Climate Change Adaptation Strategies and Policy Options for Arctic Shipping in Canada

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Executive Summary

This report presents an assessment of adaptation strategies and policy options for Arctic shipping in Canada. It is based on two stages of analysis. The first stage examines the past, present, and future trends of ship traffic, and the nature and implications of changing arctic sea ice conditions for shipping. The second stage outlines the risks and opportunities for shipping activity associated with climate change, and then assesses the adaptations and responses through expert review. The report provides for Transport Canada recommendations to address risks and opportunities of shipping in the Canadian Arctic that have been vetted directly by Arctic ship operators.

The research examined past and present shipping activities based on the NORDREG records for 1990 to 2013 plus supplementary information to generate a picture of temporal and spatial patterns of ship traffic. Marine traffic has increased dramatically over this time period, with some vessel types' involvement increasing more than others (e.g., Pleasure Craft, Government Vessels, and Icebreakers). Spatial concentrations have been consistent, though changes in intensity are evident. For example, the southeastern area off Baffin Island is an area of concentration, and the southern route of the Northwest Passage is more popular than the northern route. Some vessel types, such as Fishing Vessels and Bulk Carriers, are more spatially limited than others. The distance travelled doubled between 1990 and 2013, with a notably steep increase in distances over the years from 2006 to 2008.

The research found some correlations between increasing vessel traffic and changing sea ice conditions. Overall, there is an increasingly strong relationship between annual vessel counts and the area of multi-year ice, indicating an increase in favourable conditions for shipping. But the nuances in the relationship show that changing ice conditions alone are not responsible for overall vessel increases and observed shoulder-season increases in traffic. In order to project future trends, the research used a model to incorporate a broad range of input factors and translate them into corresponding traffic levels by ship type, location, and time period. This model simulated traffic for the year 2020 by using ship tracks from 2011. The 2020 simulation shows gridded traffic concentrations and tracks reflecting inputted environmental and economic conditions.

In the second stage of the research, interviews were undertaken to explore risks, opportunities, and adaptation strategies related to the impacts of climate change and changing shipping patterns. Interviewees reviewed the predictions about changing conditions and provided their views on the relative strength of climate change as a direct driver of shipping activity across Arctic Canada. Economic conditions, rather than climate change, was ranked as the primary driver of shipping change, although climate change was recognized by all interviewees

as an important enabler of shipping activity. Risks and opportunities of changing patterns were divided into direct impacts of climate change and compounding impacts.. A suite of adaptation strategies for further evaluation was created through this stage. Emphasis was placed on several steps of validation to assess the desirability and feasibility (i.e., affordability and ease of implementation) of strategies in order to create a set of recommendations for three time frames (short-term, medium-term, long-term). Strategies were categorized into four themes: regulation and policy; planning, preparedness, and enforcement; infrastructure, services, and training; and research. Analysis was based on the level of consensus among individual members of an expert panel. Further validation was undertaken with Transport Canada and Canadian Arctic shipping companies.

Résumé

Ce rapport présente une évaluation, basée sur deux étapes d'analyse, des stratégies d'adaptation et des politiques liées au transport maritime dans l'Arctique canadien. La première étape examine les tendances passées, présentes et futures de la circulation des navires, ainsi que la nature et les implications de l'évolution des conditions de glace de mer arctique pour le trafic maritime. La seconde étape présente les risques et opportunités pour l'activité maritime associés aux changements climatiques, et offre ensuite un avis d'expert sur les adaptations et réponses pour faire face à ces derniers. Le rapport fournit des recommandations, vérifiés directement par les exploitants de navires dans l'Arctique, pour aider Transport Canada à faire face aux risques et opportunités liés au transport maritime dans l'Arctique canadien.

L'étude a examiné l'activité maritime, passée et présente, sur la base des comptes rendus NORDREG entre 1990 et 2013, et des informations complémentaires, pour générer une image des tendances temporelles et spatiales de la circulation des navires. Le trafic maritime a augmenté de façon spectaculaire au cours de cette période de temps, avec certain types de navires augmentant plus que d'autres (ex. embarcations de plaisance, navires gouvernementaux et brise-glaces). Les concentrations spatiales sont demeurées cohérentes, cependant des variations d'intensité sont évidentes. Par exemple, la région au sud-est de l'Île de Baffin montre une forte concentration de navires, et la route sud du passage du Nord-Ouest est plus populaire que la route nord. Certains types de navires, tels que les navires de pêche et les vraquiers ont une distribution spatiale plus limitée. La distance parcourue a doublé entre 1990 et 2013, avec une augmentation spécialement marquée des distances parcourues au cours des années 2006-2008.

L’étude à révélé une corrélation entre l’augmentation du trafic maritime and l’évolution des conditions de glace ce mer. Dans l’ensemble, il y a une relation croissante entre le nombre annuel de navires et la superficie de la glace de mer pluriannuelle, indiquant des conditions plus favorables pour le trafic maritime. Cette relation est cependant nuancée et l’évolution des conditions de glace de mer n’est pas seule responsable de l’augmentation globale du nombre de navires, ni de l’augmentation du trafic observée lors des saisons intermédiaires. Afin de projeter les tendances futures, l’étude a utilisé un modèle intégrant un large éventail de paramètres pour déterminer le trafic maritime par type de navire, positionnement et période de temps. Ce modèle a été utilisé pour simuler le trafic pour l’année 2020, à l’aide des pistes de navires à partir de 2011. La simulation pour 2020 montre un maillage des concentrations de trafic et des pistes des navires reflétant les conditions environnementales et économiques introduites dans le modèle.

Dans la seconde étape de l’étude, des entrevues ont été menées afin d’explorer les risques, possibilités et stratégies d’adaptation liées aux impacts des changements climatiques et à l’évolution du trafic maritime. Les personnes interrogées ont passé en revue les prédictions concernant l’évolution des conditions et ont donnée leur avis sur l’importance relative des changements climatiques en tant que facteur direct sur l’activité maritime dans l’Arctique canadien. Les conditions économiques, plutôt que les changements climatiques, ont été classées comme le moteur principal des changements affectant le transport maritime, bien que les changements climatiques ont été reconnus comme un catalyseur important pour l’activité maritime par toutes les personnes interrogées. Les risques et opportunités associés à l’évolution de la circulation des navires ont été divisés entres les impacts directs des changements climatiques, et un ensemble d’impacts reflétant les défis dans le context politique, économique et social influençant la réponse aux changements climatiques. Un ensemble de stratégies d’adaptation a été créé dans cette seconde étape pour une évaluation plus poussée. Lors de cette évaluation l’accent a été mis sur plusieurs étapes de validation pour déterminer l’opportunité et la faisabilité (c.-à-d. l’abordabilité et la facilité de mise en oeuvre) des stratégies, afin de créer une série de recommendations pour trois périodes (à court, moyen et long terme). Les stratégies ont été classées selon quatre thèmes: réglementation et politique; planification, préparation et exécution; infrastructure, services et formation; et recherche. L’analyse a été basée sur le niveau de consensus entre les membres individuels d’un groupe d’experts, et a été ensuite été validée avec Transport Canada et des entreprises de transport maritime opérant dans l’Arctique canadien.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction and Context

Increased shipping is occurring in Arctic Canada, driven by both economic factors and increased accessibility due to diminishing sea ice and a lengthening shipping season into the spring and fall. Regional warming in the Arctic has contributed to a reduction in sea ice thickness and extent (Stewart et al. 2007; Sou & Flato, 2009), facilitating both the perception and reality of increased accessibility for marine shipping activity in the region. Recent trends show substantial ice reduction in the central Arctic and Canadian Arctic Archipelago (CAA), including the Northwest Passage (NWP) (Howell et al., 2006; Guy, 2006; Tivy et al., 2011), with expectations that the NWP will be increasingly ice-free in the next few decades (Sou & Flato, 2009).

