from the two communities surrounding TI identified year-round wildlife habitat areas, harvesting areas and camping sites, travel routes, observed and potential impacts of marine vessel traffic, and suggestions for marine vessel management options. (Carter, Dawson, & Cook, 2019; Carter, Dawson, Joyce, et al., 2018). These areas, also referred to as Culturally

Significant Marine Areas (CSMAs) were identified through participatory mapping in the form of polygon shapefiles. The participants were chosen by community organizations like the Hunters and Trappers Associations and Hamlets. The inclusion criteria for the participants were men and woman elders and/or current active land users who are: 1) experts about current significant ecological and socio-cultural marine areas; 2) experts about the impact of shipping from all types of vessels on those places and on community members; and, 3) keen to share their knowledge. For the purpose of this study, only the community identified wildlife habitat areas that were identified to be present in July through October were used for the marine mammal portion of the study, and will henceforth be referred to as the observed wildlife areas. The wildlife areas represent locally observed feeding and breeding locations of the animals, as well as their migratory routes. It should be kept in mind that these results are different than the PVC outputs since PVC are derived from KDEs, which are calculated from raw satellite telemetry data.

### **Examining potential noise disturbance events for marine mammals**

The final and 5<sup>th</sup> research step of this study was to examine potential noise disturbance events for the marine mammals. This was done in two consecutive steps, by overlapping the noise footprint (number of times that cells exceeded the 120 dB behavioural threshold) with the core use areas (50% PVC) and with observed wildlife areas. Overlapping the noise outputs with the important marine mammal area outputs locates areas of potential impacts of vessel traffic on marine mammals in TI. The more times a ship has gone through a marine mammals' area, the higher the risk of being disturbed by the noise of the vessels. The results for these analyses are presented separately below. This part of the analysis was done using ArcMap 10.6.1 software.

## **4.3 Results**

The results of the study are separated into the four main sections that correspond to the 5 research steps.

### **Vessel traffic trends**

The total annual kilometres travelled by all vessel categories in Tallurutiup Imanga was 76,389 km in 2015, 98,787 km in 2016, 138,247 km in 2017, and 158,178 km in 2018; with 2018 having 1.5 times more distance travelled than in 2015. The average annual kilometres travelled over this four-year period was

117,900 km. Trends can also be seen for the different types of vessels that have gone through the NMCA (Figure 21).

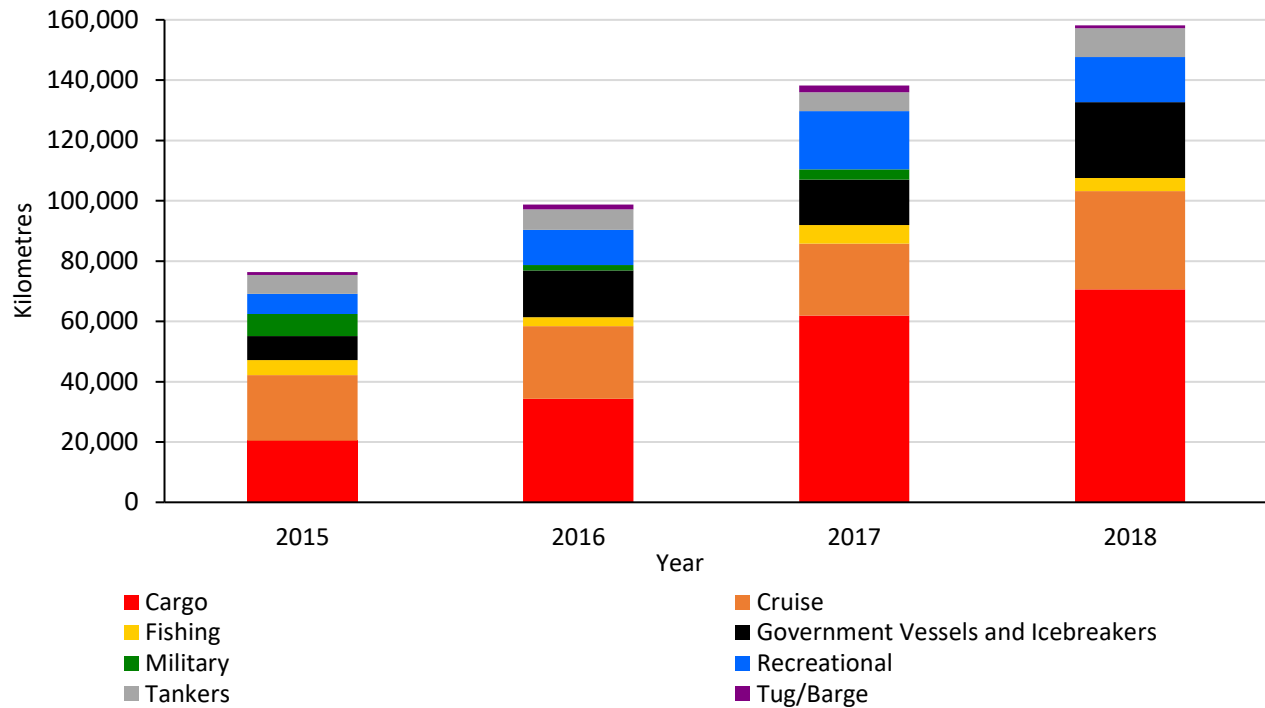


Figure 21. Total Annual Kilometres Travelled by All Vessel Types in Tallurutiup Imanga, from 2015-2018.

From 2015 to 2018 cargo, cruise ships, government vessels and icebreakers, and recreational vessels made up the most total annual kilometres travelled (average of 101,515 km). In 2015 cruise ships were the vessel type that travelled the most annual kilometres at 21,691 km, but in the following years cargo ships experienced a positive growth and had the highest total annual kilometres travelled of all vessel classes in 2016 (34,350 km), 2017 (61,899 km) and 2018 (70,603 km). Cargo ships travelled the most over the four-year period (187,296 km), followed by cruise ships (102,239 km). Government vessels and icebreakers travelled a total of 63,746 km over 2015-2018 and have had relatively stable trends over the four years. Recreational vessels have experienced an increase in annual distance travelled from 2015 (6,739 km) to 2017 (19,363 km) with a decrease in 2018 (14,992 km), most likely because 2018 was a heavy sea ice year. This brings the total distance travelled over the four-year period to 52,780 km. Tanker ships, fishing vessels, tugs/barges and military vessels had lower total annual kilometres travelled in 2015 to 2018 (average of 16,385 km), with tanker ships having the most out of those four categories

(28,851 km). These four categories of vessels travelled shorter annual distances, never going above 10,000 km in one year, and all had relatively stable trends over the four years.

In terms of spatial trends of all vessel classes combined for the study period, see Figure 22. In 2015 the highest value for kilometres travelled in a 100 km<sup>2</sup> cell was 830 km, in 2016 this more than doubled to 1,777 km, then increased again to 2,542 km in 2017 and reached a maximum in 2018 of 3,145 km, which is over three times the distance travelled in 2015. The average distance travelled per grid cell in 2015 was 36 km, 46 km in 2016, 64 km in 2017 and 74 km in 2018. The area of most distance travelled in all four years was Eclipse Sound, south of Bylot Island. Another area of high shipping activity is the eastern entrance to Eclipse Sound, where ships would have come up north along Baffin Island; this area has higher shipping activity in 2018, 2017 (maximum values of 1,725 km and 1,526 respectively) and less in 2016 and 2015 (maximum values of 1,315 and 587 km respectively). Other notable areas of higher shipping activity over the four years are the southern coastlines of Devon Island near Craker Bay and Beechey Island, the eastern coast of Devon Island (including south of Coburg Island), Resolute, Admiralty Inlet, Parry Passage, and Barrow Strait.

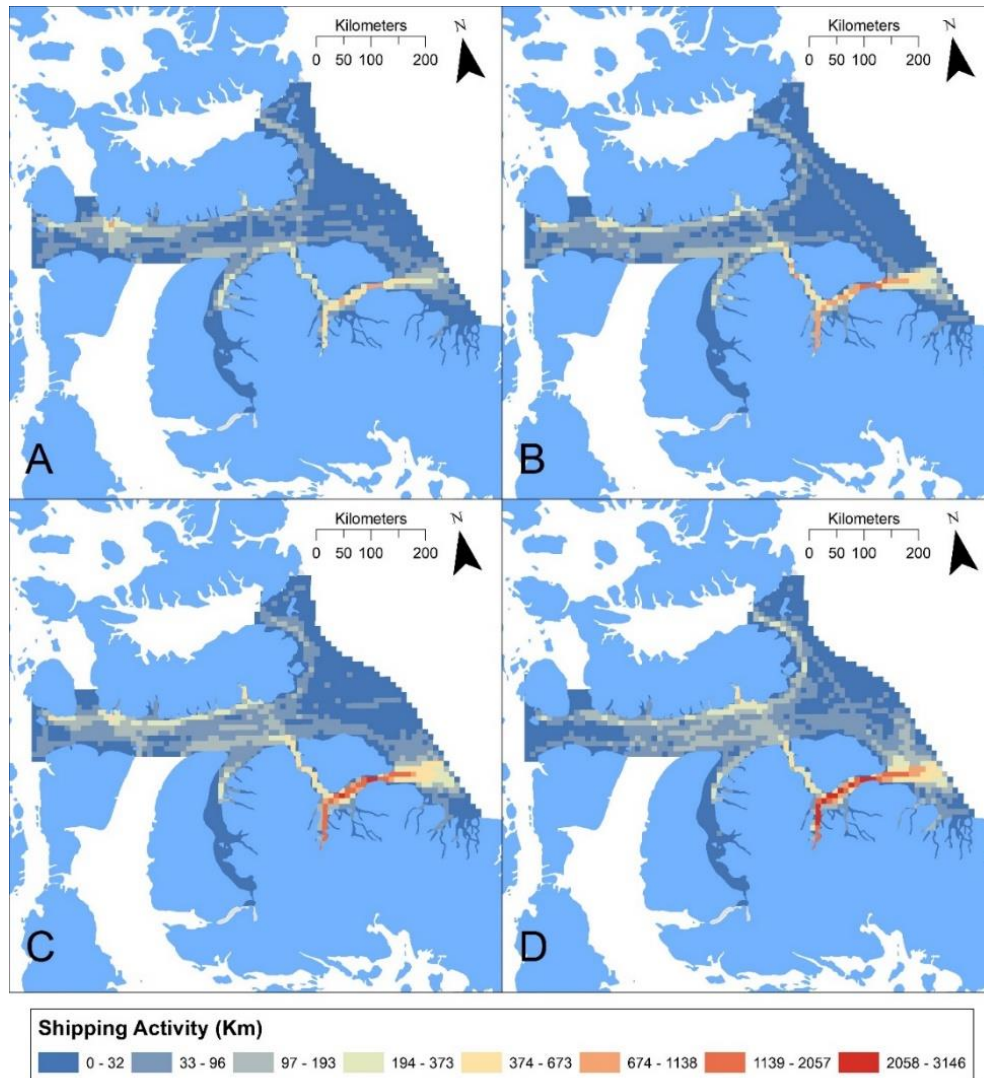


Figure 22. Ship presence per 100 km<sup>2</sup> for all vessel categories for: (A) 2015; (B) 2016; (C) 2017; and (D) 2018.

## Modelled acoustic noise footprints

Proceeding from the vessel traffic trends, acoustic noise footprints of shipping for TI were modelled (Figure 23). For all four years of the study, Milne Inlet, which is south of Bylot Island and is the main access point for the Baffinland Iron Mine, and Eclipse Sound contained the most amount of times that underwater noise levels exceeded the 120 dB threshold (Figure 23). Other areas where the 120 dB threshold was exceeded frequently were: the eastern entrance into the NMCA near southeastern Bylot Island, and the northeast coast of Devon Island. The maximum number of times that individual 500 m

grid cells exceeded the 120 dB noise threshold in 2015 was 34 times, in 2016 55, in 2017 93, and in 2018 110 times.

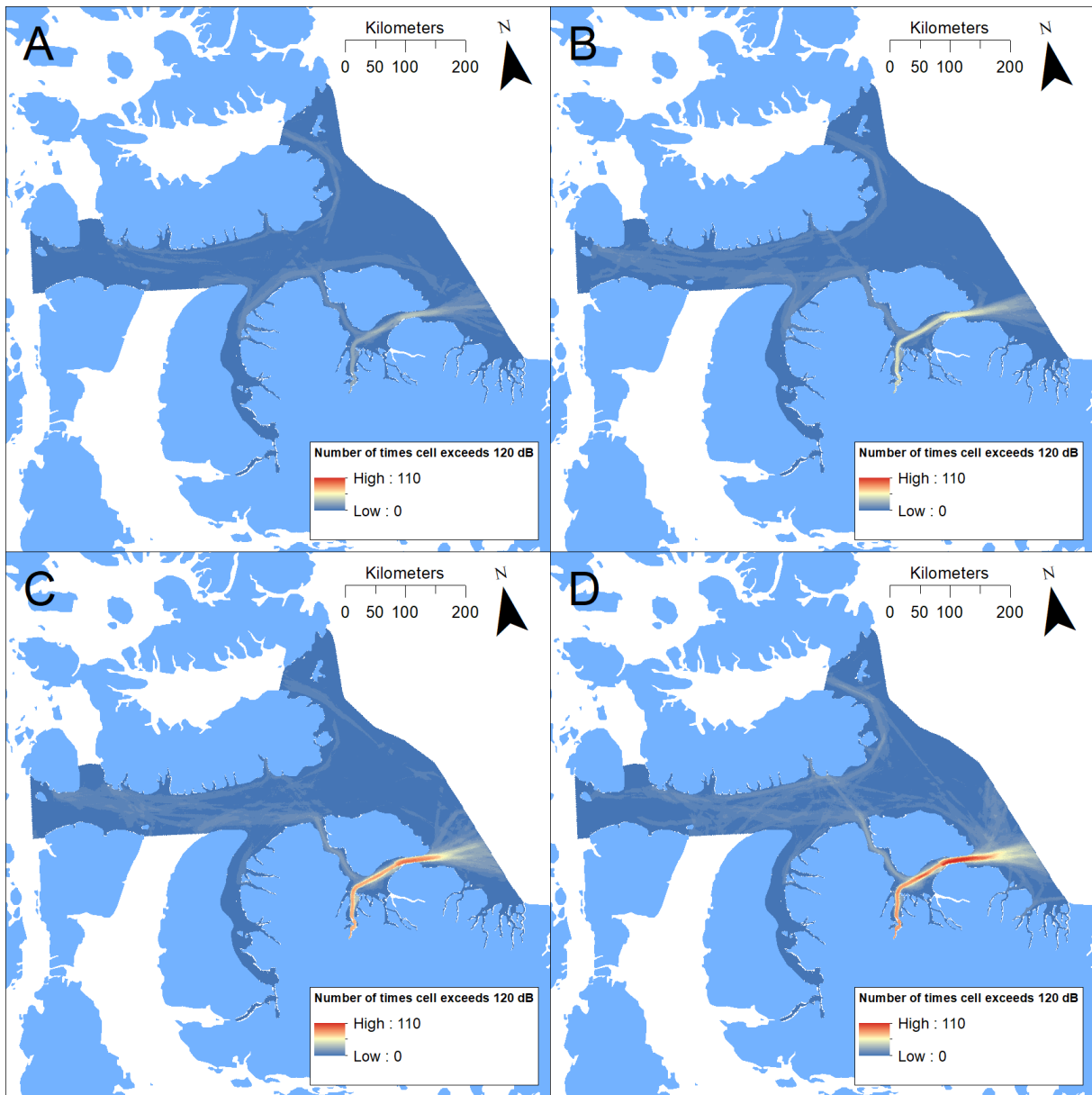


Figure 23. Number of times that each 500 m cell in the grid exceed the value of 120 dB, cumulatively for all vessels, where A is 2015, B is 2016, C is 2017, and D is 2018.

## Identifying important marine mammal areas

### Marine mammal use distribution areas (based on western science)

The 50 % PVC represents an area where animals spend at least 50% of their time; it represents the core areas used by these animals (Cominelli et al., 2018; Lees et al., 2016). Therefore, throughout the animal's total distribution this is a smaller area where the chances that the animal is there in reality are higher, because it represents an area where there is a larger concentration of the animal population. The 95% PVC is a close representation of the total species range during the summer season in this region; therefore, the 95% PVC is larger than the 50% PVC (Cominelli et al., 2018; Sprogis et al., 2016). The 95% PVC is also a valuable value because it is the larger area where the animal could possibly be throughout the summer season. It represents an area that most likely contains the animal population, but because it is larger it is more representative of animals that migrate through the area and don't necessarily stay in this area as long as they would in the 50% PVC. Animals in the 95% PVC are less concentrated than in the 50% PVC. As seen in Figure 24 the distribution of the raw marine mammal data coincides with the PVCs; specifically, the 50 % PVC is an accurate representation of where there is a high concentration of points, while the 95% PVC encompasses the larger range of points.

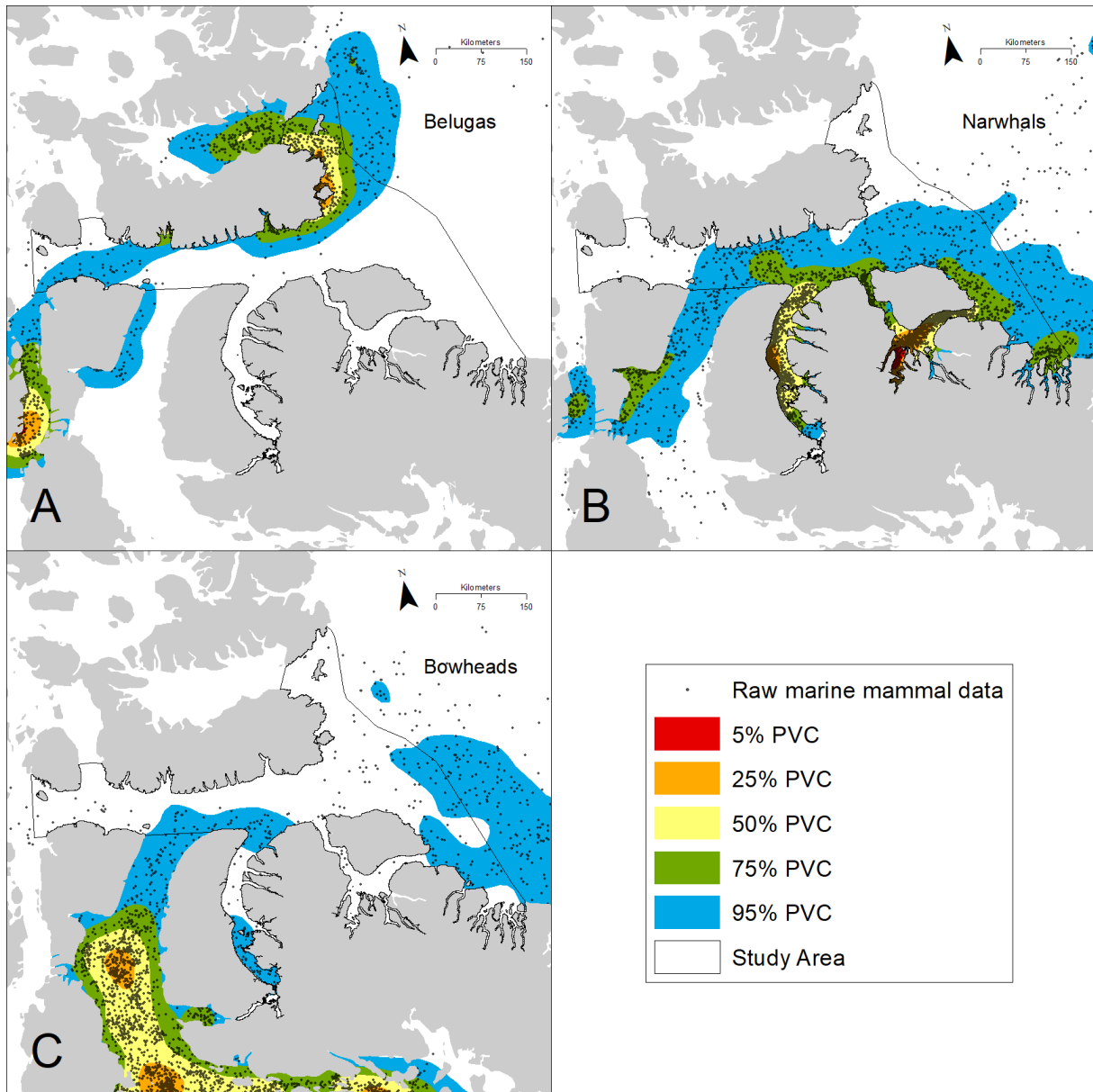


Figure 24. Percent Volume Contours (5, 25, 50, 75 and 95) for belugas (A), narwhals (B) and bowhead whales (C) overlapped by raw marine mammal daily location points. See Annex D for full details of all PVCs.