Reductions in sea ice have already had impacts on vessel patterns in the Canadian Arctic (Pizzolato, Howell, Derksen, Dawson, & Copland, 2014) and related impacts at the second-order level, which includes changes in political, social, and economic conditions. A considerable amount of work has examined these relationships in the area of tourism (e.g., Dawson, Johnston, & Stewart, 2014; Stewart, Dawson, & Johnston, 2015), but there has been insufficient examination of the implications for resource development and shipping (Cameron, 2012). Yet, increased development and shipping activity in the Arctic requires Canada to take action that would allow economic opportunities to be realized and associated risks minimized. To do this, federal strategies are needed that deal with the challenges of climate change for Arctic shipping, and help to both maximize opportunities and minimize risks. This report is the result of a comprehensive study that: 1) outlines historic, current, and future shipping patterns and trends; and 2) provides a suite of adaptation strategies and policy options aimed at enhancing the opportunities of increased shipping in the Arctic while minimizing the associated risks.

This research was undertaken in 2014, 2015, and 2016. It began with an assessment of current and future marine shipping activities in the North, particularly shipping activity in the Eastern and Western Arctic, as well as Hudson Bay (Churchill). The assessment included determining how climate change will impact northern transportation infrastructure and existing routes. The assessment provided the foundation for the development of adaptation strategies, policy options, and recommendations to deal with the impacts on transportation of changes in sea ice conditions. This took place with substantial input from shipping stakeholders in government, industry, and the Arctic region. Short-, medium-, and long-term recommendations were then prepared and prioritized for Transport Canada.

This report continues with four additional chapters and four appendices with 31 supplementary figures and tables. Chapter 2 presents an assessment of the temporal and spatial variability in marine shipping activity in the Canadian Arctic from 1990 to 2013. Chapter 3 describes projected shipping trends based on modelling. Chapter 4 outlines the drivers of shipping change and the climate change-related risk and opportunities as identified in interviews with stakeholders and experts. Chapter 5 provides an assessment of adaptation strategies and responses based on the evaluation of the expert panel members. Chapter 6 provides the final recommendations and considers verification of the strategies and potential respondent bias.

Emma Stewart

Chapter 2: Arctic Shipping Trends

2.1 Past and Present Marine Traffic in Canada: Introduction and Background

The physical environment of the Arctic is currently experiencing some of the most rapid environmental changes of all regions globally (Jeffries, Overland, & Perovich, 2013; Derksen et al., 2012). This has significant implications for the polar marine environment and, in turn, influences a number of socio-economic changes, such as increased tourism demand and potential for natural resource development (Dawson et al., 2014; Lasserre & Têtu, 2015; Guy, 2006; Prowse et al., 2009). With respect to sea ice, a shift from a predominantly thick perennial arctic sea ice regime to a younger, thinner, more seasonal sea ice regime is occurring (Parkinson, 2014; Comiso, 2012; Maslanik, Stroeve, Fowler, & Emery, 2011). For example, between 2002 and 2009, multi-year ice (MYI) coverage in the Canadian sector of the Arctic Ocean declined by 83% (Maslanik et al., 2011), and from 1979 to 2013 the pan-Arctic melt season length increased by an average of 5 days per decade^{-1} (Stroeve, Markus, Boisvert, Miller, & Barrett, 2014).

With a thinning, declining arctic sea ice extent and thickness (e.g., Howell, Duguary, & Markus, 2009; Pistone, Eisenman, & Ramanathan, 2014; Tivy et al., 2011; Laxon et al., 2013; Comiso, 2012; Serreze, Holland, & Stroeve, 2007), a major question is whether this will lead to increased maritime activity in the region. Navigation connecting Asia and Eastern North America through the Arctic instead of traditional routes through the Panama and Suez Canals could result in significant distance and cost savings (Lasserre & Têtu, 2015; Stephenson, Smith, & Agnew, 2011; Khon, Mokhov, Latif, Semenov, & Park, 2009; Somanathan, Flynn, & Szymansku, 2007; Guy, 2006). However, as enticing as these savings are, significant ice hazards (e.g., MYI, icebergs) remain present (Kubat, Collins, & Timco, 2007; Howell, Derksen, Pizzolato, & Brady, 2015; Van Wychen et al., 2014), making the region arguably more dangerous to navigate. There are also higher financial costs associated with Arctic shipping compared to conventional shipping, including higher insurance premiums, manufacturing ice-strengthened vessels, hiring trained ice pilots, and ice-breaking support services (Hodgson, Russell, & Megganety, 2013; Arctic Council, 2009). These high financial risks are further exacerbated by physical risks brought on by a lack of marine infrastructure to support shipping operations, such as the lack of deep water port facilities, limited locations for refuelling, challenges with access to search and rescue services, and poorly charted waters (Arctic Council, 2009; Hodgson et al., 2013).

Many vessel types operate within the Canadian Arctic, each with distinct operations and cargo (Table 1). Communities across the Canadian Arctic rely heavily on ships as a means of transporting goods to service the region. Supplying communities via ships is crucial, especially should the population grow or the needs of communities change (Hodgson et al., 2013; Prowse et al., 2009). Additionally, with some of the largest untapped oil and gas reserves in the world located within the Arctic, the potential for increased marine activity due to oil and gas exploration and extraction is a possibility (Prowse et al., 2009; Pizzolato et al., 2014). The prospective increase in northern resource-extraction projects (e.g., Baffinland Mary River Iron Ore Mine) and subsequent increases in the export of raw goods and materials out of the North will not only increase regular bulk shipments, but will also likely require increased marine transportation during the construction phase of these projects (Hodgson et al., 2013). Small-scale commercial fishing operations within the Canadian Arctic are expanding further north as ice-free conditions persist for longer periods (Hodgson et al., 2013). Marine tourism (both Pleasure Craft and Passenger Ships) has expanded rapidly over the past two decades in the Canadian Arctic, and is likely to increase further as the demand for "exploration" tourism increases (Dawson, Maher, & Slocombe, 2007; Dawson et al., 2014; Pizzolato et al., 2014; Hodgson et al., 2013; Lasserre & Têtu, 2015). In this chapter, an assessment is presented of the temporal and spatial variability in marine shipping activity in the Canadian Arctic from 1990 to 2013.

Luke Copland

Table 1

Description of Vessel Types Found in the Canadian Arctic and their Associated Uses (compiled from NORDREG and Arctic Council [2009] categories)

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

2.2 Study Area

The study area for this project comprises the Northern Canada Vessel Traffic Services Zone (NORDREG zone) maritime region. This region encompasses all Canadian Arctic waters, including two well-known Canadian Arctic shipping corridors: the Northwest Passage (NWP) and the Arctic Bridge (AB) (Figure 1). Excluded from this study is the McKenzie River, which was only recently included in the NORDREG zone and where availability of shipping data is inconsistent over time. The NWP connects the Atlantic and Pacific Oceans via Baffin Bay in the Eastern Arctic and the Beaufort Sea in the Western Arctic through two distinct routes: the Northern route and Southern route. The Northern deep water route extends through Parry Channel and terminates in M'Clure Strait. The Southern shallow water route extends from Baffin Bay to the Beaufort Sea via Lancaster Sound through Eastern Parry Channel, then south along the eastern coast of Prince of Wales Island, and lastly westwards along the southern coasts of Victoria and Banks Island into the Beaufort Sea (Figure 1). The AB connects Europe and Eurasia to the Port of Churchill, Manitoba, through Hudson Strait and into Hudson Bay.

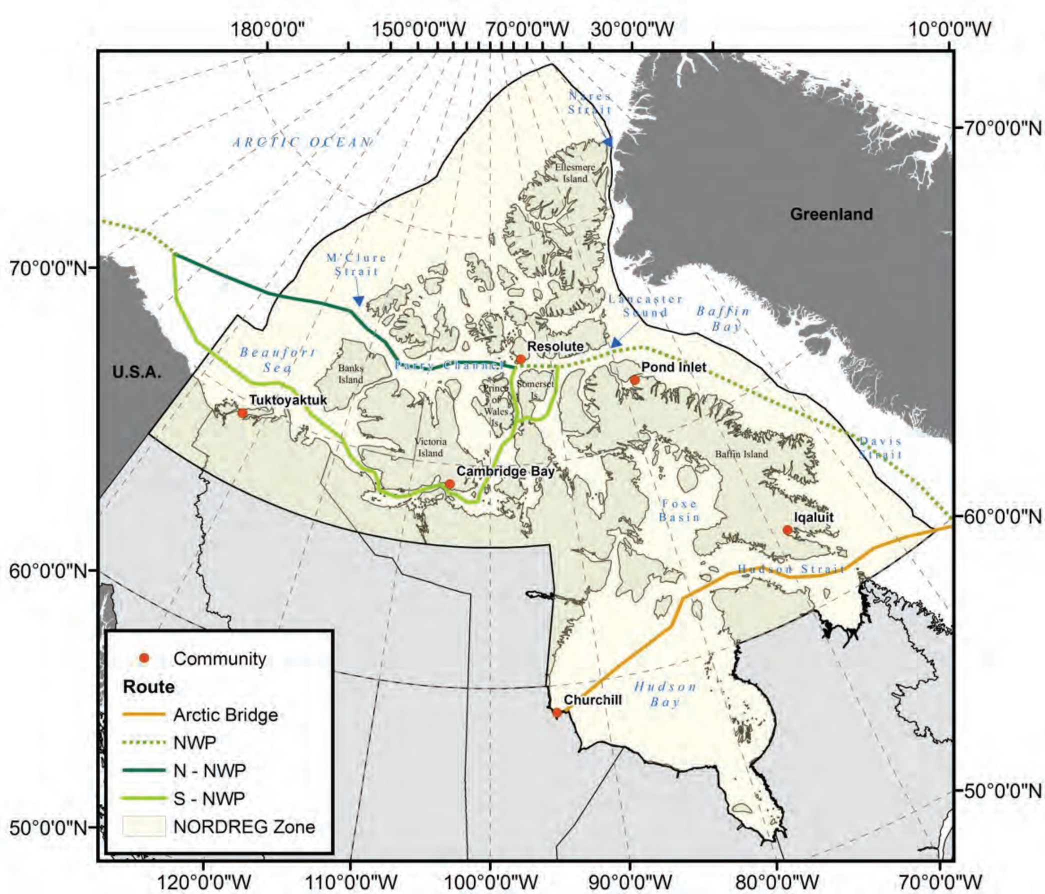


Figure 1

Map of study area outlining major shipping routes: Northern Northwest Passage (N-NWP) and Southern (S-NWP); and Arctic Bridge (AB) (CCG, 2013)

2.3 Methodology: Generation of Past and Present Arctic Shipping Routes

2.3.1 NORDREG Ship Archive

The NORDREG database was used to determine past and present ship tracks across the study area. This ship archive, provided by the Canadian Coast Guard, contains 89,669 unique reported vessel locations and 4,251 unique vessel voyages within the NORDREG zone over the period 1990 to 2013. This is a two-part dataset, with the first part containing daily reports of vessel locations at 16:00 UTC for mandatory reporting vessels since 2010 (i.e., vessels that are 300 gross tonnes or more, towing or pushing another vessel if the combined gross tonnage is 500 gross tonnage or more, carrying a pollutant or dangerous good, or towing a vessel carrying a pollutant or dangerous good [CCG, 2013]). The dataset also contains voluntary reported ship positions within the NORDREG zone from 1990 to present, mostly on a daily or sub-daily timescale. The second part of the dataset consists of an archive with vessel name, call sign, IMO number, entry and exit dates of the NORDREG zone, and vessel length, width, and other non-spatial characteristics.

Supplementary ship specification data were added to the previous quality-controlled ship archive (see Pizzolato et al., 2014) to complete the dataset used here, including ship draft, length, and width, as well as the marine mobile service identity number (MMSI) when available. This information came from various online government sources, including: Transport Canada's Vessel Registration Query System (http://wwwapps.tc.gc.ca/Saf-Sec-Sur/4/vrqs-srib/eng/vessel-registrations/), Industry Canada's Spectrum Direct Ship Station Search (https://sd.ic.gc.ca/pls/engdoc_anon/mmsi_search.Ship), and National Oceanic and Atmospheric Administration's (NOAA) Office of Science & Technology Vessel Documentation Search by Name (http://www.st.nmfs.noaa.gov/st1/CoastGuard/VesselByName.html); and freely available public websites including: Vessel Finder (http://www.vesselfinder.com/), Maritime Connector (http://maritime-connector.com/ship/), and ShipSpotting.com (http://www.shipspotting.com/). Both parts of the ship archive were then linked by a unique identifier based on year, vessel name, and voyage number as defined by a single entry and exit of the NORDREG zone.

2.3.2 Canadian Ice Service Digital Archive (CISDA)

The Canadian Ice Service Digital Archive (CISDA), which contains weekly regional ice charts, was used to extract total sea ice concentration for the entire study area. The weekly regional ice charts are derived from surface observations, aerial and satellite reconnaissance, operational model results, and ice forecaster knowledge from 1968 to present (CIS, 2007; Tivy et al., 2011). Furthermore, analysis of the quality of the CISDA by Tivy et al. (2011)

shows that biases in the dataset from technological advancements from 1979 to present do not introduce inhomogeneities to the time series, making it appropriate for use across the 1990–2013 study period.