Both the 50% PVC and 95% PVC were analyzed further in the study; however, the focus was more on the 50% PVC because of its representation as the core use areas of marine mammals versus the larger PVC. The 95% PVC represents a possible range and is a generalized area for the marine mammals to be in, so although animals could be in that area they might not be spending most of their time there. In contrast, the 50% PVC is the area where the marine mammals spend most of their time, so this area is a better

representation of where the population spends most of its time. Hereinafter, 50% PVC will also be referred to as the “core use area” of a marine mammal. Beluga whales and narwhals both had part of their core use areas in the area of the NMCA (see Figure 24 and Table 6). The beluga core use area was concentrated towards the northern part of TI near Devon Island, while for narwhals it was concentrated in Eclipse Sound and Admiralty Inlet. All three mammals had part of their 95% PVCs in the area of the NMCA. The beluga 95% PVC was concentrated in the northern and western part of TI near Devon Island and Cornwallis Island, and the bowhead 95% PVC was concentrated along the southern side of Parry Passage and the eastern limit of TI. The narwhal 95% PVC was located throughout almost all the NMCA, except for the northern portion near Coburg Island and then western portion near Cornwallis Island.

*Table 6. Total area of the 50 and 95 Percent Volume Contours within the official Tallurutiup Imanga boundary (112,833 km<sup>2</sup>) after KDE analysis for three marine mammal species.*

<b>Species</b>	<b>Percent Volume Contour</b>	<b>Area (Km<sup>2</sup>)</b>
Beluga	50	5,832
	95	33,675
Bowhead	50	0
	95	28,259
Narwhal	50	13,107
	95	76,891

Beluga whales had a total 50% PVC area of 5,832 km<sup>2</sup>. 5,708 km<sup>2</sup> of that area was on the northeast coast of Devon Island and 124 km<sup>2</sup> was in Maxwell Bay. Narwhals had a larger 50 % PVC area of 13,107 km<sup>2</sup> of which 7,337 km<sup>2</sup> was in Admiralty Inlet and 5,770 km<sup>2</sup> was in Eclipse Sound. Belugas had a total 95% PVC of 33,675 km<sup>2</sup>, while narwhal had the largest 95% PVC at 76,891 km<sup>2</sup>. Bowhead whales had a 95% PVC area of 27,512 km<sup>2</sup> within TI, the smallest of the three whales, and did not have any 50% PVC in the NMCA.

### **Observed wildlife areas (based on Inuit and local knowledge)**

The second part of research step 4 was to identify observed wildlife areas that are based on Inuit and local knowledge data from the ACNV project (green areas in Figure 26). Figure 26 also compares the observed wildlife areas which are community identified locations of marine mammals, with the marine mammal use distribution areas (orange striped areas and red outlined areas) which are based on PVCs. The core use area estimations (orange) are 50% PVCs and the species range estimations (red) are the 95% PVC.

The observed beluga use areas (Figure 26, panel A) were only identified by the community of Resolute, so there was a clear trend of beluga use areas being concentrated to the west of the NMCA. The small beluga core use area in Maxwell Bay overlapped with the observed beluga use area, while the larger beluga core use area on the eastern coast of Devon Island did not overlap with the observed beluga area. Again, the species range estimation overlapped with the observed beluga use area in the west on the NMCA, but not in the east which is further away from Resolute. Observed narwhal use areas (Figure 26, panel B) were identified by both Resolute and Pond Inlet community members. The narwhal core use areas overlapped with the observed narwhal use areas, both in Admiralty Inlet and Eclipse Sound. The narwhal species range estimations also corresponded with the observed narwhal areas, but go further up north than the observed use areas. Observed bowhead use areas (Figure 26, panel C) were identified only by community members in Resolute, so there was a clear trend of identified bowhead area in the west of the NMCA. There was no core use area for bowhead whales that existed within the TI NMCA; therefore, it was not pictured in Figure 26, panel C. The estimated species range of bowhead whales overlapped with the observed bowhead area but extended further west than the species range estimation.

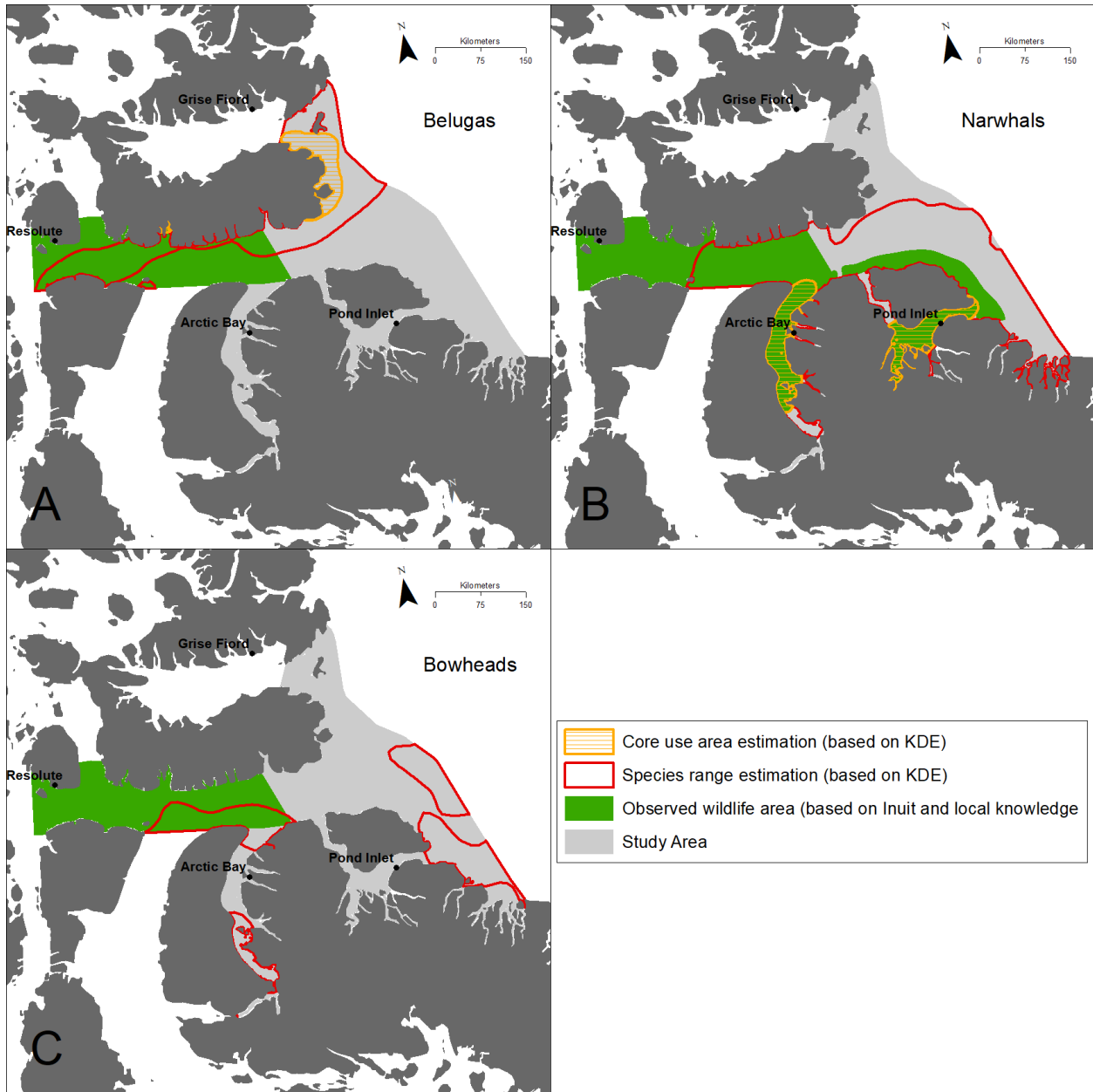


Figure 25. Spatial comparison between observed wildlife areas (from community members in Resolute and Pond Inlet) and marine mammal use distribution areas (based on western science, specifically Percent Volume Contours (PVCs)), where A is belugas, B is narwhals and C is bowhead whales.

## Examining the potential for noise disturbance events for belugas, narwhals and bowheads

The final research step was to examine potential noise disturbance events for the marine mammals. This was completed in the first section by overlapping marine mammal use distribution areas derived from

PVCs, with noise footprints, then completed in the next section by overlapping observed wildlife areas with the same noise footprint.

### **Marine mammal use distribution areas (based on western science)**

The vessel noise footprints were overlapped with the 50% PVC of belugas (Figure 27) and narwhals (Figure 28). While the vessel noise footprints were also overlapped with the 95% PVCs of beluga whales, narwhals and bowhead whales (Tables 7 and 8). Only the overlaps of the 50% PVCs with belugas and narwhals are shown in the following figures because of the importance of the core use area (50%) versus the total species range (95%); however, more details and analyses of the overlapping areas of all three marine mammals and both PVCs are seen in Tables 7 and 8, and further in this section. The core use areas are more representative of the main areas of use of marine mammals compared to the species range. The animals are more concentrated in the core use areas than in species ranges, which means that they spend the most of their time in the core use areas, and are more likely to be found there than in the species range. This is crucial for the analyses of noise impacts because it is in the core area that there is a higher potential for more marine mammals to be impacted.

The maximum number of times that 500 m cells exceeded the 120 dB noise threshold, in the core use (50% PVC) areas of belugas were: 8 in 2015, 7 in 2016, 6 in 2017 and 13 in 2018 (Figure 27). The cumulative number of cells in the beluga core use area is 4,480. For all four years, the area with the greatest number of noise exposure events (received level  $\geq$  120 dB), within the beluga core areas was approximately 8 to 15 km from the eastern shoreline of Devon Island.

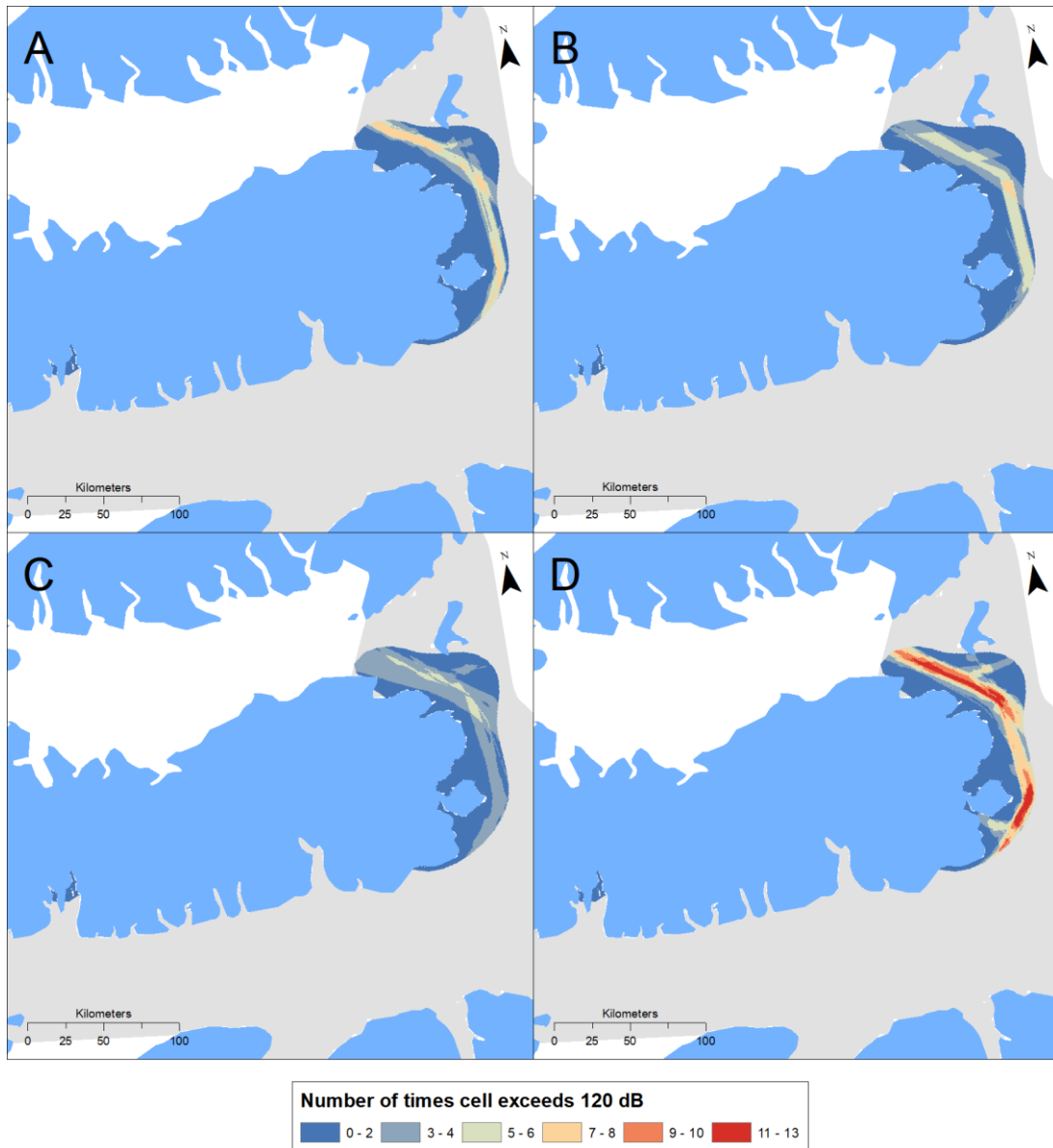


Figure 26. Number of times that each 500 m cell in the grid exceed the value of 120 dB, cumulatively for all vessels, in the beluga core use areas off of Devon Island, Nunavut; where A is 2015, B is 2016, C is 2017, and D is 2018. See Appendix B for the figures of each individual ship type.

The beluga core use area is mostly on the northeastern coast of Devon Island and the ship tracks followed roughly in the middle of that area, with increased behavioural disturbance events in the year 2018 (Figure 27). When examining the behavioural disturbance events per vessel type in the beluga core use areas, cargo vessels and cruise ships had the most disturbances events in the 4 years study period (Table 7). These multiple events are likely due to: cruise ships travelling to the inlets along the coast, to

visit Coburg Island, and to visit Grise Fiord on Ellesmere Island; and, cargo ships delivering supplies to Grise Fiord. The maximum number of times that the 500m cell exceeded the 120 dB threshold in the core use areas of the belugas was: 8 in 2015, 7 in 2016, 6 in 2017 and 13 in 2018. The cumulative number of cells in the beluga core use area was 23,328.

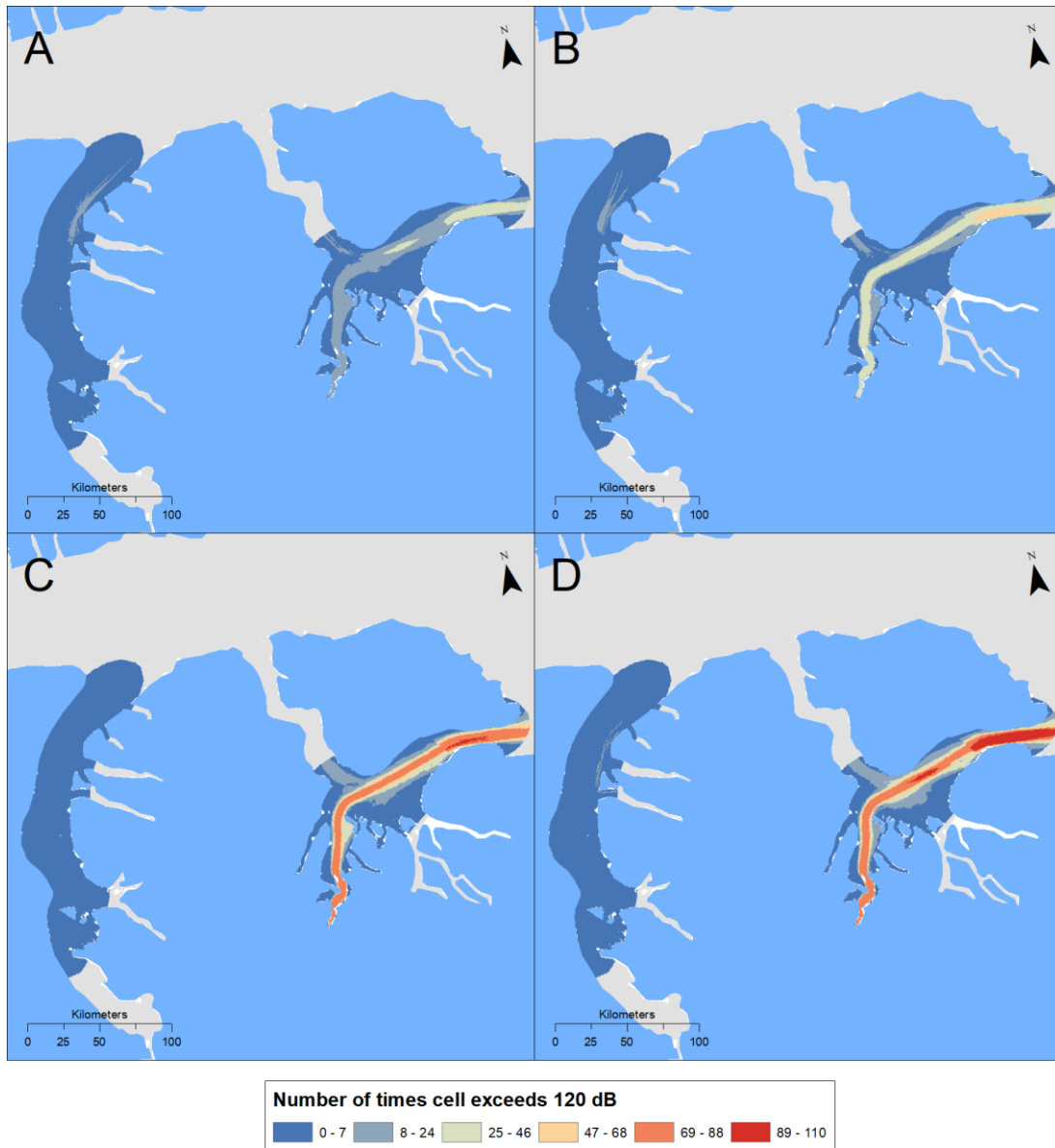


Figure 27. Number of times that each 500 m cell in the grid exceed the value of 120 dB, cumulatively for all vessels, in the narwhal core use areas in Admiralty Inlet and Eclipse Sound, Nunavut; where A is 2015, B is 2016, C is 2017, and D is 2018. See Appendix C for the figures of each individual ship type.