2.3.3 Bathymetry

The ETOPO2v2 elevation and bathymetry dataset used for the entire study area was acquired from the NOAA National Geophysical Data Center (NGDC) (http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html). This dataset, published in 2001 and revised in 2006, contains both terrain elevation and seafloor topography on a 2 Arc-minute grid, and a vertical precision of 1 m (NGDC, 2006). This dataset was derived from 6 assimilated bathymetric databases, including Smith and Sandwell's 1978 satellite radar altimetry, International Bathymetric Chart of the Arctic Ocean (IBCAO), Global Land One-kilometer Base Elevation (GLOBE), and the NGDC Coastal Relief Model (NGDC, 2006).

2.3.4 Least Cost Path Reconstruction

To identify where observed changes to shipping activity have occurred across the Canadian Arctic on an annual basis, the generation of voyage tracks was undertaken using a Least Cost Path (LCP) approach that integrated the above three unique datasets: the NORDREG ship archive, the Canadian Ice Service Weekly Regional Ice Charts, and the ETOPO2v2 elevation and bathymetry dataset. All analysis was undertaken using ESRI ArcGIS 10.2, Python, and the ArcPy Python scripting module. The coastline mask used in the analysis was derived from the land mask used in the generation of the CISDA weekly regional ice charts. In the LCP workflow, known vessel reporting records (points) are connected (by a line) based on a weighted cost surface (Figure 2; Table 2).

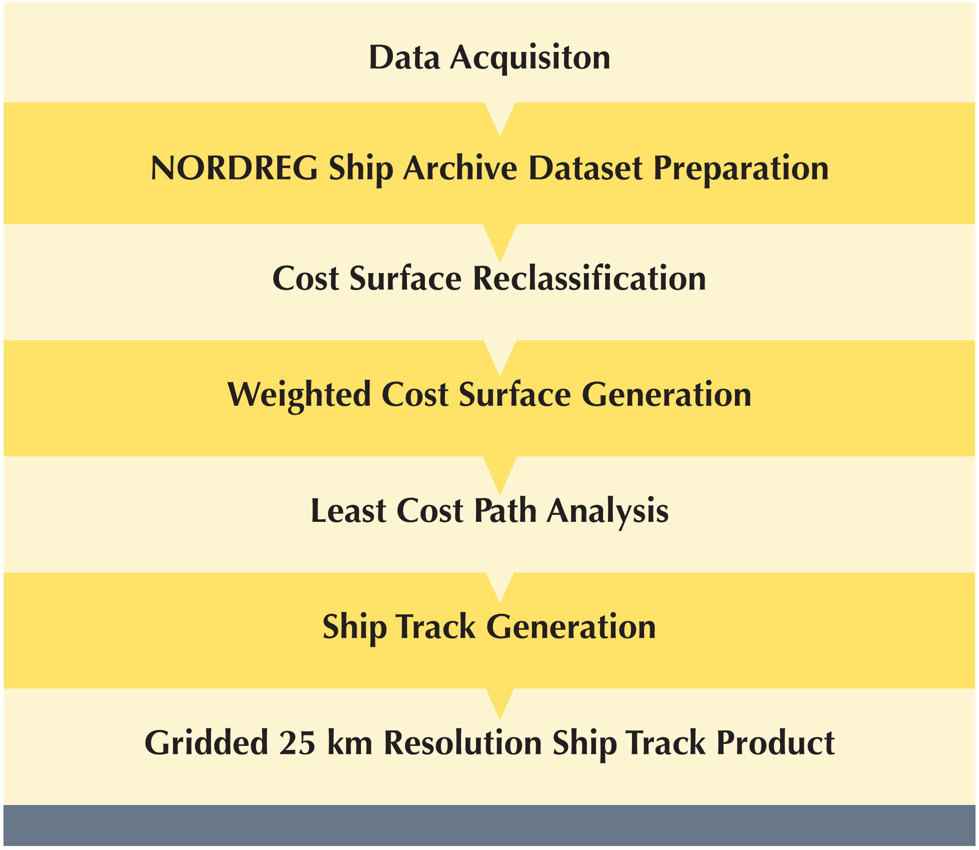


Figure 2

Least Cost Path (LCP) Workflow

In the LCP analysis, costs are considered to be hindrances to the safe transit of a vessel and can be prescribed for any type of condition (e.g., a vessel cannot pass over land, some vessels traverse through a certain concentration of sea ice more easily than others, or require a certain depth for safe transit). Therefore, the lower the cost surface, the more favourable the pathway is to connect known ship-point records; conversely, the higher the cost, the less favourable the pathway. For each pair of points, a weighted cost surface was generated using three cost parameters: total sea ice concentration (total SIC, using the CISDA weekly regional ice chart nearest the date of the initial reported point); bathymetry; and distance from land. Each cost surface was then reclassified based on criteria in Table 2 and using values between 0 and 100, with 0 signifying no cost, and 100 signifying maximum cost. All reclassified cost surfaces were sampled to a 1 km x 1 km raster surface by resampling the 25 km Equal-Area Scalable Earth Grid (EASE-Grid 2.0) prior to the LCP analysis. Subsequently, the weighted cost surface (now at a 1 km x 1 km resolution) was then used in the LCP analysis to establish a route between each pair of points.

Table 2

Least Cost Path Cost Surface Reclassification

Total sea ice concen-tration	Graphic of Total SIC	*Ice Description	Cost	Bathymetry (- values) Elevation (+ values)	Cost	Distance from Land	Cost
0-1		Ice Free/ Open Water	0	-3818 m to Maximum Draft	0	> 25 km	0
2		Very Open Drift	50	Maximum Draft to Minimum Draft	25	25 km to 0 km	Increasing linearly from 0 at 25 km from the coastline to 100 at the coastline
3			55	Minimum Draft to 0 m	50		
4		Open Drift	60	0 m to 1257 m	100		
5			65				
6			70				
7		Close Pack	85				
8			90				
9		Very Close Pack to Compact	100				
10			100				

* Derived from CCG, 2012

Total sea ice concentration was chosen as the ice cost parameter based on the Ice Navigation in Canadian Waters recommendation, "Do not enter ice if an alternative, although longer, open water route is available" (CCG, 2012, p. 85). This provided a cost surface using a conservative approach that considered the contribution of both first-year ice (FYI) and MYI equally in the ice cost surface generation. Even within a region of high FYI concentration, the presence of any MYI remains a severe threat to ship navigation (CCG, 2012), and thus total sea ice concentration incorporating both MYI and FYI was employed as the ice cost parameter in the LCP analysis. Therefore, 0/10 to 1/10 ice concentration were assigned a cost of 0 (as these are the most favourable open-water and ice-free conditions) and total sea ice concentration of 2/10 was assigned a cost of 50, increasing to a cost of 100 for 10/10 total sea ice concentration (CCG, 2012; Table 2).

For the cost surface related to bathymetry, the maximum draft was established based on the known ship draft plus 3 m of under-keel clearance. This clearance was chosen based on the most conservative values used for operations in the St. Lawrence River, as no such value was available for Arctic Waterways (CCG-DFO, 2015). The minimum draft is the known ship draft as recorded in the NORDREG ship archive. In cases where vessel draft data was not available for use in the LCP generation, 8 m was prescribed for the minimum draft of the vessel based on the mean value of known draft data for 596 unique vessels over the entire 1990 to 2013 dataset, and 11 m for the maximum draft following the 3 m safe under-keel clearance.

A cost surface for distance from land was established based on the criteria that any area further than 25 km away from land has no cost, and any area between 0 to 25 km away from the coast has a cost decreasing from 100 (at the coastline) to 0 (25 km away from the coast and beyond) (Table 2). This weighting scale was chosen based on three criteria: a) LCP tracks avoid a path directly along the coastline unless absolutely necessary, as it is unlikely that ships travel directly along the edge of the coastline; b) coastal contamination within the 25 km x 25 km pixel of the final gridded product is accounted for to ensure that a more favourable voyage track exists beyond cells that contain the coastline; and c) 65% of all reported NORDREG records are within 0 and 25 km of the coastline.

Once calculated, all three reclassified cost surfaces were integrated into a weighted cost surface (Figure 3). Where total sea ice concentration information was available, the final weighted cost surface consists of 50% sea ice information, 25% bathymetry, and 25% distance from land. For areas in the NORDREG zone where sea ice information was not available, the weighted cost surface consisted of 75% bathymetry and 25% distance from land. These weightings were chosen based on the relative impedance to a ship's safe routing for each of the criteria. For example, in the presence of sea ice, this criterion was more heavily weighted (50%), as this contributes to an immediate threat to safe vessel transit, followed by the bathymetry and distance from land. As a result, this would weight an area with equally sufficient depth and distance from land that has sea ice present less favourably than an area that is absent of sea ice. For situations where sea ice information was not available, the 25% bathymetry and 75% distance from land proportions were chosen to illustrate the relative importance of each criterion in the ship routing, with sufficient depth being paramount, followed by distance from land.

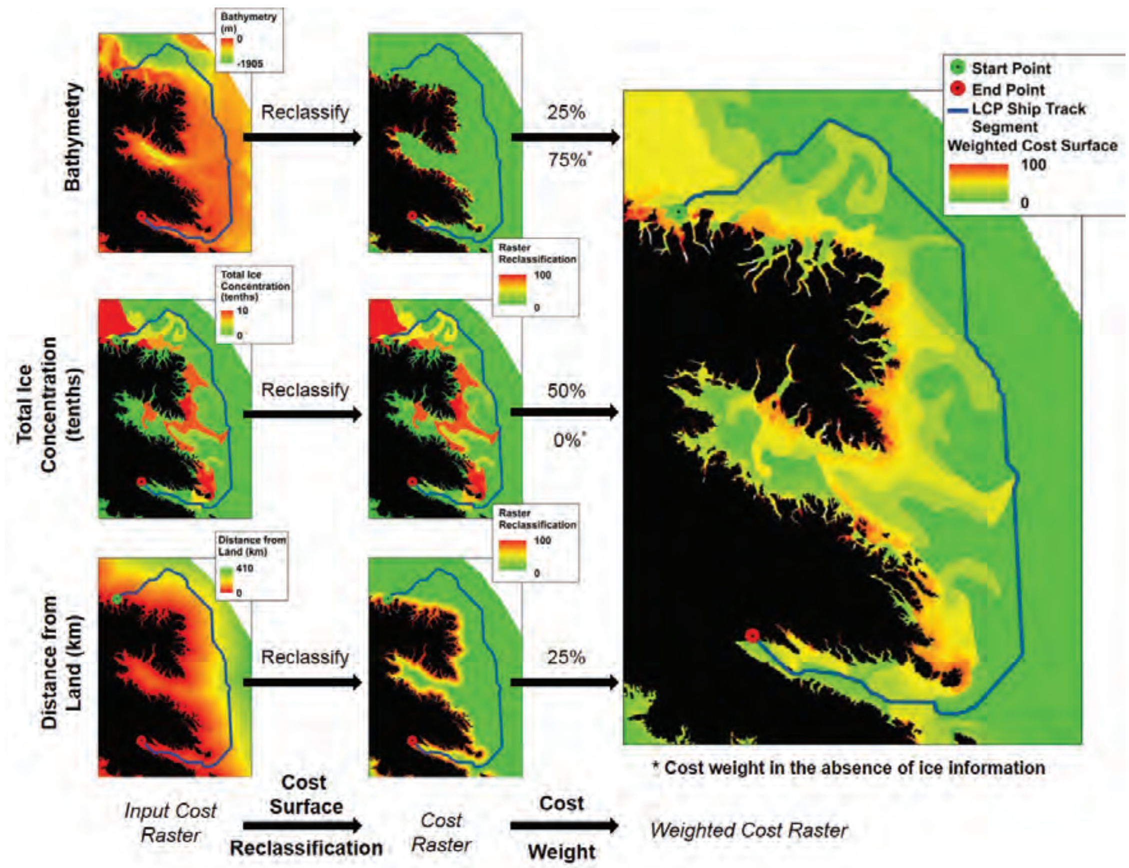


Figure 3

Least Cost Path Cost Surface Generation Workflow

A LCP segment using the aforementioned weighted cost surfaces was used to connect known points using a cost-path algorithm for each pair of points in the NORDREG ship archive for every year between 1990 and 2013 (Figure 4). For example, if a voyage contained three known points, two LCP segments would be generated between points 1 and 2, then again between points 2 and 3 (see Figures 4B, 4C). These segments were then merged to create a route for the entire vessel voyage throughout the NORDREG zone (Figure 4D).