The narwhal core use area (50% PVC) is located in Eclipse Sound and in Admiralty Inlet with varying trends in ship tracks throughout the area (Figure 28). In Eclipse Sound there were multiple behavioural disturbance events that go all the way from the eastern entrance into Eclipse sound, south to Milne Inlet. The multiple disturbance events were in the middle of the narwhal core use area, approximately 8 to 25 km from the shoreline of Bylot Island. Another region with a high number of behavioural disturbance events was Milne Inlet; here the highest values are between 1 and 10 km away from the shoreline of Baffin Island. During the shipping season there were one or more ships that travelled to and from the mine per day. Other sources are cargo ships delivering supplies to Pond Inlet and to the Mary River Mine and icebreakers, as well as cruise ships exploring Eclipse Sound. The maximum number of times that the 500m cell exceeded the 120 dB threshold in the core use areas of the narwhals was: 34 in 2015, 55 in 2016, 93 in 2017 and 110 in 2018. The cumulative number of cells in the narwhal 50% PVC was 52,428.

*Table 7. Details of the 500 m cells that exceeded 120 dB, in beluga and narwhal core use areas (50% PVC), with individual vessel categories from 2015 to 2018.*

<b>Vessel type</b>	<b>Marine mammal 50% PVC overlapped</b>	<b>Year</b>	<b>Maximum number of behavioural disturbance events</b>	<b>Cumulative total of all cells in PVC</b>	<b>Area of behavioural disturbance events overlapping 50% PVC core use areas (Km<sup>2</sup>)</b>	<b>Average area of behavioural disturbance events overlapping 50% PVC core use areas (Km<sup>2</sup>)</b>
<b>Cargo</b>	<i>Belugas</i>	2015	2	23,328	1,603	2,048
		2016	3		2,189	
		2017	2		1,987.5	
		2018	4		2,411	
	<i>Narwhals</i>	2015	20	52,428	5,540.5	5,530
		2016	37		4,929.5	
		2017	72		6,017.75	
		2018	76		5,632.5	
<b>Cruise ship</b>	<i>Belugas</i>	2015	5	23,328	2,682.25	2,479
		2016	1		1,286.25	
		2017	2		2,108	
		2018	9		3,839.5	
	<i>Narwhals</i>	2015	7	52,428	3,100.75	3,544
		2016	5		3,773.25	
		2017	5		2,965.75	
		2018	14		4,335.5	
<b>Fishing</b>	<i>Belugas</i>	2015	0		0	96

<b>Government</b>		2016	1	23,328	122.25		
		2017	2		136.75		
		2018	1		124.5		
	<i>Narwhals</i>	2015	1		827.5		
		2016	1	52,428	341.25	800	
		2017	3		814.5		
		2018	2		1217		
		<i>Belugas</i>	2015	1		3,407.5	
			2016	2	23,328	3,396	2,939
	2017		1		1,919.5		
	2018		1		3,032.75		
	<i>Narwhals</i>	2015	2		3,461.25		
2016		5	52,428	7,688	5,114		
2017		4		4,827.5			
2018		6		4,477.25			
<b>Military</b>	<i>Belugas</i>	2015	0		0		
		2016	0	23,328	0	0	
		2017	0		0		
		2018	0		0		
	<i>Narwhals</i>	2015	1		102.5		
		2016	0	52,428	0	104	
		2017	3		313		
		2018	0		0		
<b>Recreational</b>	<i>Belugas</i>	2015	1		15.75		
		2016	1	23,328	43.25	15	
		2017	0		0		
		2018	0		0		
	<i>Narwhals</i>	2015	1		188		
		2016	3	52,428	621.25	897	
		2017	3		1,147.25		
		2018	6		1,631.75		
<b>Tanker</b>	<i>Belugas</i>	2015	1		1,407.5		
		2016	1	23,328	1,301	1,480	
		2017	1		1,768.75		
		2018	1		1,442.25		
	<i>Narwhals</i>	2015	4		3,446.25		
		2016	5	52,428	3,076	3,452	
		2017	4		3,421		
		2018	7		3,861.5		
<b>Tug</b>	<i>Belugas</i>	2015	0		0		
		2016	0	23,328	0	0	
		2017	0		0		
		2018	0		0		
	<i>Narwhals</i>	2015	1		2,173		
		2016	3	52,428	2,205.5	1,942	
		2017	4		1,733		
		2018	3		1,657.75		

In beluga core use areas, government vessels and icebreakers had the highest average area over the study period where behavioural disturbance events cover 2,939 km<sup>2</sup>, followed by cruise ships at 2,479 km<sup>2</sup>, cargo at 2,048 km<sup>2</sup> and then tankers at 1,480 km<sup>2</sup>. Meanwhile for narwhals, cargo had the highest average area over the study period where behavioural disturbance events spanned 5,330 km<sup>2</sup>, followed by government vessels and icebreakers at 5,114 km<sup>2</sup>, cruise ships at 3544 km<sup>2</sup> and tankers at 3452 km<sup>2</sup>.

Table 8. Details of the 500 m cells that exceeded 120 dB, in beluga, narwhal and bowhead estimated species ranges (95% PVC), with individual vessel categories from 2015 to 2018.

Vessel type	Marine mammal 50% PVC overlapped	Year	Maximum number of behavioural disturbance events	Cumulative total of all cells in PVC	Area of behavioural disturbance events overlapping 95% PVC areas (Km <sup>2</sup> )	Average area of behavioural disturbance events overlapping 95% PVC areas (Km <sup>2</sup> )
Cargo	Belugas	2015	2	134,701	4,862.25	9,881
		2016	3		6,272.25	
		2017	4		12,057	
		2018	4		16,332	
	Narwhals	2015	20	307,562	23,835.25	28,997
		2016	37		20,766.75	
		2017	72		36,362.25	
		2018	76		35,025.25	
	Bowheads	2015	20	113,036	9,066.75	11,893
		2016	37		9,699	
		2017	72		15,063.25	
		2018	76		13,743.5	
Cruise ship	Belugas	2015	5	134,701	10,880.5	11,518
		2016	4		8,045.5	
		2017	4		10,815.5	
		2018	12		16,332	
	Narwhals	2015	7	307,562	20,485.5	26,505
		2016	5		19,119	
		2017	5		23,976.5	
		2018	14		42,439.5	
	Bowheads	2015	6	113,036	6,944.5	8,877
		2016	4		7,072.25	
		2017	5		7,372.25	
		2018	14		14,119.75	
Fishing	Belugas	2015	1	134,701	138.25	574
		2016	1		632	
		2017	2		1,012.75	
		2018	1		513.25	

	<i>Narwhals</i>	2015	1		1,447.75		
		2016	1	307,562	1,313.5	1,844	
		2017	3		2,412.75		
		2018	2		2,202.5		
	<i>Bowheads</i>	2015	1		429.25		
		2016	1	113,036	406	545	
		2017	3		756.75		
		2018	2		587.5		
	<b>Government</b>	<i>Belugas</i>	2015	1		7,987.5	
			2016	5	134,701	19,303.25	13,404
			2017	3		11,948.5	
			2018	3		14,375.25	
	<i>Narwhals</i>	2015	3		21,953.25		
		2016	5	307,562	35,426.5	28,978	
		2017	5		29,521		
		2018	6		29,012.5		
	<i>Bowheads</i>	2015	3		7,382		
		2016	4	113,036	13,222.5	12,430	
		2017	5		16,601.5		
		2018	6		12,514.25		
	<b>Military</b>	<i>Belugas</i>	2015	2		282	
			2016	0	134,701	0	81
			2017	1		43.25	
			2018	0		0	
<i>Narwhals</i>		2015	2		718.5		
		2016	0	307,562	0	513	
		2017	3		1,334.75		
		2018	0		0		
<i>Bowheads</i>		2015	1		158.5		
		2016	0	113,036	0	184	
		2017	3		577.25		
		2018	0		0		
<b>Recreational</b>	<i>Belugas</i>	2015	2		210.25		
		2016	2	134,701	615	996	
		2017	4		1,364.75		
		2018	5		1,795.25		
	<i>Narwhals</i>	2015	2		622.25		
		2016	5	307,562	1,891.25	3,163	
		2017	4		3,962.75		
		2018	6		6,176.5		
	<i>Bowheads</i>	2015	2		232.75		
		2016	2	113,036	426.25	750.25	
		2017	2		714.75		
		2018	4		1,627.25		
<b>Tanker</b>	<i>Belugas</i>	2015	2		6,576.5		
		2016	2	134,701	5,188.5	5,660	
		2017	1		5,427.5		
		2018	3		5,447.25		

	<i>Narwhals</i>	2015	4		15,913.75		
		2016	5	307,562	13,581.5	15,543	
		2017	4		12,232		
		2018	7		20,446		
	<i>Bowheads</i>	2015	4		7,072		
		2016	5	113,036	5,758.5	6,100	
		2017	4		3,004.75		
		2018	7		8,564		
	<b>Tug</b>	<i>Belugas</i>	2015	0		0	
			2016	0	134,701	0	0
			2017	0		0	
			2018	0		0	
	<i>Narwhals</i>	2015	1		2,795.75		
		2016	3	307,562	3,556.75	3,790	
		2017	4		6,347.75		
		2018	3		2,459.75		
	<i>Bowheads</i>	2015	1		498.25		
		2016	2	113,036	1,187	1,341	
		2017	2		2,981		
		2018	1		696.25		

Although the 50% PVCs were the focus because they represent the core use areas of marine mammals, 95% PVCs are commonly used to represent the total species range of marine mammals; therefore, they were analyzed in this study as well. It is important to analyze the total species ranges because although the mammals are not as concentrated in these 95% PVCs as they are in the core use areas, these are still locations where the animals have passed through and would still have the potential to be impacted by vessel noise. The 95% PVCs of the belugas, narwhals and bowhead whales were all larger than the corresponding 50% PVCs. The maximum value of behavioural disturbance events for the beluga 95% PVC was in 2018 when cruise ships had the potential to cause 12 events. The maximum for narwhal 95% PVC was in 2018 when cargo ships had the potential to cause 76 behavioural disturbance events, and the same maximum value of 76 was reached for the 95% PVC of bowheads in 2018 for cargo as well. In the beluga 95% PVC, government vessels and icebreakers had the highest average area over the study period where behavioural disturbance events cover 13,404 km<sup>2</sup>, followed by cruise ships at 11,518 km<sup>2</sup>, cargo at 9,881 km<sup>2</sup> and then tankers at 5,660 km<sup>2</sup>. Meanwhile for narwhals, cargo had the highest average area over the study period where behavioural disturbance events spanned 28,997 km<sup>2</sup>, followed by government vessels and icebreakers at 28,978 km<sup>2</sup>, cruise ships at 26,505 km<sup>2</sup> and tankers at 15,543 km<sup>2</sup>. See Appendix D for a table of other common PVC overlaps with noise footprint for all three marine mammals.

### Observed wildlife areas (based on Inuit and local knowledge)

The second part of the final research step combined the vessel noise outputs with the observed wildlife areas, which are based on Inuit and local knowledge. Figure 29 shows this overlap, only for the vessel noise data from the most recent year, 2018.

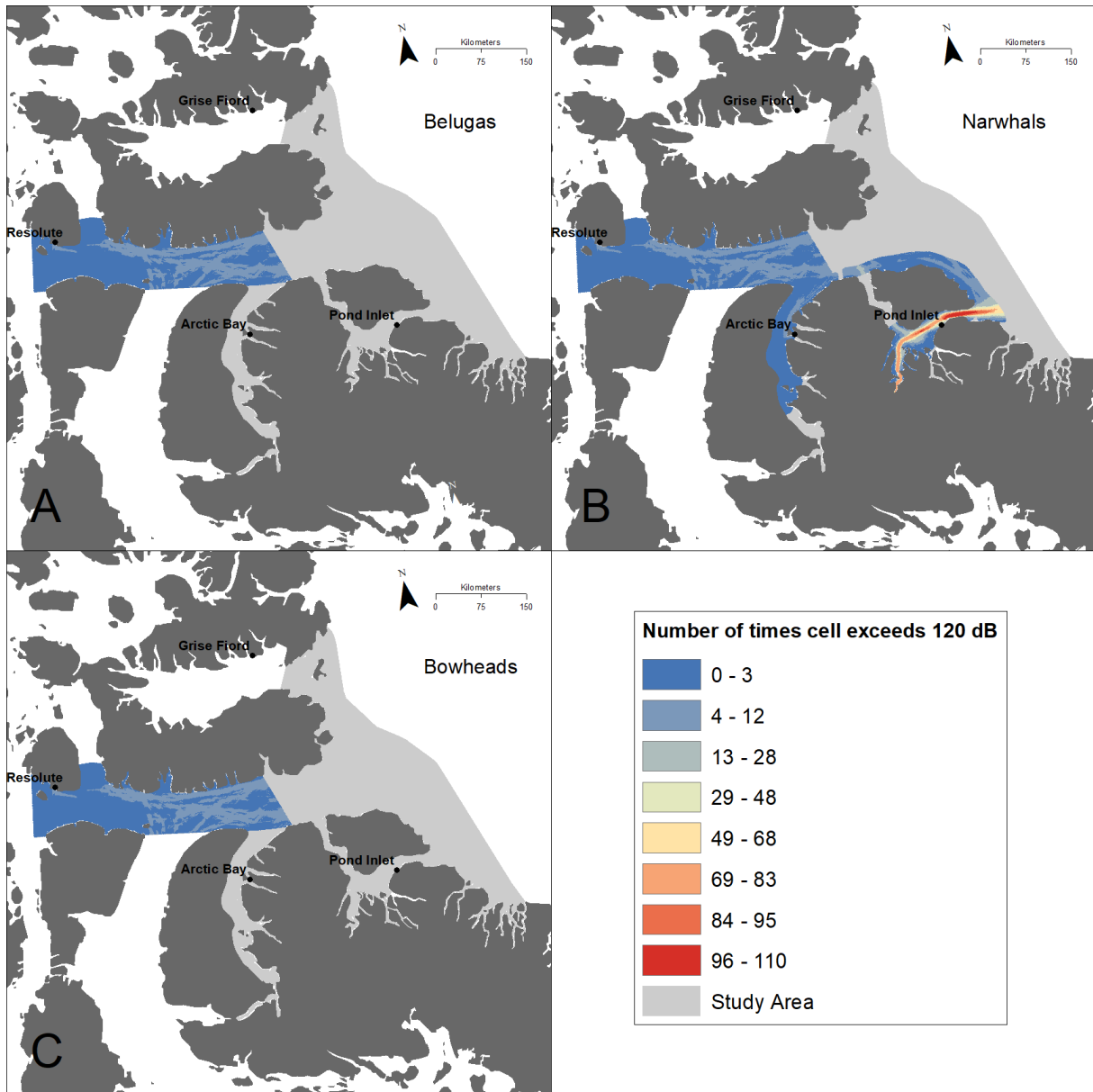


Figure 28. Number of times that each 500 m cell in the grid exceed the value of 120 dB, cumulatively for all vessels, in the observed beluga (A), narwhal (B) and bowhead (C) areas in 2018.

Observed narwhal areas (Figure 29, panel B) had the most potential behavioural disturbance events in 2018 with a maximum of 110, while belugas and bowheads (Figure 29, panels A and C) each had a maximum of 12 events in 2018. The increase in behavioural disturbance events for narwhals was due to the increase of events specifically in Eclipse Sound, which was only identified as narwhal area and not bowhead or beluga area. The observed narwhal area noise footprints were similar to the noise footprints of the narwhal core use areas in 2018 (Figure 28, panel D). This was because part of the core use area was in Eclipse Sound, as well as part of the observed narwhal area (Figure 26, panel B). Since Eclipse Sound was the location that has the highest number of behavioural disturbance events in 2018 (Figure 23, panel D), both the core use area and the observed narwhal area had similar noise footprint profiles and the same maximum of 110 potential noise disturbance events. Both results also included Admiralty Inlet which had a lower number of potential behavioral distance events. Furthermore, the observed narwhal area extended further west into Parry Passage, while the narwhal core area did not. This could be because both Pond Inlet and Resolute community members identified narwhal use areas so there was a tendency of data to the west because Resolute is in the western part of TI, on Cornwallis Island.

Observed beluga and bowhead area noise footprint for 2018 were the same because their areas cover the same western location in Parry Passage (Figure 29, panels A and C). They each had a maximum of 12 potential behavioural disturbance events. The result was similar in terms of maximum value to the beluga core use area results for 2018 (Figure 27, panel D) because the maximum value of potential behavioural disturbance events for the beluga core use area was 13. However, the locations of the two areas were different. The observed beluga area was in the western section of Parry Passage near Resolute, while the beluga core use area was on the eastern coast of Devon Island and in Maxwell Bay on southern Devon Island. Note that there was no core use area for bowheads so this comparison was not discussed here.

Table 9. Details of the 500 m cells that exceeded 120 dB, in observed narwhal, beluga and bowhead use areas; and, in 95% PVCs, for all vessel categories from 2015 to 2018.

Marine mammal	Year	Area of behavioural disturbance events overlapping observed wildlife areas (Km <sup>2</sup> )	Area of behavioural disturbance events overlapping 95% PVC areas (Km <sup>2</sup> )
Narwhal	2015	32,316.75	87,772
	2016	41,765.75	95,655.25
	2017	41,938.5	116,149.75
	2018	40,894.75	137,762
Belugas	2015	18,565.75	30,937.25
	2016	27,763.25	40,056.5
	2017	28,126.25	42,669.25
	2018	26,596.25	48,621
Bowheads	2015	18,565.75	87,772
	2016	27,763.25	95,655.25
	2017	28,126.25	116,149.75
	2018	26,595.5	137,762

Next, the community identified areas were compared to the 95% PVC areas in Table 9. The 95% PVCs were the biggest contour and come closest in total area to the community identified areas. The 95% PVCs were larger than the observed wildlife areas for all three marine mammals, where the maximum area of behavioural disturbance events for narwhals was in 2017 at 116,150 km<sup>2</sup>, for belugas was in 2018 at 48,621 km<sup>2</sup> and for bowheads was in 2018 at 137,762 km<sup>2</sup>.

Out of all the observed wildlife areas, narwhal areas contained the biggest areas of behavioural disturbance events with the maximum being 41, 939 km<sup>2</sup> in 2017, and the minimum in 2015 being 32,317 km<sup>2</sup>. Observed beluga areas contained smaller areas compared to narwhals, with behavioural disturbance events reaching a maximum of 28,126 km<sup>2</sup> in 2017 and a minimum of 18,566 km<sup>2</sup> in 2015. Observed bowhead areas contained the exact same maximum and minimum areas for the same years as the beluga areas.

## 4.4 Discussion

### Congruency between areas with behavioural disturbance events and important marine mammal areas

#### Marine mammal use distribution areas

Shipping in the Arctic entails risk from a security and economic perspective as well as in relation to culture and the environment (Dawson, Copland, Johnston, et al., 2017; Fissel et al., 2013; Halliday et al., 2018; Huntington et al., 2015; McWhinnie et al., 2018). Noise disturbances are one example of the environmental risks of shipping to the Canadian Arctic. This study found that multiple vessels transit through the core use areas of narwhals and belugas, which had the potential to lead to multiple behavioural disturbance events, where some areas had a greater risk of disturbance events than other. NOAA (2016) defines the behavioural disturbance threshold for marine mammals at 120 dB. In this study, a single behavioural disturbance event was defined as a 500 m cell having a received level value that was greater than or equal to 120 dB during a single ship voyage. An assumption made in the received level calculation was that an individual ship track will only represent ones and zeros (presence of a behavioural disturbance event or not, respectively). This assumption was accurate for most cases, except for when vessels doubled back on their own tracks. This means that the estimates presented here were underestimates in certain cases because they do not account for vessels that doubled over their tracks within a single month. However, when these double backs occurred it was usually a cruise ship idling in an inlet or fiord or going in then out of an area within a short time frame (i.e. 24 hours). In this case it will trace over its track more than once, which may still be a single disturbance event for the marine mammals in that area if they exhibit a strong fleeing reaction.

The vessel type and route are key factors in determining which core use areas have the potential to be impacted most. Vessels with higher source levels (Table 3) like government vessels and icebreakers, tankers, cargo vessels and cruise ships will affect larger areas because their sounds travel further; therefore, the vessels will most likely cause a larger radius of behavioural disturbance events within their vicinity. While vessels with lower source levels (Table 3) such as recreational, military and fishing vessels will create smaller radii of behavioural disturbance events in their surrounding area.

Furthermore, areas with more traffic will have a higher chance of increased disturbance events which have a greater potential to negatively impact marine mammals transiting through that region. Both beluga and narwhal areas had a number of ships with high source levels transit through their 50% PVC

core use areas, which led to a high number of behavioural disturbance events, particularly in the core use areas for narwhals' (Table 7). The results indicated that cargo ships had the potential to cause the most impact on narwhals in Tallurutiup Imanga, followed by cruise ships. Cruise ships also had the potential to cause the most impact for belugas, although at a lower rate than they could for narwhals. It is important to also note that the source levels were retrieved from the ECHO Underwater Listening Station program in Vancouver, British Columbia and that there is currently no data available for the source levels of ships that travel through Tallurutiup Imanga. The exact source levels of the ships in the NMCA are not known; therefore, the expected variation is also unknown. Due to this uncertainty there is also uncertainty in the final received levels from the noise model.

It is important to recognize that many areas were occupied by multiple types of vessels throughout the relatively short but dynamic shipping season. The core use areas of belugas had the estimated potential to have up to 13 behavioural disturbance events from various vessel types in 2018, meaning that if a beluga stayed in that area for the entirety of the shipping season it has the potential to be disturbed up to 13 times. Meanwhile, narwhal core use areas had the potential to have up to 110 behavioural disturbance events from various vessel types in 2018. Moreover, these disturbance events could increase in the future due to the projected decreases of sea ice extent and the expected increases of shipping activity in the Arctic (Melia et al., 2016; Stephenson et al., 2013).

Underwater noise originating from vessels has a high potential for negative impacts on marine mammals in the Arctic (Halliday, Pine, & Insley, in press). For instance, belugas have been observed to avoid icebreakers and alter their behaviours for days after an icebreaker disturbed them (Finley et al., 1990), and likely also avoid vessels in the shallow Mackenzie River estuary (Halliday et al., 2019). Narwhals have been observed to temporarily stop all movement, and then flee from icebreakers (Finley et al., 1990), which jeopardizes their communication for breeding and hunting, and subsequently introduces direct negative impacts on survival (McWhinnie, Smallshaw, Serra-Sogas, O'Hara, & Canessa, 2017). Moreover, vessel noise has the potential to cause auditory masking in belugas, which diminishes the ability for the marine mammal to detect or even recognize a signal that it is listening for (Pine et al., 2018).

Furthermore the 120 dB threshold was chosen for this study because of the 2016 NOAA Technical Guidance document that synthesized scientific literature to produce updated acoustic thresholds for marine mammals affected by anthropogenic noise (National Marine Fisheries Service, 2016). However fixed numerical threshold themselves are not guaranteed representations of how marine mammals react in real life because there can be multiple factors that influence at which sound levels marine

mammals' behaviours will be disturbed, such as: the marine mammal's hearing sensitivity, the acoustic characteristic of the source and the context of exposure (Gomez et al., 2016). Given that various types of disturbances can occur, and most Arctic marine mammals are top predators in their ecosystems and they play an important role in supporting the ecosystem (Meek, Lauren Lovecraft, Varjopuro, Dowsley, & Dale, 2011), ensuring that marine mammals are not negatively impacted by vessel traffic is crucial to the ecosystems in Tallurutiup Imanga.

### **Observed wildlife areas**

Not only does vessel traffic have a potential negative impact on the behaviour and survival of these unique marine mammals, it also consequently impacts the traditional hunting of Inuit communities who depend on subsistence hunting because it is culturally important and nutritionally beneficial (Ford, 2012; Meek et al., 2011; Reeves et al., 2012). Among other animals, narwhals and belugas are both hunted by Inuit (Carter, Dawson, & Cook, 2019; Carter, Dawson, Joyce, et al., 2018; Wenzel, 2009). The food acquired by local hunters is more cost-effective than store-bought food, which also tends to be higher in fats and sugars and can lead to health problems like obesity and diabetes (Andrachuk & Smit, 2012; Donaldson et al., 2010; ITK, 2017; Meredith et al., 2019). The long-lived tradition of hunting in the Arctic is a crucial part of Inuit culture that is passed on from generations and enhances self-worth, as well as strong intercommunal relations that come from sharing the food and learned experiences (Pearce et al., 2015).

The noise footprints that overlapped the observed wildlife areas have some similarities and some differences with the noise footprint that overlapped core use areas and species range areas. Although there are differences between the two types of data, the results themselves were unique and both provide valuable input to this study. The overlaps of observed wildlife areas and noise footprints in Figure 29 showed that these areas undergo the potential for behavioural disturbance events as well. These observed wildlife use areas are culturally significant marine areas (CSMAs) identified by the key maritime knowledge holders in Resolute and Pond Inlet. Including this Inuit and local knowledge of CSMAs and combining it with scientific knowledge has great value and is vital when understanding impacts of shipping route (Chénier, Abado, Sabourin, & Tardif, 2017; Dawson et al., 2020). Key knowledge holders expressed concerns that vessel noise has negative impacts on the behaviours of wildlife, causing some animals to move away from the noise. In turn, this decreases the ability to successfully harvest country food since the hunters' abilities to know where animals are located are impacted; therefore, this leads to food insecurity and dependence on store-bought food (Carter,

Dawson, & Cook, 2019; Carter, Dawson, Joyce, et al., 2018). Further, their recommendations, like reduced speed zones show that they consider certain areas important to be protected from vessel traffic because they will minimize the disturbance to animals (Dawson et al., 2020). These community-based results should be used in a complementary way with the estimated PVC area overlaps to incorporate both western scientific knowledge and traditional knowledge for comprehensive decision making (Cobb, 2011). The areas themselves differ because of the methods in collecting the data. The observed wildlife data came from key knowledge holders from Resolute and Pond Inlet who are out on the land and water frequently so they are familiar with their surroundings, including the animals that they hunt and their estimated habitats. This can also be limiting because community members are limited in their travel based on how far they move from each of their communities. The PVC data is based off of telemetry data meaning that certain mammals were tagged and monitored through automatic transmission. Both types of knowledge should still be considered and used in tandem to ultimately manage the area. As is shown through the data collection there are multiple stakeholders who currently use the area and study the area; therefore, there are many people to consider in the protection of the NMCA (i.e. communities, researchers, government).

Furthermore, in Canada there is a legal and moral requirement for the Government of Canada to secure informed consent when taking actions which impact Indigenous peoples' rights, lands and resources (Department of Justice Canada, 2018). There is also the Arctic specific Nunavut Land Claims Agreement Act (usually referred to as the Nunavut Agreement) that provides the right for Inuit to participate in decision making for management and conservation of their lands, water and resources (Nunavut Land Claims Agreement Act, SC 1993, c 29,).

It is also crucial to note that not all the communities that travel through, hunt and harvest in Tallurutiup Imanga were included in the ACNV project. Grise Fiord, Arctic Bay and Clyde River are the other communities that are situated near TI and travel through the area to hunt. Therefore, the observed wildlife use areas were limited by the communities that were included in the study and how far they venture from each community. Furthermore, there may be other CMSAs that were not documented in the ACNV study because there were only 8 participants from Resolute and 9 from Pond Inlet; however, the results are representative of each community because they were verified with the rest of the community members' for validity (Carter, Dawson, & Cook, 2019; Carter, Dawson, Joyce, et al., 2018). If the three other communities participated in the ACNV project, the observed wildlife areas would probably be more spread out and would cover more over the NMCA. The Clyde River Knowledge Atlas is

an online platform that contains Inuit knowledge data from various projects in Clyde River, some of which represent CSMAAs (Ittaq Heritage and Research Centre, n.d.). The inclusion of different sources of CSMAAs like from the Clyde River Knowledge Atlas would help create a more inclusive data set for Tallurutiup Imanga. It is especially important to monitor the potential negative impacts of vessels on marine mammals because climate change itself is altering Inuit hunting habits, due to unexpected changes in sea ice dynamics and patterns in the weather that are not predictable anymore (Ford & Pearce, 2012; Ford et al., 2006; Pearce et al., 2015). Being able to potentially limit the impact of shipping on marine mammals, which is one these factors that could make hunting unsuccessful, is important to human wellbeing and ecosystem services in the region (Cunsolo Willox et al., 2013).

## **Management implications**

The congruency between areas with behavioural disturbance events and marine mammal core use area, as well as observed wildlife areas overlapping with behavioural disturbance events had the potential to cause negative impacts on the belugas and narwhals in Tallurutiup Imanga. This gives a strong indication that vessel mitigation measures and management plans are needed for future vessels that will be transiting the NMCA.

There are many vessel management tools that have been implemented in marine protected areas in the past; however, few are Arctic-specific. The main categories of vessel management tools as explored by McWhinnie et al. (2018) are: spatial tools, vessel tools, monitoring tools and outreach tools. Of the spatial tools, the two that were most commonly used in marine protected areas were voluntary speed restrictions and voluntary avoidance areas, of which speed restrictions would be more feasible for the Arctic seeing as avoidance areas might not be possible due to the geographical limitations and navigational hazards presents in this region (McWhinnie et al., 2018). For example, voluntary speed limits such as the one in the Salish Sea (Vancouver Fraser Port Authority, 2018) could be implemented to help decrease the vessel source levels, and therefore received levels of vessels. It is uncertain to which degree vessel slowdown regulations would reduce the acoustic risk for marine mammals in Tallurutiup Imanga; therefore, future work should be done to analyze the effects of slowdown mitigations on noise exposure. Speed reduction generally leads to a reduction in source level (MacGillivray, Li, Hannay, Trounce, & Robinson, 2019) and this would lead to a reduction in the received level, which for the scope of this project reduces the radius around the ship that the 120 dB threshold is surpassed. For example, a ship with a source level of 188 dB has a 120 dB range of roughly 10 km, given a transmission loss value of  $17 \log R$ . If there was a speed reduction which caused the source level to be 185 dB, the range would

decrease to 6 km, and if the source level was 182 dB, the range would be 4 km. This all assumes that the transmission loss value remains identical between those three source levels.

Project-related bulk carrier vessels from Mary River Mine have already implemented slowdowns to 9 knots in the shipping corridors in Milne Inlet (Golder Associates, 2018; QIA, 2019); therefore, ship speed of bulk carriers is already being managed close to the mine. The potential reduced source levels of bulk carriers as part of the Mary River Mine operation were not taken into account in this study, and more details about the source levels of specific vessels would be required to determine if the slowdown alone was sufficient to reduce the number of noise disturbance events within that area. However, even with the speed limitations, slow ships will still cause some behavioural disturbance. Furthermore, other vessels travelling through that region do not have slowdowns implemented and were recorded going up to 15.9 knots in 2017 (Golder Associates, 2018), which indicates that there were vessels of other classes transiting the region that could have had a higher potential to cause behavioural disturbance events.

Moreover, as part of the Arctic Corridors and Northern Voices (ACNV) research project, 14 communities in the Canadian Arctic identified recommendations for the low impact shipping corridors, which are marine transportation corridors being developed by the Government of Canada that will provide safe shipping throughout the Arctic (Dawson et al., 2020; Transport Canada, 2017). The local knowledge holders in all of the communities identified spatial management tools to limit the impact of marine vessel traffic on marine mammals in the shipping corridors. Some common recommendations suggested were: avoid specific wildlife habitats; move existing corridors further away from shorelines; restrict shipping during harvesting, animal migrations, and ice freeze-up; chart existing and future corridors; and, create vessel slowdown area (Dawson et al., 2020). While the community identified recommendations have not yet been legislated, it is a crucial and important step to document and consider local and traditional knowledge in the protection of the Arctic coast and water (Dawson et al., 2020).

Another method to help reduce the potential impact of underwater vessel noise on marine mammals is the maintenance of hulls and propellers and the incorporation of new designs to quiet vessel movement (Clear Seas, 2018; DFO, 2017). Currently there are no mandatory requirements for quiet ship designs, but the IMO has produced guidelines for the reduction of underwater noise from commercial ships to specifically address the impact on marine life (IMO, 2014). These guidelines can be adopted by vessels transiting Tallurutiup Imanga to try and reduce underwater vessel noise.

As studies like this one add to the scientific knowledge foundation, and strengthen and accumulate to close knowledge gaps, the precautionary principle should be applied to ensure that marine mammals in Tallurutiup Imanga are still protected during the time when some research results are not yet available (DFO, 2005; Moore et al., 2012). In fact, the primary considerations for the development and modification of management plans for National Marine Conservation Areas in Canada are, principles of ecosystem management and the precautionary principle (DFO, 2015; Parks Canada, 2019c).

This study estimated core use areas for belugas and narwhals in Tallurutiup Imanga based on satellite telemetry data. Through the Arctic Corridors and Northern Voices project ([arcticcorridors.ca](http://arcticcorridors.ca)), local and Inuit knowledge holders from Pond Inlet and Resolute identified regions that belugas, narwhals and bowheads used. There was limited overlap of the marine mammal CSMAs and the 50 % and 95% PVCs from this study; however, in general they were different. Because of this, the results of the noise footprint were different for the two methodologies, but were equally important to include because the use of traditional knowledge and scientific knowledge leads to more comprehensive decision-making (Cobb, 2011) and can result in new insights and in ongoing partnerships between communities and external institutions (Johnson et al., 2015). Furthermore, the difference in the results from the two types of knowledge could have advantages within management of the area. Since the areas are different, once combined they cover more area than they would cover if they were considered separately. This will increase the area that is considered for management, and will consider multiple stakeholders. On the contrary, if there is a bias towards one type of data during management this could negatively impact future management if some areas are not included. For example, if the community-based data contains an area that is unique and not covered by the PVC data, this area might not be considered for management and this would greatly impact that community for whom it has ecological and cultural value.

The current lack of vessel management in Tallurutiup Imanga, and the results of this study reiterate the need for policy makers to develop and put into practice various ship-related legislations to mitigate the potential impacts of underwater vessel noise on marine mammals in Tallurutiup Imanga. The marine mammal CSMAs from the ACNV project could be used to establish areas of vessel avoidance or slow down to keep the management plans for the NMCA in motion. Once scientific literature is published about the modelled or measured impact of underwater vessel noise in Tallurutiup Imanga, it should be used in tandem with the Inuit and local knowledge. The NMCA is the only possible pathway for vessels transiting the eastern entrance of the Northwest Passage, but it is also home to a multitude of animals,

such as migratory marine mammal species like belugas and narwhals, seabirds, fish, and to Inuit who hunt and harvest in the area. Therefore, it is of the utmost importance to find management options that will mitigate the potential negative impacts of vessel traffic.

## 4.5 Conclusion

In 2018 vessels of all categories travelled an average of 74 km per 100 km<sup>2</sup> in Tallurutiup Imanga, compared to 65 km in 2017, 46 km in 2016 and 26 km in 2015. During the study period bulk carriers, passenger ships, government vessels and icebreakers, pleasure crafts and general cargo were the vessel categories that made up the most total annual kilometres travelled (average of 91,517 km). Based on AIS ship tracks for all vessel categories, noise footprints were modelled and then limited to the 50% PVC core use areas of belugas and narwhals and to the observed wildlife areas. The results show that there were higher numbers of behavioural disturbance events (received level exceeding 120 dB) on the northeastern coast of Devon Island, and Admiralty Inlet and Eclipse Sound. Belugas, narwhals and bowheads are at risk of ship noise exposure, especially from cargo vessel and cruise ships which produced the most behavioural disturbance events, and this risk will only increase with the expected increases in shipping activity in the Canadian Arctic (Lasserre & Pelletier, 2011; Melia et al., 2016; Stephenson et al., 2013). The results in this study can help to inform the upcoming decisions related to ship traffic in the NMCA and reiterate the importance of including both local and Inuit knowledge as well as western science. This comes at a time when the interim management plan for the area is being discussed and although the IIBA does not include any restrictions or rules for shipping in the NMCA, several methods can be implemented that could address this issue of ship-source noise exposure that could potentially impact the marine mammals. Vessel management tools as outlined by McWhinnie et al. (2018) could be implemented in the NMCA. A mix of the four tools (spatial, vessel, tools and outreach) could be applied, but it is also important to note the uniqueness in the Arctic. For example, ice cover and remoteness are two factors that are unique to a NMCA in the Arctic, so it will be crucial to assess the possible management tools and keep these factors in mind.

Furthermore, with increases in shipping frequency, there are consequently environmental, cultural and economic impacts associated with these trends (Arctic Council, 2009; Huntington et al., 2015). In terms of other environmental disturbances there are possibilities of ship strikes, invasive species originating from ballast waters and hull fouling, air pollution from emissions, and water pollution from waste disposals (Arctic Council, 2009; Huntington et al., 2015). There are also positive impacts associated with increases in Arctic shipping, like the deliveries of cargo to each community, which are essential (Arctic

Council, 2009; ITK, 2017), and have lower costs and higher volumes of supplies than air supply (Giguère et al., 2017). Economic development also has the potential to benefit from increases shipping as this would support mining, tourism and fisheries (Hodgson, Russell, & Megannety, 2014; Pelletier & Guy, 2015).

Because of the complexity associated with shipping in the Canadian Arctic it is important to address potential issues of the increases in vessel traffic before they cause harm in the future. This study helps to support decision and policy makers in their plans to manage vessels in Tallurutiup Imanga, with a focus on the potential impacts of underwater noise from ships.

# Chapter 5: Contributions, limitations and recommendations for further research

## 5.1 Contributions

There is currently one study published about the potential impacts of underwater ship noise on marine mammals in the TI area and it was released long before the NMCA designation (Finley et al., 1990). Chapters 2, 3 and 4 made a contribution to this research gap that exists for the newly formed NMCA, and provided a comprehensive investigation on areas of potential underwater noise risks to belugas and narwhals.

Chapters 2 and 3 provided spatial and temporal overviews of the vessel traffic trends in Tallurutiup Imanga from 1990 to 2018. This data which spans a long spatiotemporal time period, is beneficial for stakeholders like Transport Canada and can be used a tool to understand the past trends of traffic in the region. Chapter 3 was written as a technical report (Kochanowicz et al., 2020; see [www.arcticcorridors.ca/repots](http://www.arcticcorridors.ca/repots)) and it was used to support the Nunavut General Monitoring Program (NGMP). The NGMP collects and analyzes data about ecosystems and socio-economic topics in Nunavut so that research gaps can be identified and long-term information about the environment, communities and economy in Nunavut can be collected (Nunavut General Monitoring Plan, 2019). An understanding of the changing trends in Tallurutiup Imanga could also help federal decision makers to distribute or invest in various resources to ensure a more safe and sustainable shipping environment. Notably, in 2016 the Government of Canada announced that it launched a \$1.5 billion, 5-year Oceans Protection Plan to ensure safer, cleaner and healthier oceans (Transport Canada, 2019). Part of this initiative includes a focus on the Canadian Arctic: improvements in community re-supply operations, and building infrastructure to ensure safe and efficient sealift operations (Transport Canada, 2020).