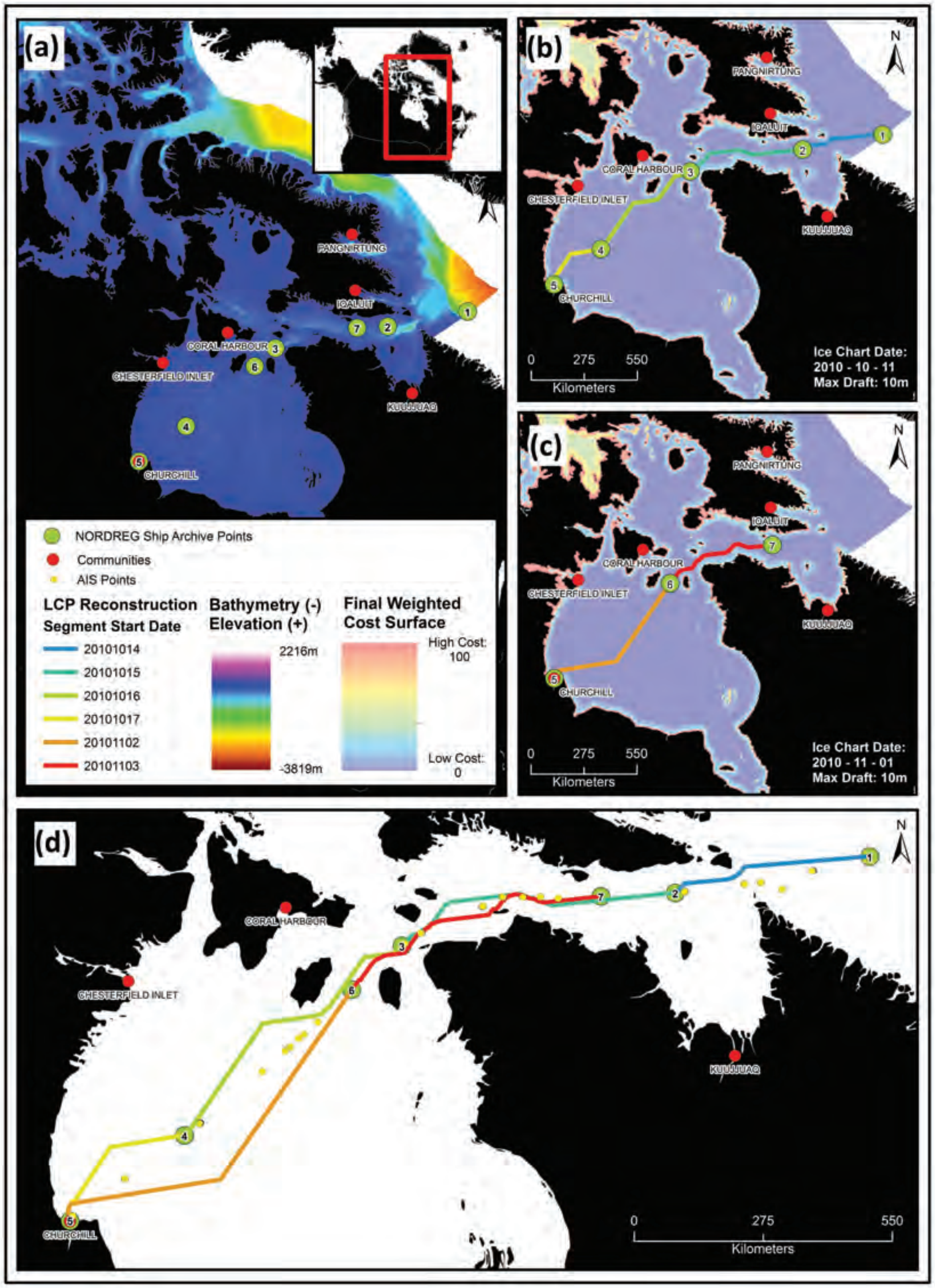


Figure 4

(a) NORDREG ship archive points for one vessel voyage; (b) Cost surface for a vessel with a maximum draft of 10 m, and for the ice chart dated 11 October 2010, showing the LCP reconstructed segments; (c) Cost surface for a vessel with a maximum draft of 10 m, and for the ice chart dated 1 November 2010, showing the LCP reconstructed segments; (d) Reconstructed vessel segments compared to Automatic Identification System (AIS) points

Once all the LCP segments were generated for all the ship-point records in the spatial NORDREG ship archive, the generated ship tracks were extracted to the 25 km National Snow and Ice Data Center (NSIDC) Equal-Area Scalable Earth Grid (EASE-Grid 2.0). The length of each individual voyage segment (in km) within each 25 km x 25 km cell was then calculated. A 25 km x 25 km grid over the entire Canadian Arctic domain provides a suitable compromise between a comprehensive shipping activity inventory and the computational processing power that it takes to derive the ship tracks. Subsequently, the sum of all voyage segment lengths within each cell was calculated to provide a proxy for the amount of shipping activity that occurred within each cell for that year.

2.3.5 Least Cost Path Error Analysis

To assess the accuracy of the LCP analysis to predict vessel voyage pathways using the weighted cost surfaces outlined above, a random sample of 25 LCP-derived vessel voyage routes were selected from the year 2010. These vessel voyages were represented in both the NORDREG and the Automatic Identification System (AIS) ship archives, and represent all the AMSA vessel classes with the exception of two: Oil/Gas Exploration/Exploitation and Other. These 25 voyages consisted of 617 LCP-generated voyage segments. The distance from each independent AIS data source was calculated to the nearest generated LCP voyage segment for the same date (Figure 4D). This value represents the displacement from the known AIS point to the generated LCP segment.

The mean displacement was calculated for the sample of known AIS points ($n = 925$) to the LCP-generated voyage segments, then a Margin of Error (ME) was constructed at the 95% confidence level for the 25 voyages across the study area (Figure 1). This analysis indicates that voyages can be reconstructed to an accuracy of 10.42 ± 0.67 km within the NORDREG zone as a whole. Subsequently, an error estimate was constructed for Hudson Bay (13.78 ±1.99 km) and the NORDREG zone excluding Hudson Bay (8.77 ±0.91 km). This indicates that we are 95% confident that the actual route that vessels took fell within a distance of ~8–14±2 km of the LCP-generated route. Given that the error estimates fall within the 25 km x 25 km grid surface generated for subsequent ship analysis, we can be very confident that the true voyage falls within the grid cell that the LCP track is in.

2.4 Results

2.4.1 Results: Current Patterns

Marine traffic in Arctic Canada has increased markedly in the past decade (Figure 5). This increase has been more pronounced for particular types of vessels. Based on NORDREG data from the CCG, between 1990 and 2013 Bulk

Carriers and Passenger Ships have increased at a rate of 3 vessels per decade, while Government Vessels (including research vessels) have increased at 8 vessels per decade, and Pleasure Craft have increased at 20 vessels per decade. Because of changes in sea ice conditions, the shipping season has lengthened, resulting in increased ship traffic during the shoulder seasons. Overall vessel traffic has increased by 9 vessels per decade in June, by 22 vessels per decade in July, and by 13 vessels per decade in November.

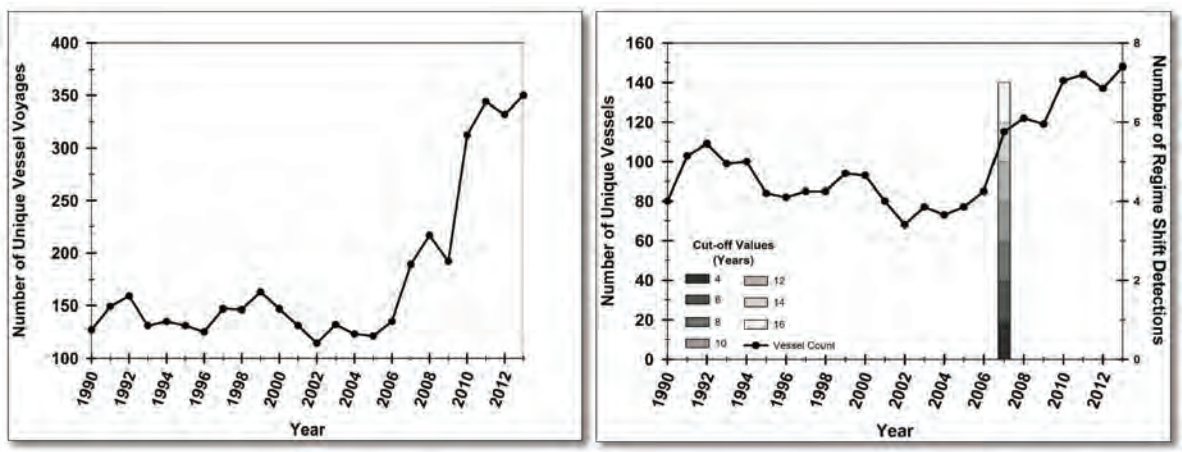


Figure 5

(Left) Number of unique vessel voyages in Arctic Canada 1990–2013; (Right) Number of unique vessels operating in Arctic Canada 1990–2013 (from Pizzolato et al., 2014)