The research in Chapter 4 built on findings in Chapter 3 and identified areas in TI where there is a higher risk for marine mammals to be behaviorally disturbed by ships. This research contributed to many avenues. Firstly, this study partly answered to principle 1.16 in the Tallurutiup Imanga IIBA :“Threats to Tallurutiup Imanga NMCA ecosystem and its wildlife populations including from climate change, will be monitored” (Parks Canada, 2019b). The results of this research were one way to monitor the possible negative impacts to marine mammals in the region. Furthermore, as previously mentioned, the final

management plan for the NMCA will be established over the coming 5 years and this research could help to inform that process in terms of possible risks to marine mammals in the NMCA.

Chapter 4 also contributed to the Polar Code which is a mandatory code of conduct that exists to increase the safety of the operations of international ships and to mitigate the impacts on people and the environment in the Arctic (IMO, 2017). Section 11.3 states that the master of a ship travelling through polar waters, must take into account information that relates to known areas with densities of marine mammals (IMO, 2017). Therefore, the estimated core use areas of belugas and narwhals in this study could be used by vessels as areas of avoidance, or speed restricted areas. This study also directly responded to the recommendation in the Arctic Council's Arctic Marine Shipping Assessment 2009 Report, to further assess the effects of ship noise on marine mammals (Arctic Council, 2009).

## **5.2 Limitations**

In each of the methods in Chapter 3 and 4 there were limitations that need to be acknowledged. In Chapter 3 the model that was used to develop shipping trends from NORDREG data was found to sometimes overestimate the kilometres travelled or estimated vessel tracks to be further from shore than in reality. Although AIS data is more geographically precise, this method was used in Chapter 3 to provide historic shipping trends since 1990, instead of AIS because of the lack of AIS data prior to 2012.

In Chapter 4, some limitations originated from the noise modelling in dBSea. As with any model, the parameters are not perfect and sometimes differ slightly from reality. For example, a better model would have used more detailed information for bathymetry, sound speed profile, and sediment, as well as true source levels for individual ships. For the transmission loss equations, different zones were established based on broad geographic regions so this means that in some transition areas the bathymetry changes abruptly; this does not reflect the natural slopes and variability of the ocean floor. The sediment type used for the transmission loss calculation is not exactly precise, but it is the best option that exists for the region. The data was collected by Letaïef et al. (2018) aboard the Amundsen in 2014 and although some data in the region was collected, the final values are based on interpolation.

One challenge in the noise propagation modelling was that the spatial resolution of all inputs was defined by the bathymetry level, which in this case was 500m because they data came from International Bathymetric Chart of the Arctic Ocean, but it was the most current and accurate data of the Arctic at this time. Another limitation was that the final outputs for each year of the study represented the entire shipping season (July 19 and October 10). This means that the output

represented the maximum number of times that a ship could transit a particular grid cell in one shipping season, and there was a possibility that they were not all individual ships, but a few ships going back and forth through the grid cell multiple times. Nonetheless, it was appropriate to complete the noise modelling per year, because the computation time to model the outputs otherwise would have taken too long for this project. The noise modelling was done over a monthly scale and then combined for the entire shipping season, for every year. The computation time for modelling every day or week, of each of the 4 years would have been too long for the timeline of this specific research project.

As for the kernel density estimations, some limitations existed as well. Since the data from the Canadian Arctic did not fully represent all of the marine mammals that migrate to TI (Yurkowski et al., 2018) data from Mads Peter Heide-Jørgensen, from the Greenland Institute of Natural Resources was included as well. This data came in a slightly different format than the Canadian data. The data from Yurkowski et al. (2018) contained one modelled point per day (midnight UTC) originating from satellite telemetry data, while the data from Greenland was also modelled positions but at all different times of day. To make the data as consistent as possible, only one point (i.e. of one individual animal) of the Greenland data was used per day. This does not make a big difference in the data because the important factor is to have one point per day, not matter what time of day it was taken at.

### **5.3 Recommendations for further research**

There are multiple future research needs in the Tallurutiup Imanga NMCA, and they should begin as soon as possible because of the managements plans that are currently being written by the Government of Canada, Nunavut and the QIA.

In terms of marine mammal specific research, there needs to be multiple monitoring and tracking programs for marine mammals to find out where the animals are in reality; furthermore, if they have changed their core use areas over time. Research like this could be done by Inuit which empowers Inuit, creates a stronger base of research and incorporates knowledge sharing and knowledge interpretation (Snook, Cunsolo, & Dale, 2018). Furthermore, there should be acoustic recording done in Tallurutiup Imanga to measure direct received levels of multiple vessel types in the region. This study relied on the modelling of ship noise footprints, so received levels measured by multiple hydrophones would be more accurate to model ship noise directly, and could be used to predict potential areas of behavioural disturbance events more precisely, especially as the shipping season lengthens in the Canadian Arctic (Stroeve, Markus, Boisvert, Miller, & Barrett, 2014). It can be possible as well to record in areas where

ships overlap core use areas of marine mammals to catch a glimpse of their behavioural reactions. It will be important to collect the data consistently to be able to see when vocal marine mammals and ships are both present. Although not all behavioural disturbance events can be caught in audio recordings, some scenario like changes in vocalizations and the mammals leaving the area due to ship presence could be documented (Finley et al., 1990). This recommendation also directly answers to principle 1.16 in the Tallurutiup Imanga IIBA, which states that threats to the wildlife populations in TI will be monitored (Parks Canada, 2019b).

In terms of shipping trends, AIS data should continue to be analyzed for this region and could even be modelled for future trends to reveal possible vessel traffic trends in the upcoming future. This would help the policy makers to better prepare for the future traffics trends and the possible consequent impacts of these vessels. Future research should aim to incorporate multiple stakeholders, academic researchers, decision makers, and community members because the future of the Tallurutiup Imanga National Marine Conservation Area will impact this whole network of people.

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## Appendix

### A. Details from the CTD cast measurements used to calculate average sound speed profile for the study area

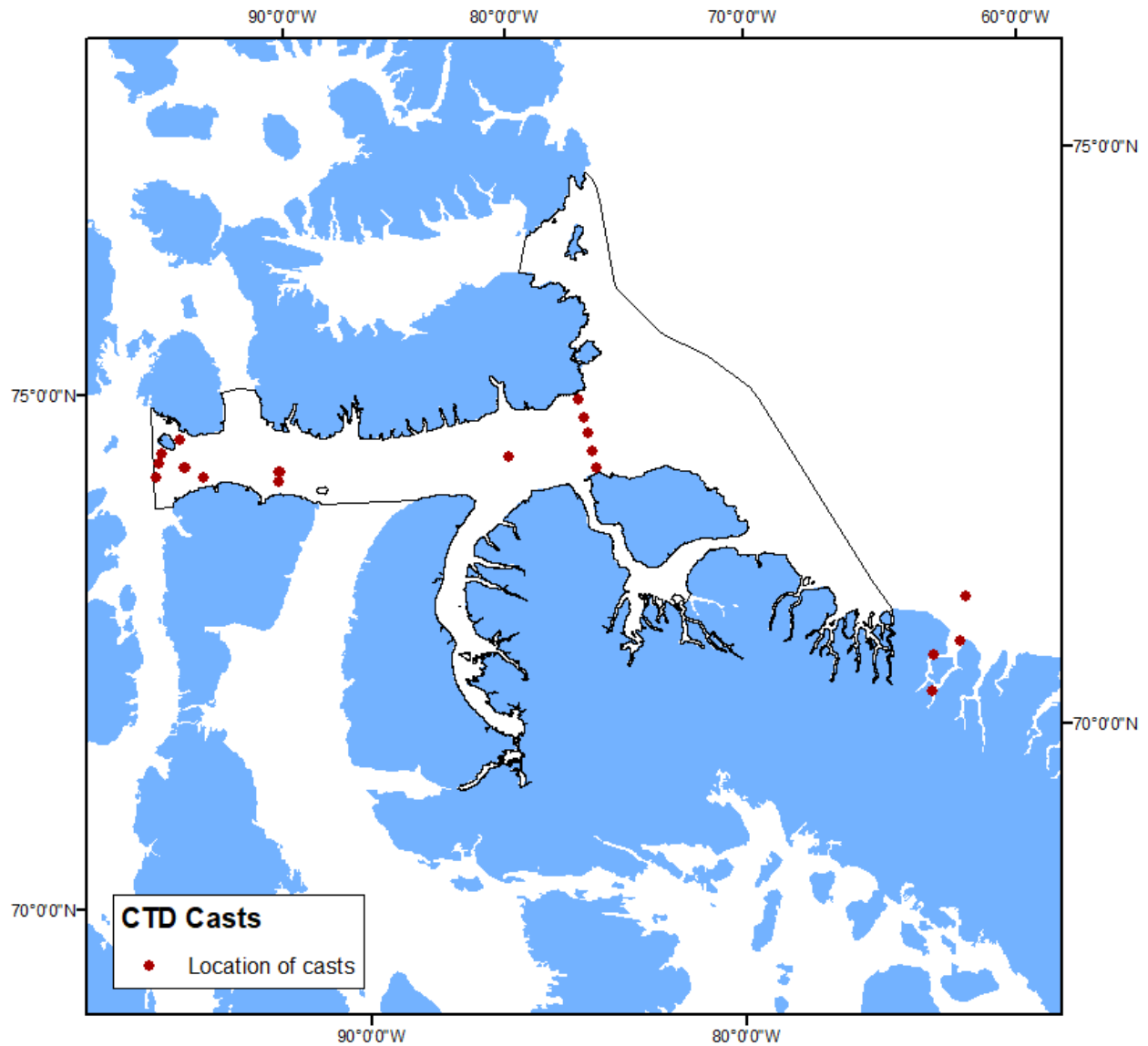


Figure 29. Conductivity, Temperature and Depth measurements taken aboard the Amundsen in 2014; data acquired from the Polar Data Catalogue (<https://www.polardata.ca>).

## B. 50 % PVC beluga core use areas overlapping with shipping noise footprints

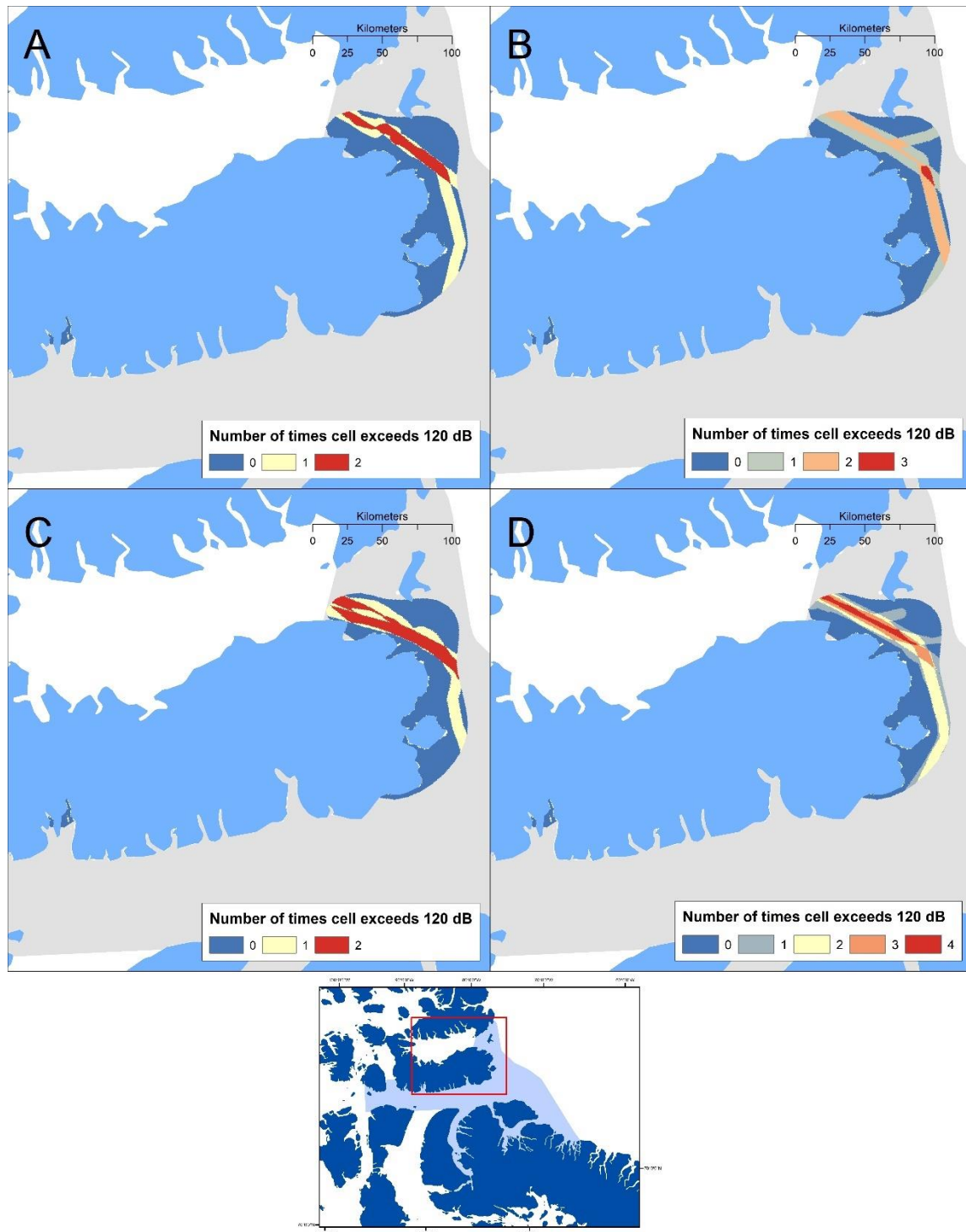


Figure 30. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for cargo ships, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

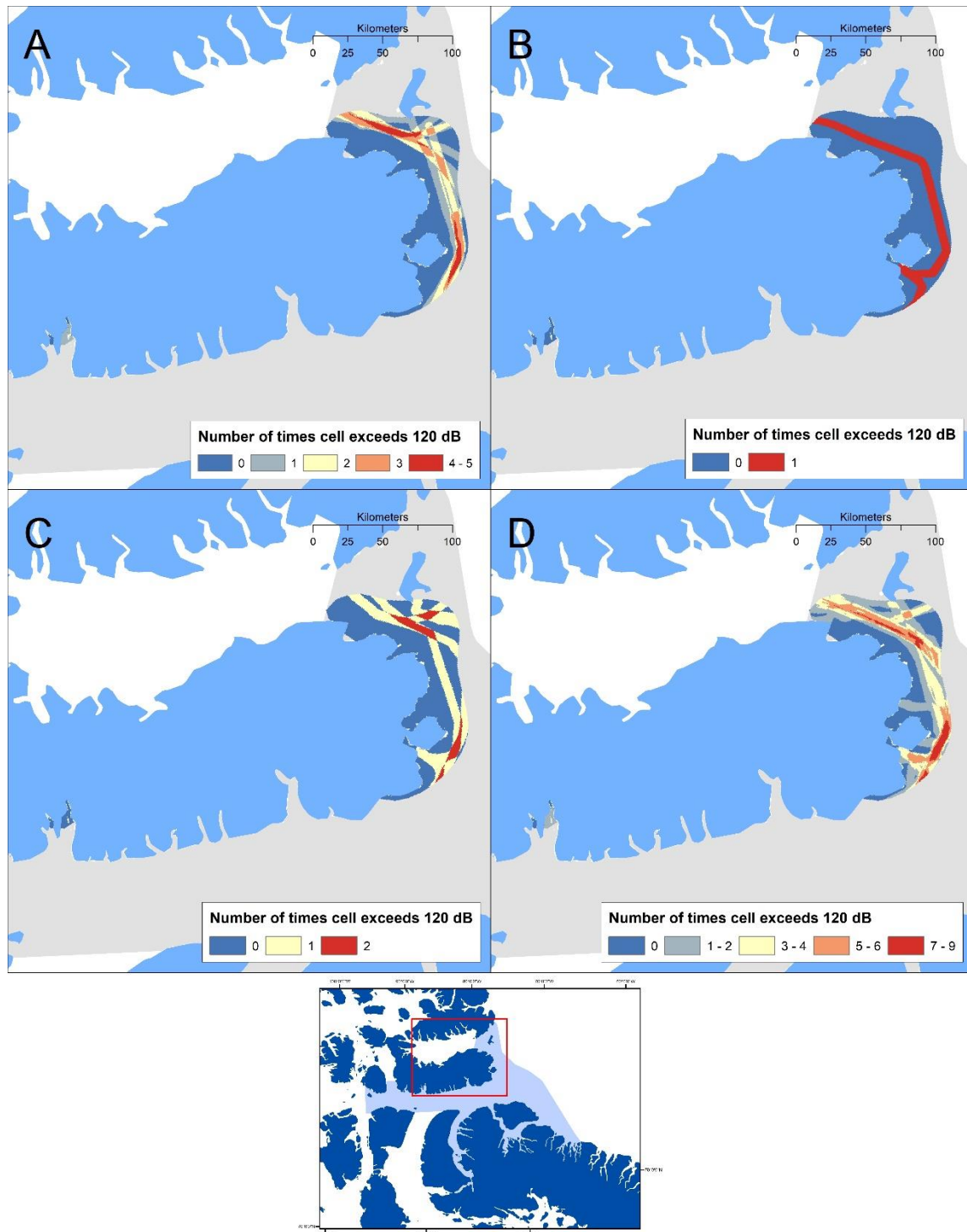


Figure 31. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for cruise ships, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

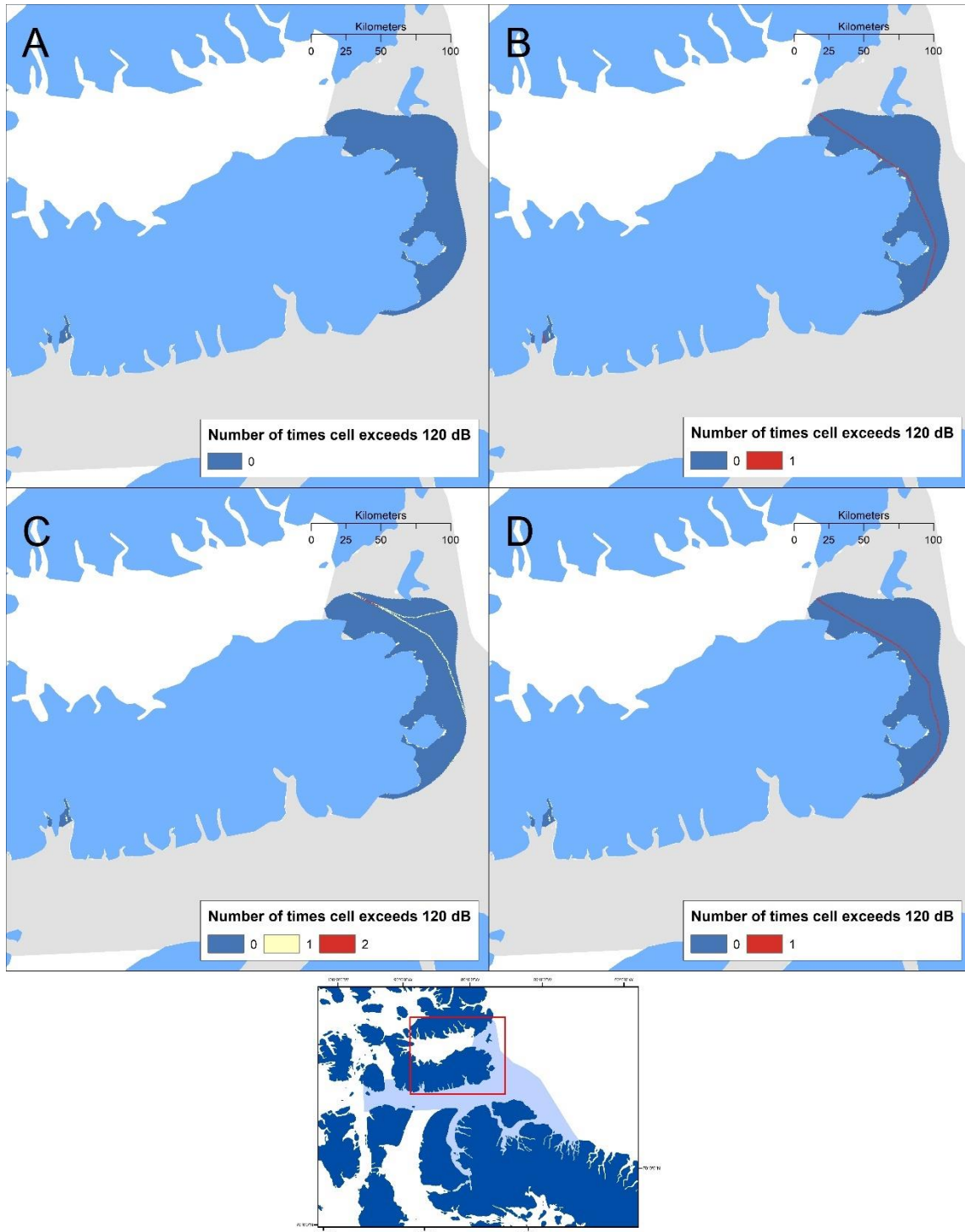


Figure 32. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for fishing vessels, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

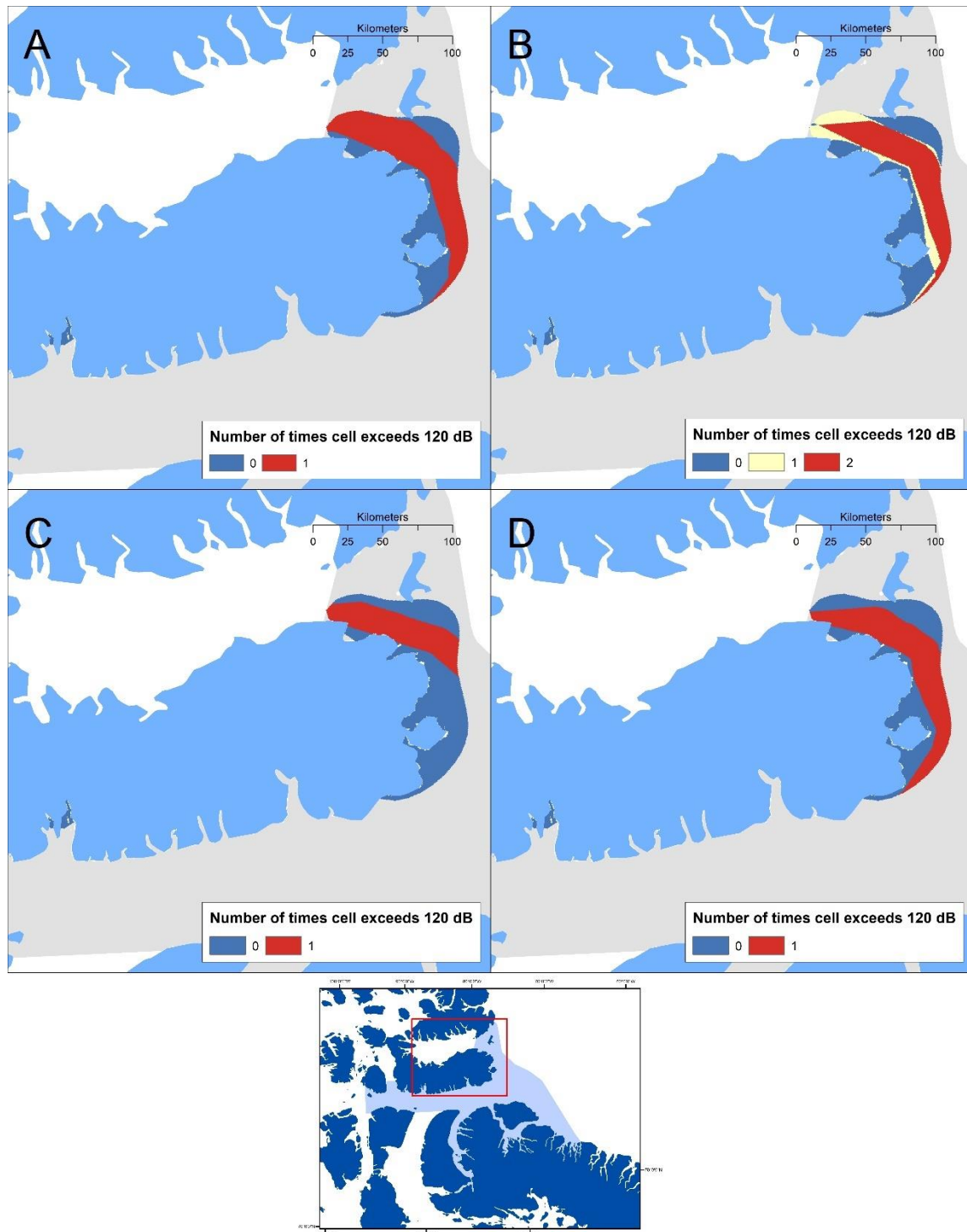


Figure 33. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for government vessels and icebreakers, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

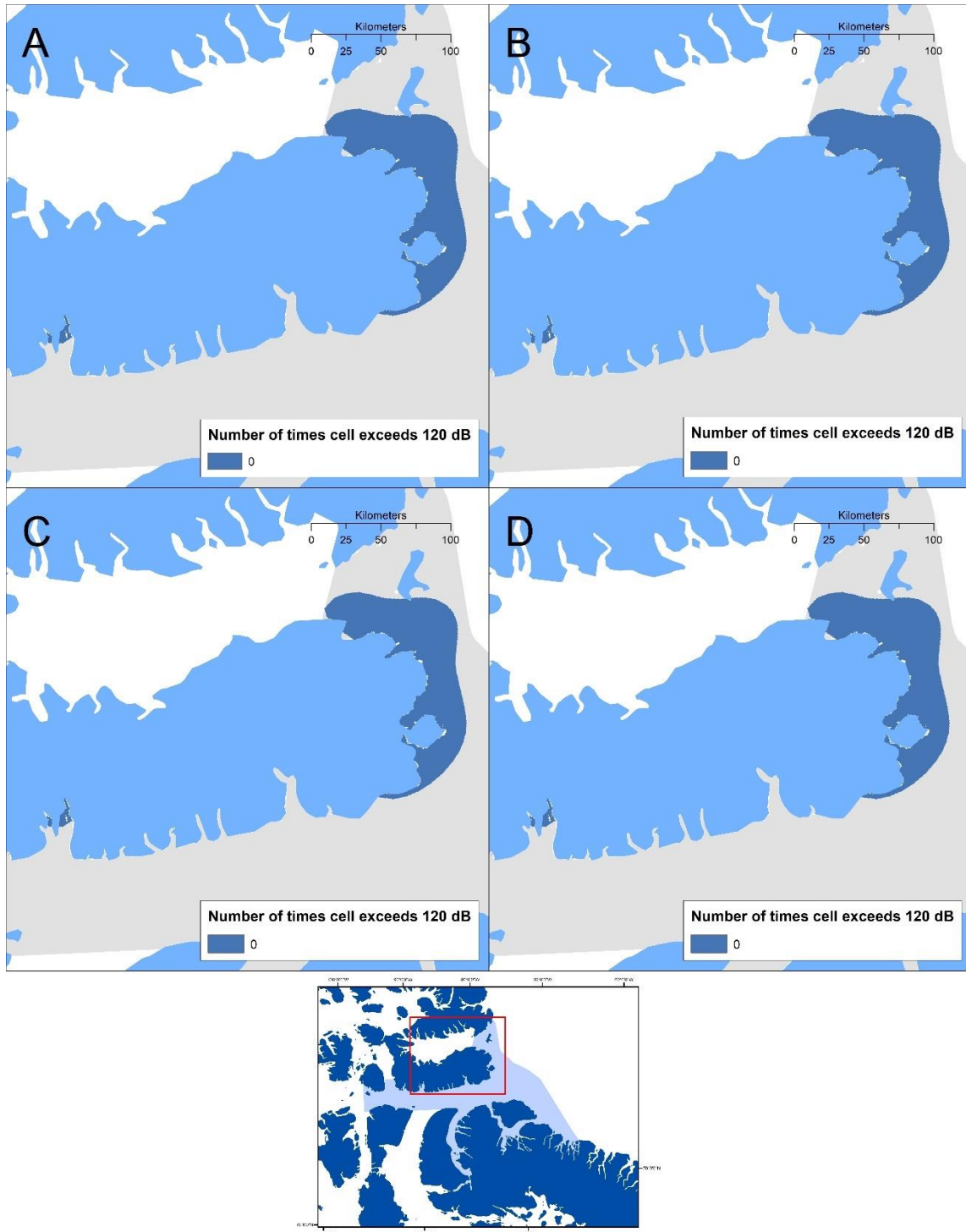


Figure 34. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for military ships, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

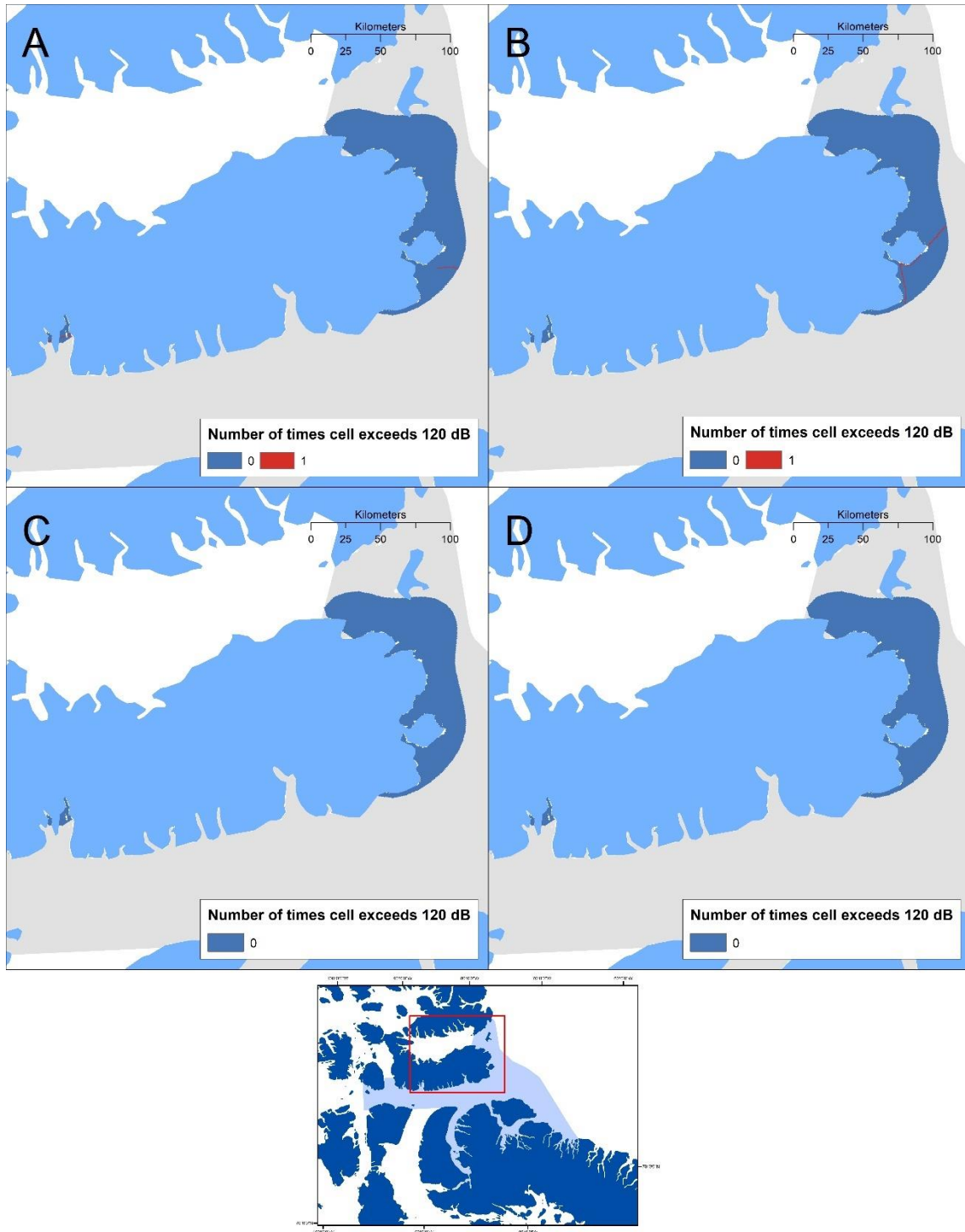


Figure 35. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for recreational vessels, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

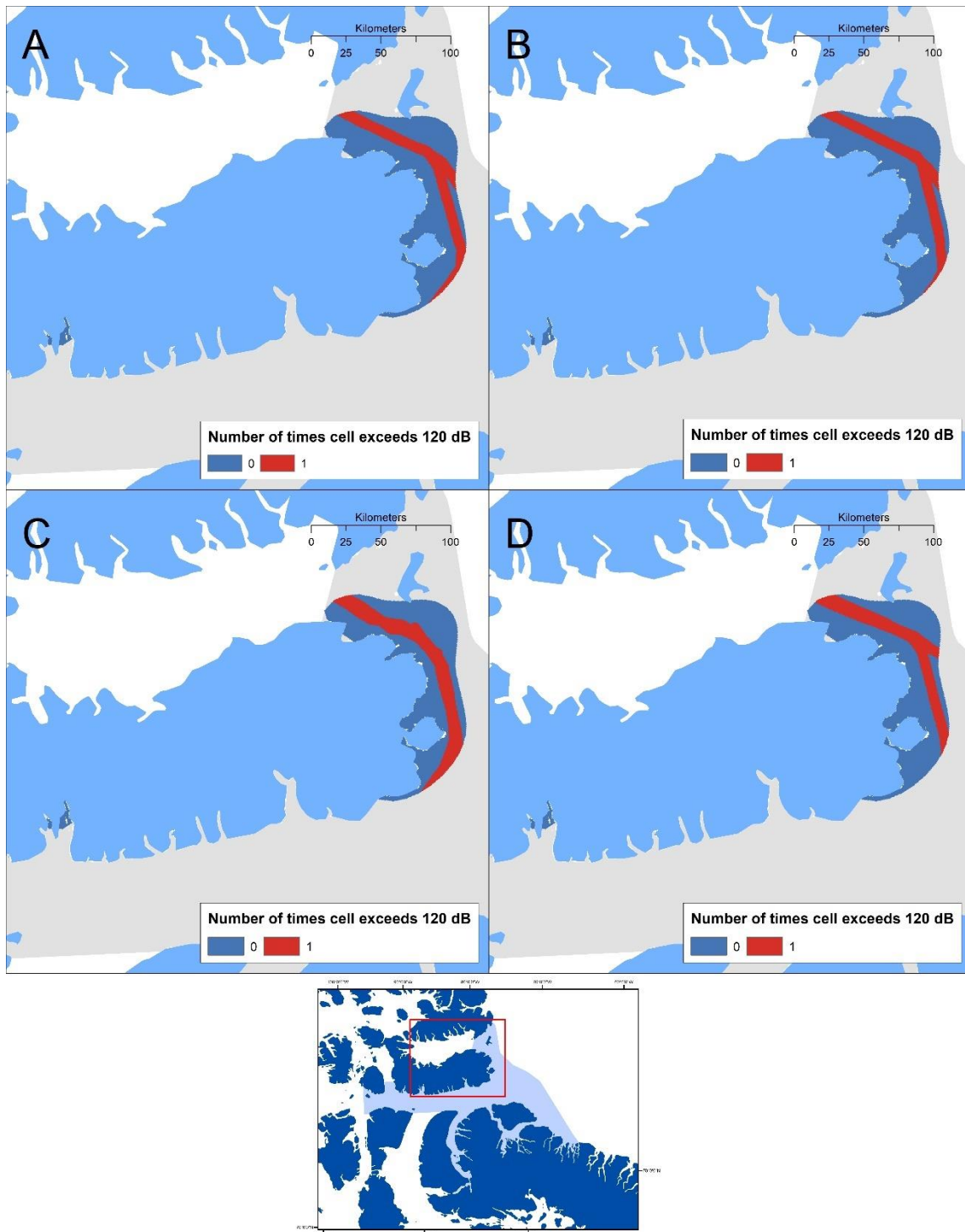


Figure 36. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for tankers, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

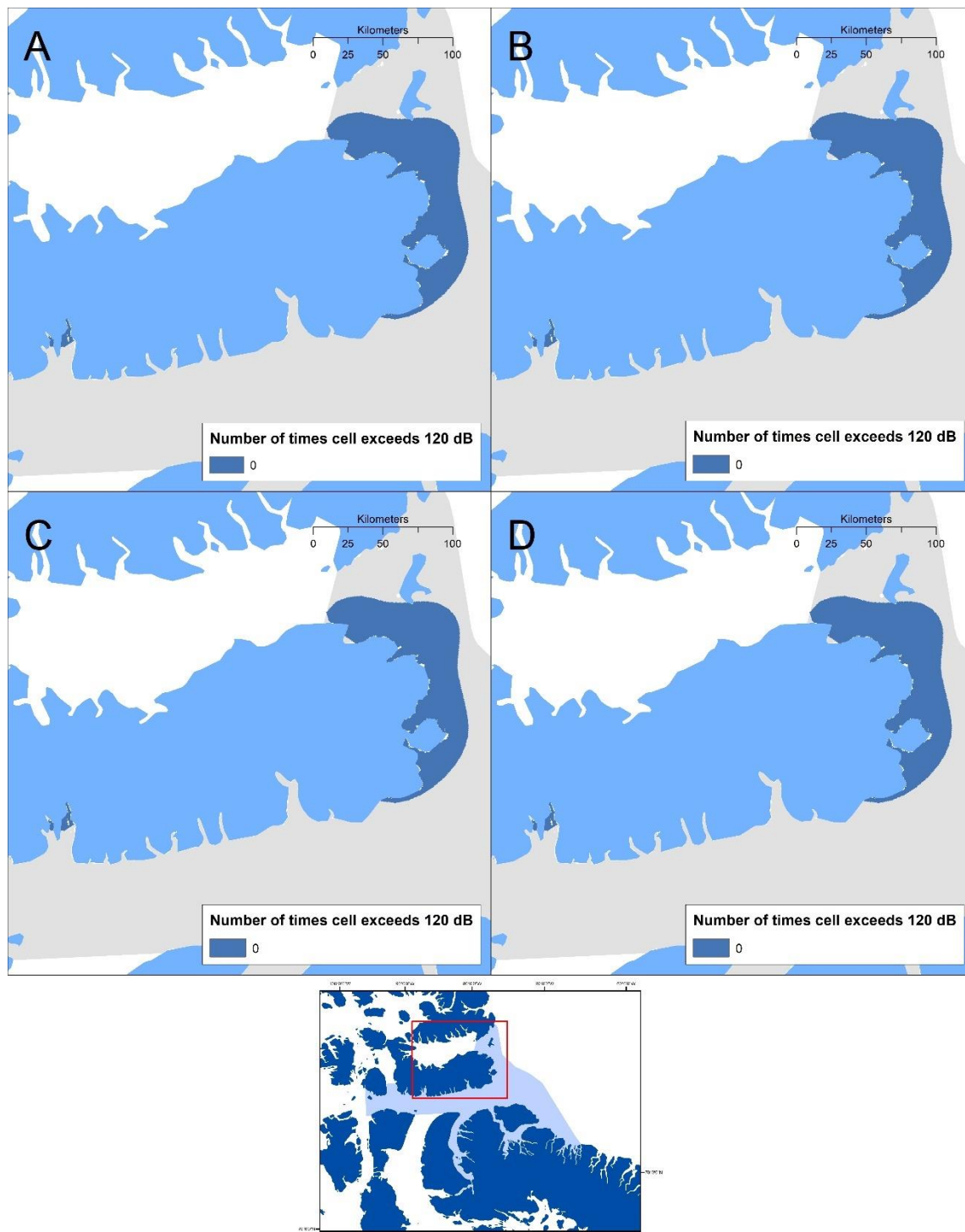


Figure 37. Number of times that each 500 m cell in the grid exceed the value of 120 dB, tugs, in the beluga core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