The results clearly show the spatial distribution of shipping activity across the Canadian Arctic. The detailed patterns for every ship type for every year from 1990 to 2013, along with mean sea ice conditions for that year, are provided in the Appendices. In assessing these patterns, there are several significant features that stand out. The first is the strong concentration of shipping in the more southerly and easterly portions of the study area (Figure 6). The intensity of shipping activity varies over time, but the broad patterns stay consistent, with many ships around southeastern Baffin Island (near Iqaluit) and through Hudson Strait. Numbers are moderate on the main shipping routes into Hudson Bay (Arctic Bridge), but drop off rapidly in more northerly areas. Very few ships enter the interior of the Queen Elizabeth Islands, and the Southern NWP route is much more popular than the Northern NWP.

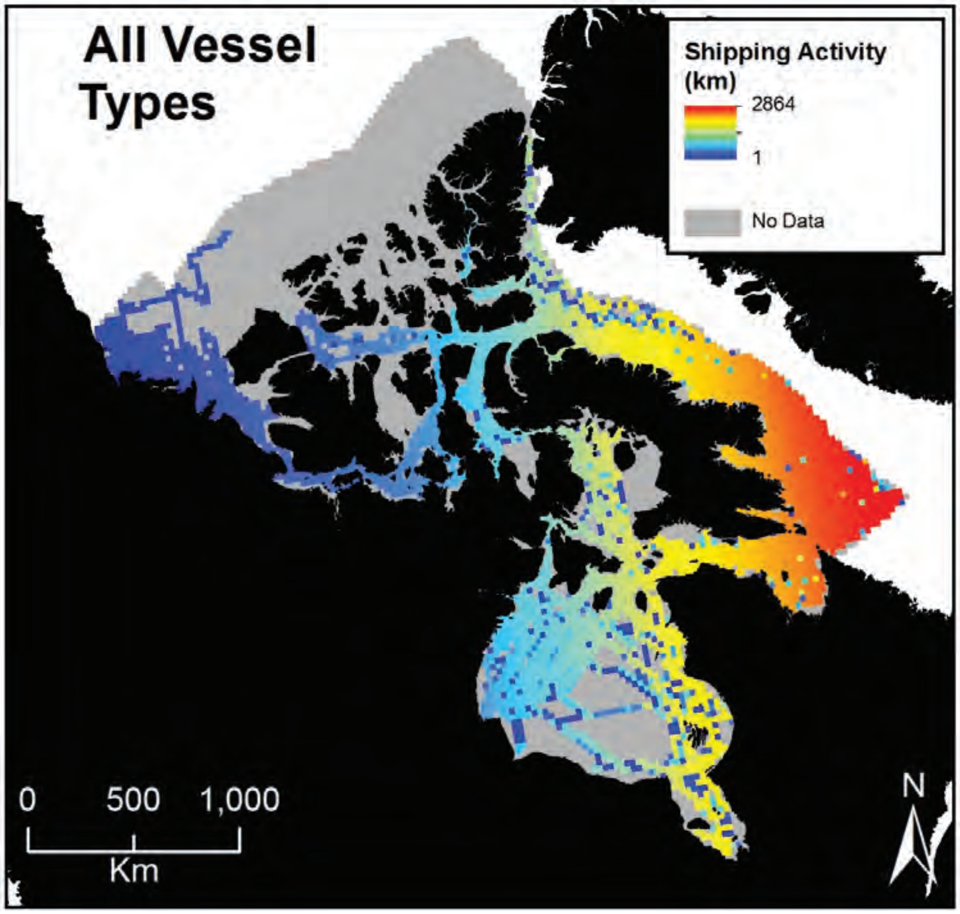


Figure 6

Distribution of current (2013) shipping activity across Arctic Canada

There are marked variations in spatial patterns by vessel type. The most spatially limited vessel type is Fishing Vessels, which are currently restricted almost entirely to SE Baffin Island (Figure 7a). This likely reflects the commercial fisheries present in locations such as Iqaluit and Pangnirtung, combined with the fact that most Fishing Vessels are non-ice strengthened, which restricts their activities to waters with the lowest sea ice concentrations (Figure 7d). Bulk Carriers are also limited spatially, found primarily along the Arctic Bridge route to Churchill and to the mines along the southern edge of Hudson Strait (e.g., Deception Bay) (Figure 7b). There was only one transit of a Bulk Carrier through the S-NWP in 2013. Tugs and Barges are also limited to more southerly areas, particularly around Hudson Strait and James Bay, as well as the region around the head of the Mackenzie River (Figure 7c).