**C. 50 % PVC narwhal core use areas overlapping with shipping noise footprints**

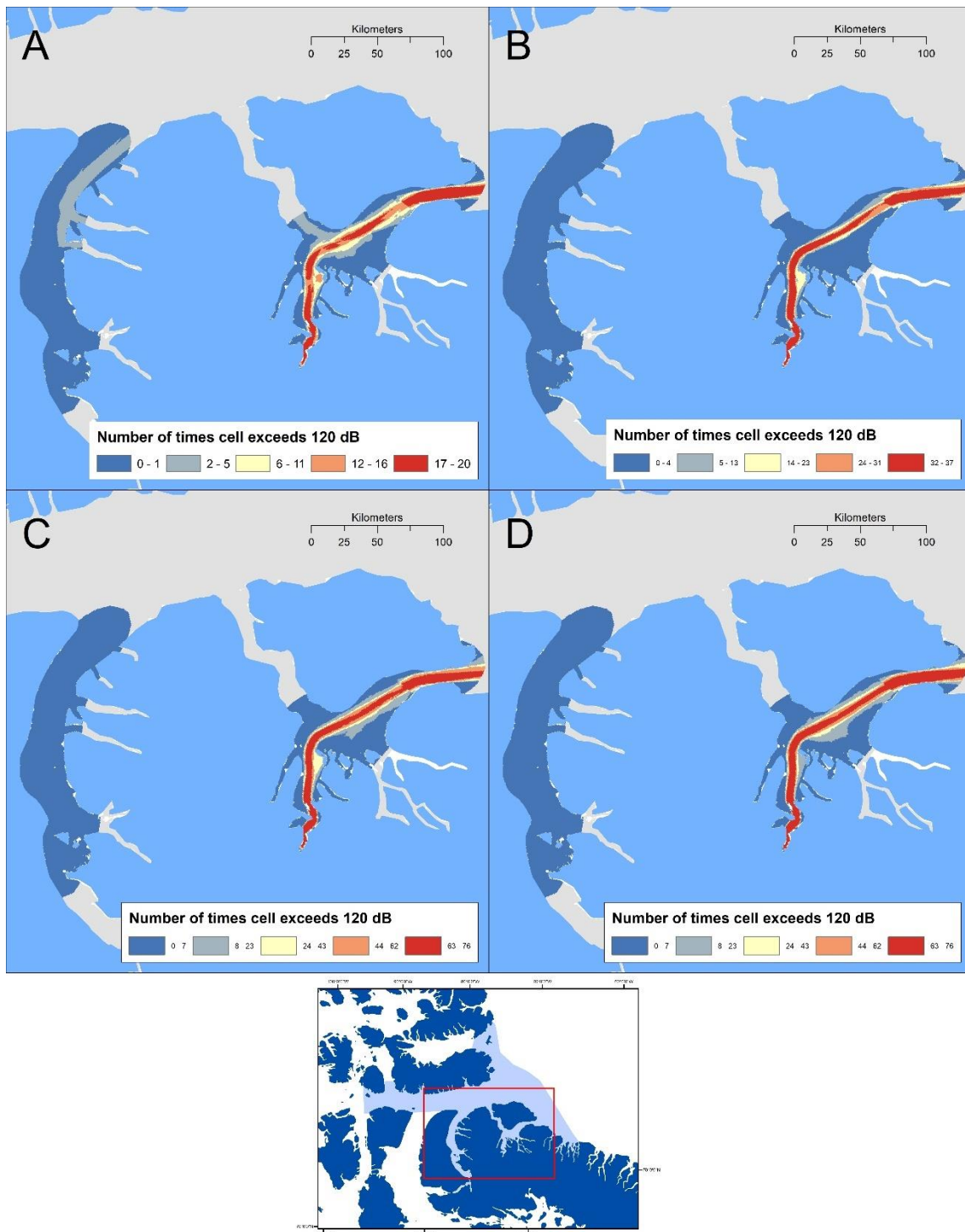


Figure 38. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for cargo ships, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

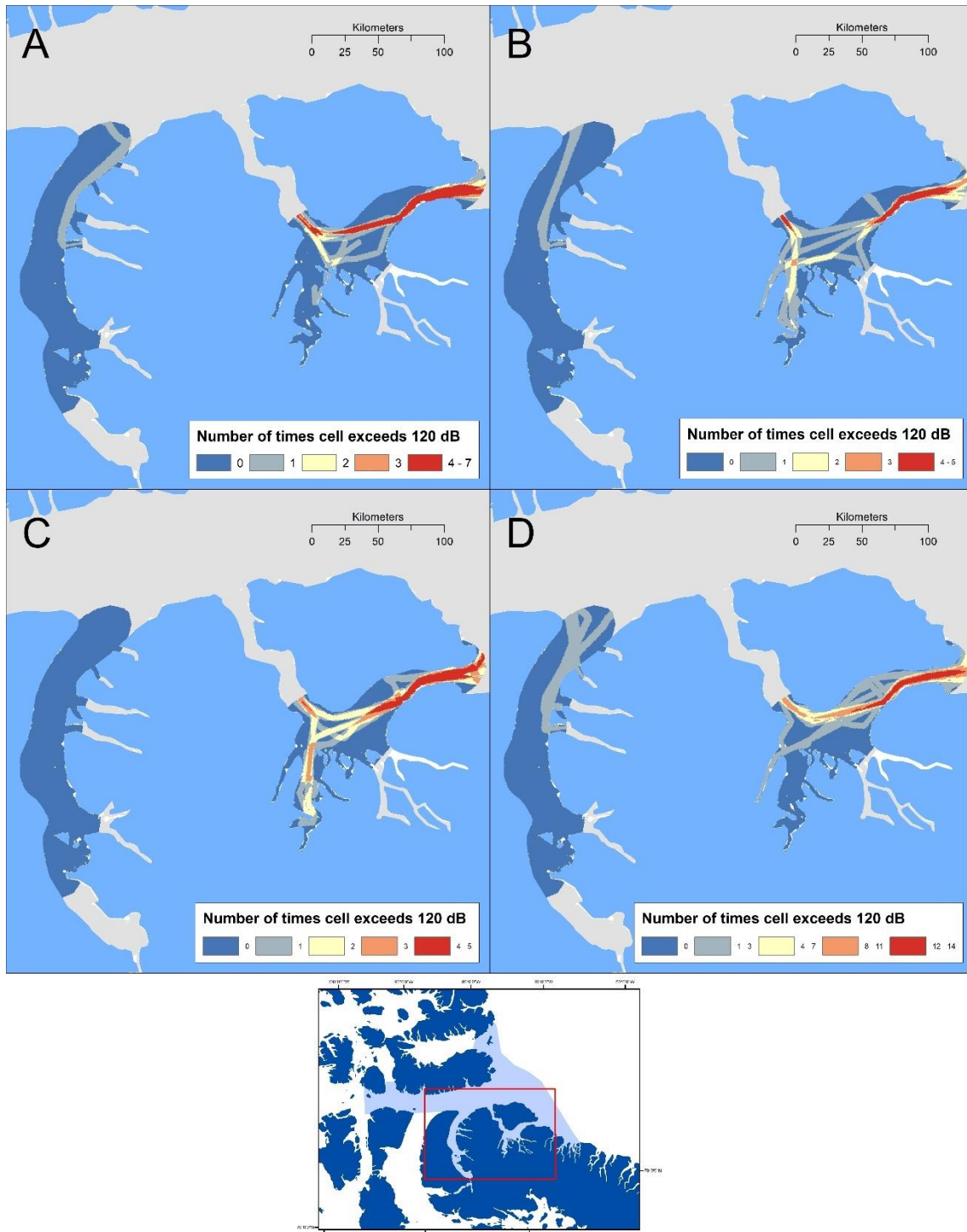


Figure 39. Number of times that each 500 m cell in the grid exceeded the value of 120 dB, for cruise ships, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

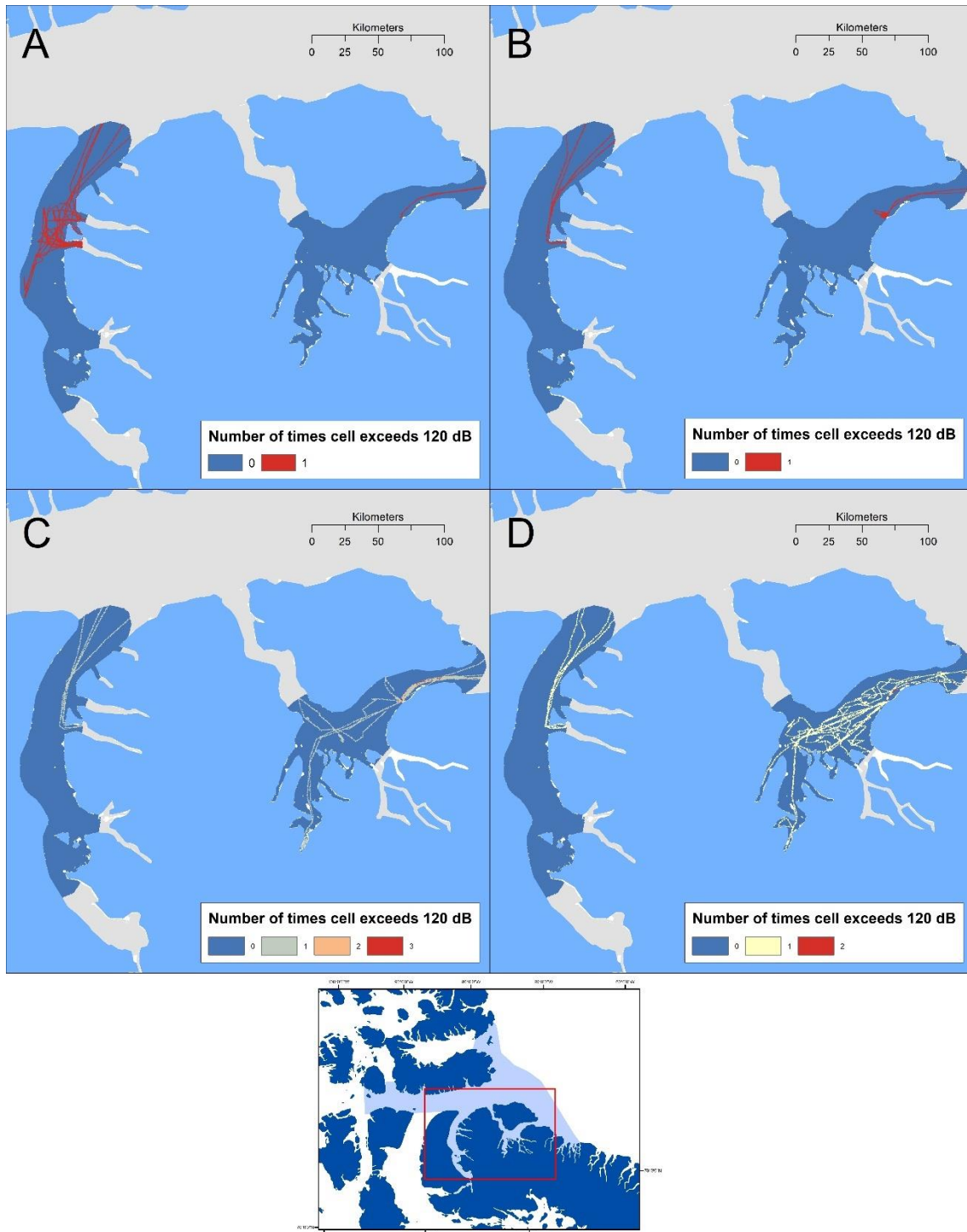


Figure 40. Number of times that each 500 m cell in the grid exceeded the value of 120 dB, for fishing vessels, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

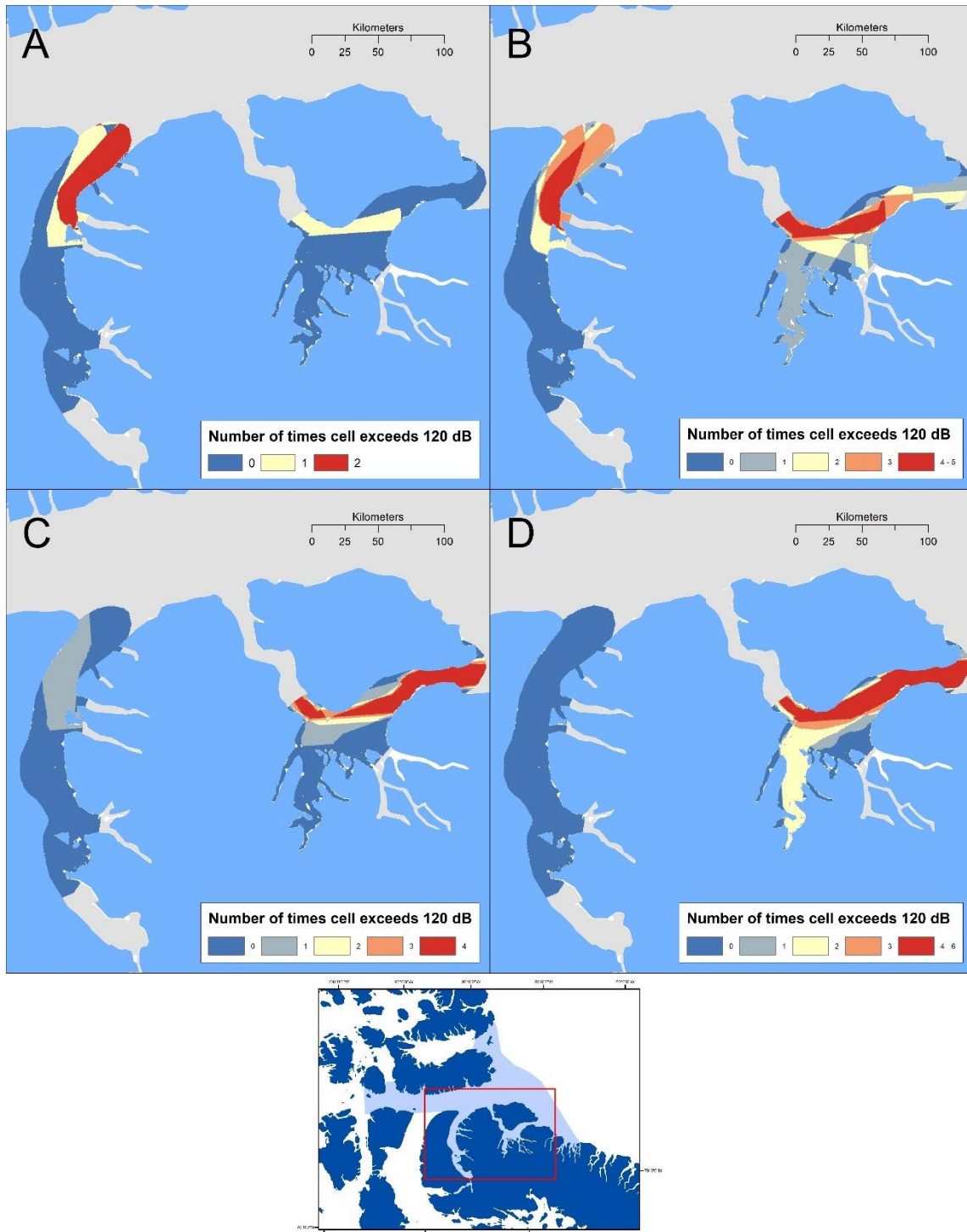


Figure 41. Number of times that each 500 m cell in the grid exceed the value of 120 dB, government vessels and icebreakers in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

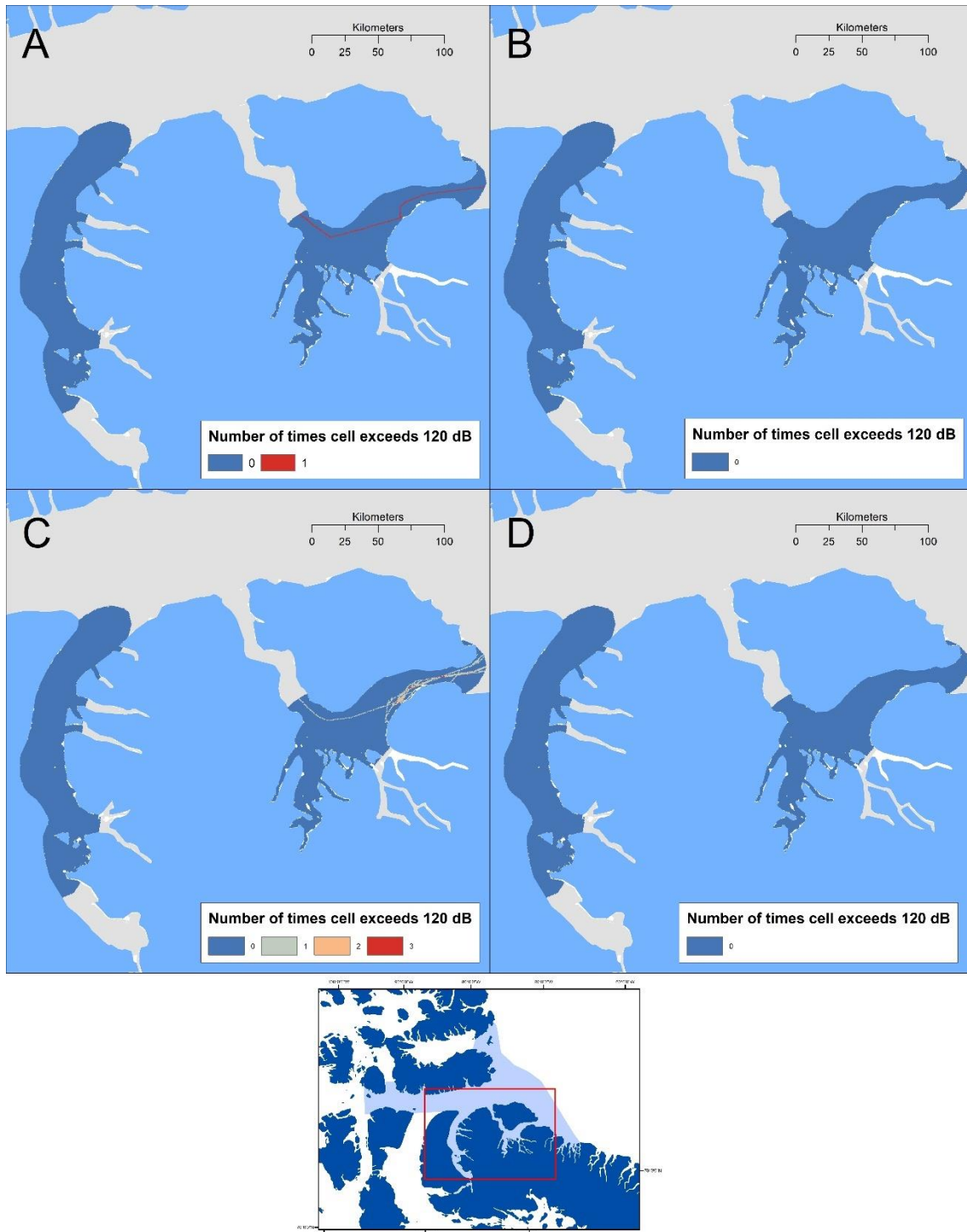


Figure 42. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for military vessels, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

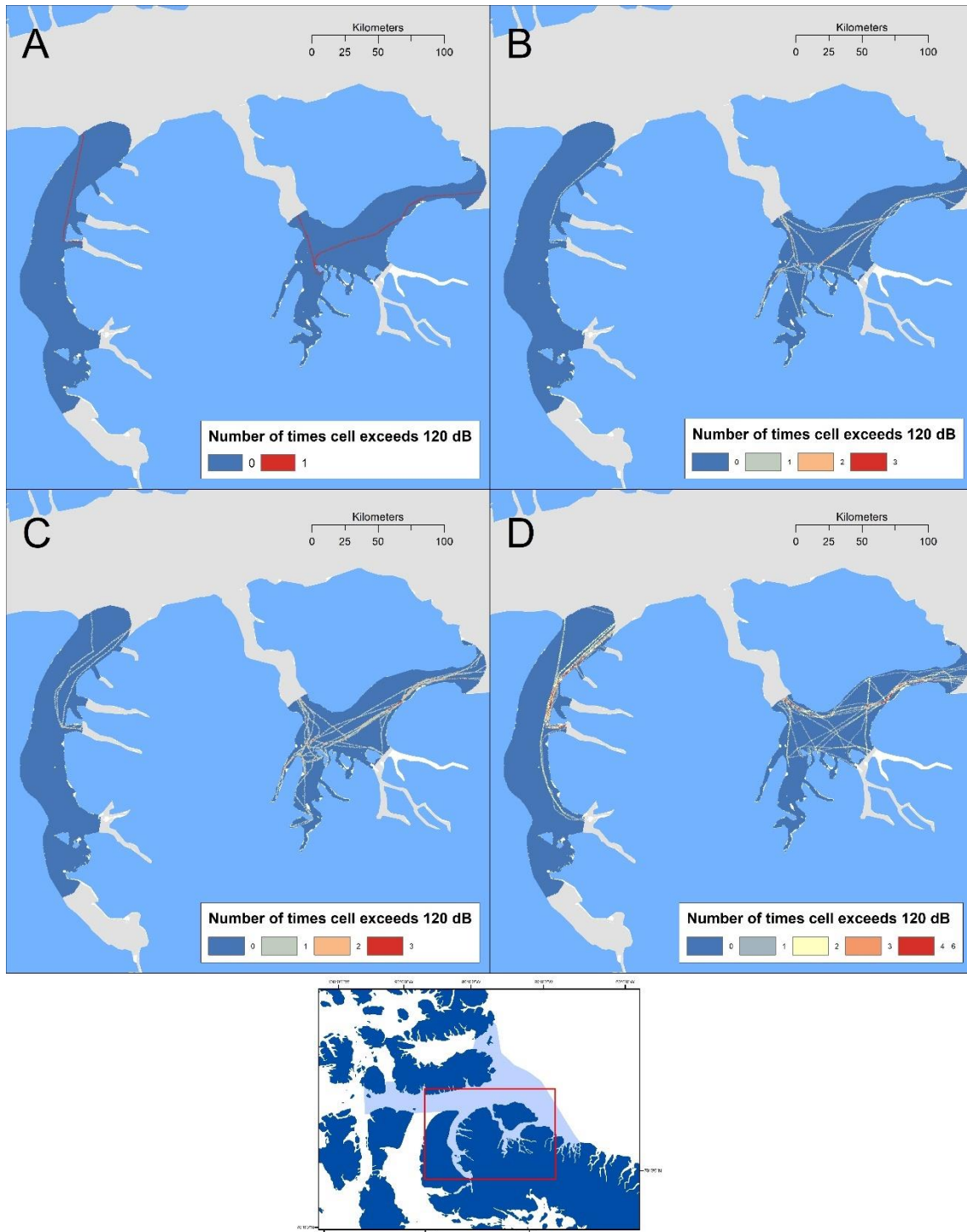


Figure 43. Number of times that each 500 m cell in the grid exceeded the value of 120 dB, for recreational vessels, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

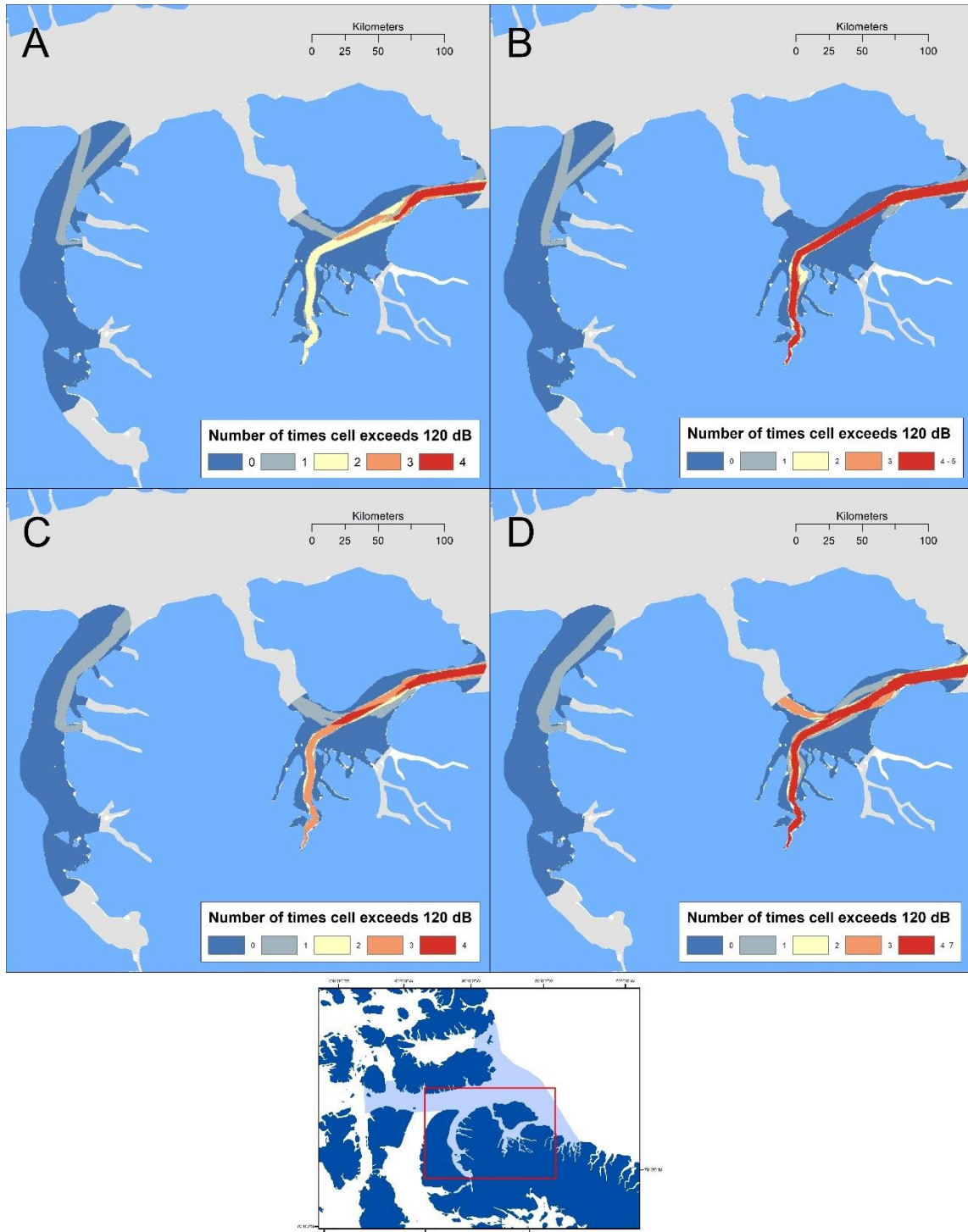


Figure 44. Number of times that each 500 m cell in the grid exceed the value of 120 dB, for tankers, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

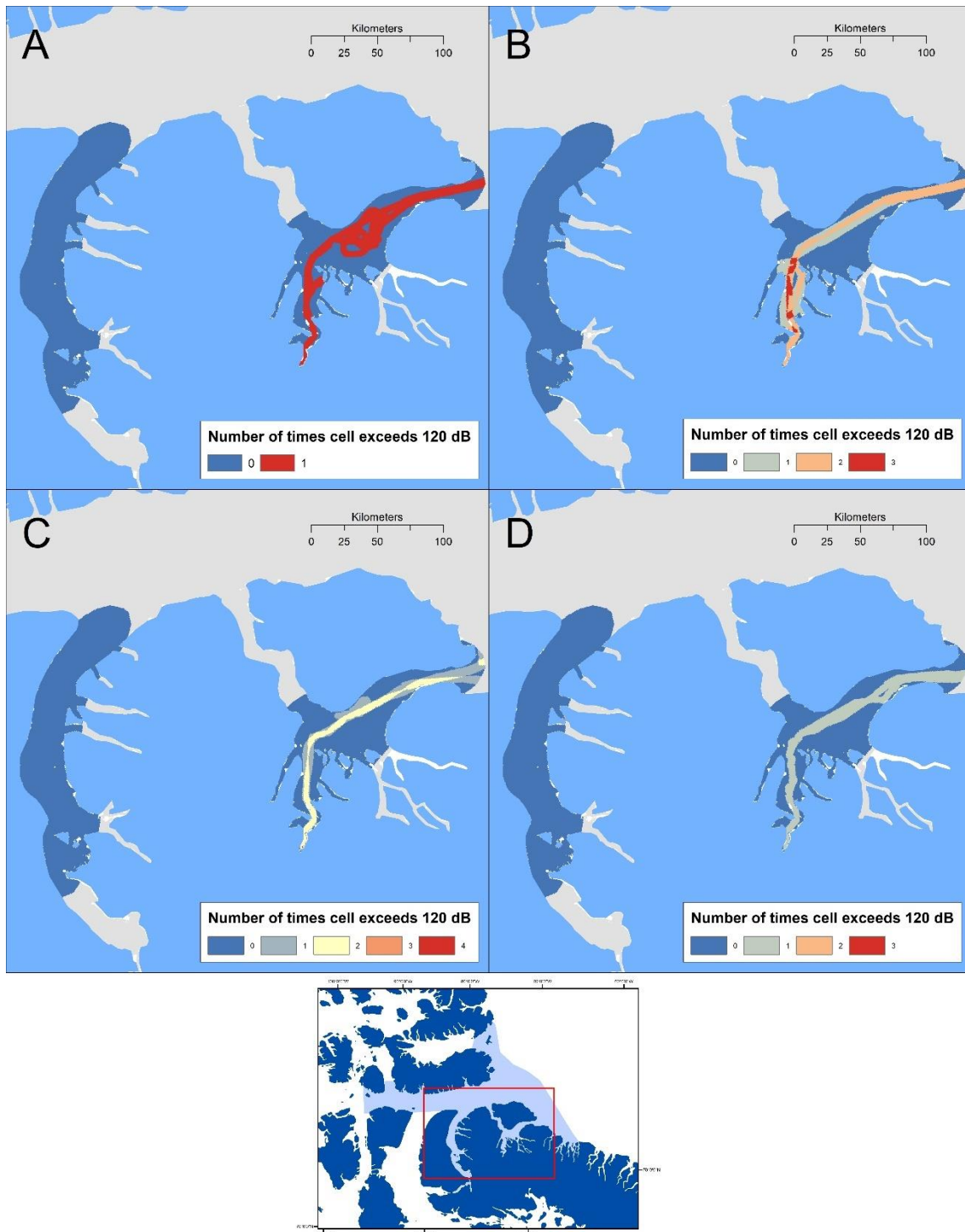


Figure 45. Number of times that each 500 m cell in the grid exceeded the value of 120 dB, for tugs, in the narwhal core use areas; where A is 2015, B is 2016, C is 2017, and D is 2018.

## D. Detail of marine mammal Percent Volume Contour overlaps with shipping noise outputs

Table 10. Details of beluga, narwhal and bowhead Percent Volume Contour overlaps with behavioural disturbance events in Tallurutiup Imanga, with individual vessel categories from 2015 to 2018

Marine Mammal	Percent Volume Contour (PVC)	Vessel Type	Year	Total area of behavioural disturbance events overlapping PVC (Km <sup>2</sup> )
Narwhal	5	Cargo	2015	392.75
			2016	385.25
			2017	426
			2018	431.75
		Cruise ship	2015	42.25
			2016	387
			2017	338
			2018	56.75
		Fishing	2015	0
			2016	0
			2017	38.5
			2018	34.75
		Government	2015	0
			2016	480
			2017	0
			2018	471.5
		Military	2015	0
			2016	0
			2017	0
			2018	0
		Recreational	2015	10.75
			2016	66.25
			2017	116
			2018	32.25
		Tanker	2015	238.5
			2016	335.75
			2017	253.5
			2018	338.75
Tug	2015	264		
	2016	437.5		
	2017	240		
	2018	205		
Narwhal	25	Cargo	2015	1972.5
			2016	1764.5
			2017	2321.25
			2018	2282.75

<b>Narwhal</b>	50	Cruise ship	2015	974
			2016	1722.25
			2017	1573.5
			2018	1182.75
		Fishing	2015	60.25
			2016	0
			2017	238.75
			2018	555.5
		Government	2015	410.75
			2016	2547.25
			2017	1225.5
			2018	2409.5
		Military	2015	32.25
			2016	0
			2017	30
			2018	0
		Recreational	2015	58.5
			2016	311.25
			2017	541.75
			2018	379.75
		Tanker	2015	1073.5
			2016	997.75
			2017	1092.5
			2018	1394.75
		Tug	2015	1276
			2016	1462.75
			2017	922.25
			2018	901.75
		Cargo	2015	5540.5
			2016	4929.5
			2017	6017.75
			2018	5632.5
		Cruise ship	2015	3100.75
			2016	3773.25
			2017	2965.75
			2018	4335.5
		Fishing	2015	827.5
			2016	341.25
			2017	814.5
			2018	1217
Government	2015	3461.25		
	2016	7688		
	2017	4827.5		
	2018	4477.25		
Military	2015	102.5		
	2016	0		
	2017	313		
	2018	0		

<b>Narwhal</b>	75	Recreational	2015	188
			2016	621.25
			2017	1147.25
			2018	1631.75
		Tanker	2015	3446.25
			2016	3076
			2017	3421
			2018	3861.5
		Tug	2015	2173
			2016	2205.5
			2017	1733
			2018	1657.75
		Cargo	2015	12623.5
			2016	12419.25
			2017	15556.75
			2018	15849.5
Cruise ship	2015	9797.5		
	2016	9834.25		
	2017	9958		
	2018	16259.5		
Fishing	2015	1087.75		
	2016	642.5		
	2017	1269.25		
	2018	1641		
Government	2015	11728.75		
	2016	17225.25		
	2017	14164		
	2018	13647		
Military	2015	357.75		
	2016	0		
	2017	840		
	2018	0		
Recreational	2015	450.25		
	2016	1195.25		
	2017	2146.25		
	2018	3308.25		
Tanker	2015	8346.5		
	2016	6544		
	2017	6359.25		
	2018	10376.25		
Tug	2015	2564		
	2016	2968.25		
	2017	2974.25		
	2018	2158		
<b>Narwhal</b>	95	Cargo	2015	23835.25
			2016	20766.75
			2017	36362.25
			2018	35025.25

		Cruise ship	2015	20485.5
			2016	19119
			2017	23976.5
			2018	42439.5
		Fishing	2015	1447.75
			2016	1313.5
			2017	2412.75
			2018	2202.5
		Government	2015	21953.25
			2016	35426.5
			2017	29521
			2018	29012.5
		Military	2015	718.5
			2016	0
			2017	1334.75
			2018	0
		Recreational	2015	622.25
			2016	1891.25
			2017	3962.75
			2018	6176.5
		Tanker	2015	15913.75
			2016	13581.5
			2017	12232
			2018	20446
Tug	2015	2795.75		
	2016	3556.75		
	2017	6347.75		
	2018	2459.75		
Cargo	2015	85.5		
	2016	104.5		
	2017	117.75		
	2018	145		
Cruise ship	2015	9.25		
	2016	177.75		
	2017	115.5		
	2018	429.75		
Fishing	2015	0		
	2016	9		
	2017	0		
	2018	10.5		
Government	2015	223.5		
	2016	244.5		
	2017	156		
	2018	201.75		
Military	2015	0		
	2016	0		
	2017	0		
	2018	0		
<b>Beluga</b>	<b>25</b>			

<b>Beluga</b>	50	Recreational	2015	0.75
			2016	21.25
			2017	0
			2018	0
		Tanker	2015	20.75
			2016	30.25
			2017	81.75
			2018	24.5
		Tug	2015	0
			2016	0
			2017	0
			2018	0
		Cargo	2015	1603
			2016	2189
			2017	1987.5
			2018	2411
		Cruise ship	2015	2682.25
			2016	1286.25
			2017	2108
			2018	3839.5
Fishing	2015	0		
	2016	122.25		
	2017	136.75		
	2018	124.5		
Government	2015	3407.5		
	2016	3396		
	2017	1919.5		
	2018	3031.75		
Military	2015	0		
	2016	0		
	2017	0		
	2018	0		
Recreational	2015	15.75		
	2016	43.25		
	2017	0		
	2018	0		
Tanker	2015	1407.5		
	2016	1301		
	2017	1768.75		
	2018	1442.25		
Tug	2015	0		
	2016	0		
	2017	0		
	2018	0		
<b>Beluga</b>	75	Cargo	2015	2210.25
			2016	3727.25
			2017	4425.5
			2018	5093

<b>Beluga</b>	95	Cruise ship	2015	6101.75
			2016	2976.75
			2017	4836
			2018	8823.25
		Fishing	2015	66.5
			2016	266.25
			2017	327.75
			2018	317
		Government	2015	5302.75
			2016	6927.5
			2017	2682.75
			2018	5842.75
		Military	2015	38
			2016	0
			2017	0
			2018	0
		Recreational	2015	58.5
			2016	200.5
			2017	362.25
			2018	581.5
		Tanker	2015	2233
			2016	2376.5
			2017	2476
			2018	2383.5
		Tug	2015	0
			2016	0
			2017	0
			2018	0
		Cargo	2015	4862.25
			2016	6272.25
			2017	12057
			2018	10158
		Cruise ship	2015	10880.5
			2016	8045.5
			2017	10815.5
			2018	16332
		Fishing	2015	138.25
			2016	632
			2017	1012.75
			2018	513.25
Government	2015	7987.5		
	2016	19303.25		
	2017	11948.5		
	2018	14375.25		
Military	2015	282		
	2016	0		
	2017	43.25		
	2018	0		

		Recreational	2015	210.25
			2016	615
			2017	1364.75
			2018	1795.25
		Tanker	2015	6576.5
			2016	5188.5
			2017	5427.5
			2018	5447.25
		Tug	2015	0
			2016	0
			2017	0
			2018	0
<b>Bowhead</b>	95	Cargo	2015	9066.75
			2016	9699
			2017	15063.25
			2018	13743.5
		Cruise ship	2015	6944.5
			2016	7072.25
			2017	7372.25
			2018	14119.75
		Fishing	2015	429.25
			2016	406
			2017	756.75
			2018	587.5
		Government	2015	7382
			2016	13222.5
			2017	16601.5
			2018	12514.25
		Military	2015	158.5
			2016	0
			2017	577.25
			2018	0
		Recreational	2015	232.75
			2016	426.25
			2017	714.75
			2018	1627.25
		Tanker	2015	7072
			2016	5758.5
			2017	3004.75
			2018	8564
Tug	2015	498.25		
	2016	1187		
	2017	2981		
	2018	696.25		