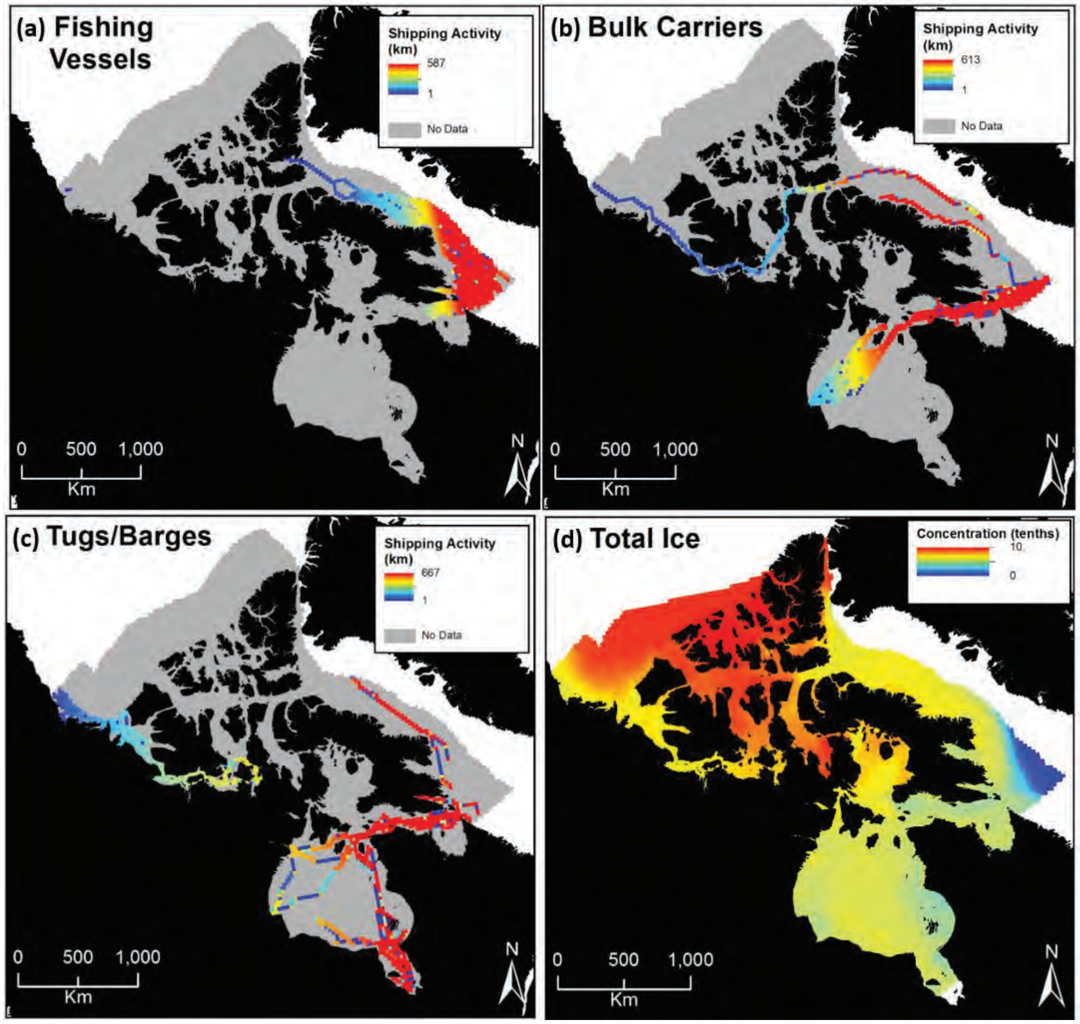


Figure 7

Distribution of shipping activity for 2013 for vessels with limited spatial distribution: (a) Fishing Vessels; (b) Bulk Carriers; (c) Tugs and Barges, compared to (d) Sea Ice concentration

Most other vessel types are found throughout the Canadian Arctic, albeit with the strongest concentration in more southerly waters. For example, the patterns for General Cargo (Figure 8a) and Tanker Ships are very similar, closely related to the locations of communities and reflecting their annual re-supply runs. Passenger Ships (Figure 8b) and Pleasure Craft (Figure 8c) are unique in displaying little activity in Hudson Strait and Hudson Bay, but demonstrate much more activity in more northerly areas, particularly along the eastern side of Baffin Island and the Southern NWP. This reflects the preferred destinations for expedition tourism and some prime locations for spotting wildlife. Finally, the vessel type with the greatest spatial variability is Government and Icebreakers (Figure 8d), which were found throughout the study area, including areas such as the Northern NWP, where few-to-no other ship types are found, likely due to the severe sea ice conditions present there (Figure 7d).

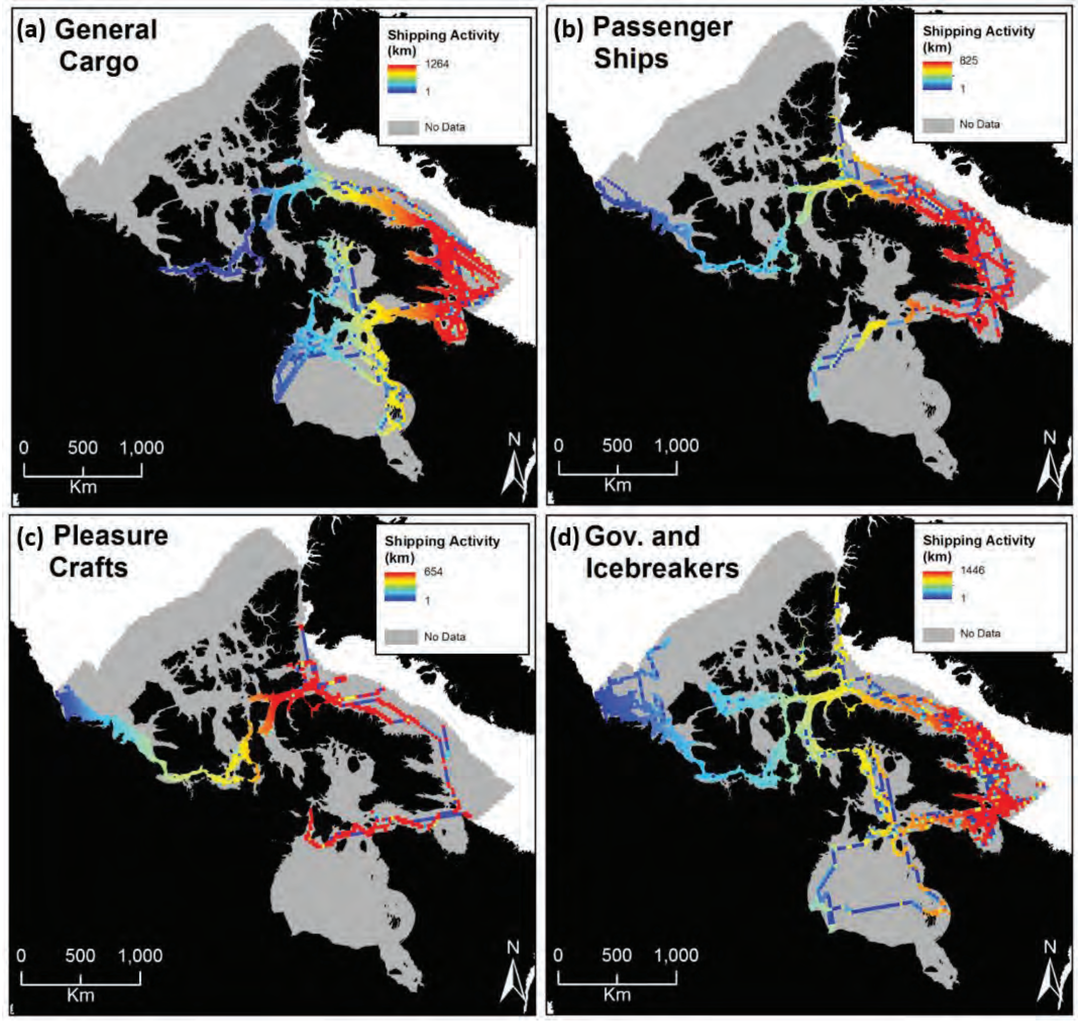


Figure 8

Distribution of shipping activity for 2013 for vessels with wide spatial distribution: (a) General Cargo; (b) Passenger Ships; (c) Pleasure Craft; (d) Government and Icebreakers

2.4.2 Results: Changes Over Time

When looking at changes in shipping activity over the period 1990–2013, it is clear that there have been marked increases for most ship types (Table 3). In particular, General Cargo, Government Vessels & Icebreakers, Passenger Ships, Pleasure Craft, Tanker Ships, and Tugs/Barges all increased significantly during this period.

Table 3

Annual Shipping Activity (km) by Vessel Type in the NORDREG Zone, 1990–2013

Year	Bulk Carriers	Fishing Vessels	General Cargo	Government Vessels and Icebreakers	Oil/Gas Exploration/ Exploitation	Passenger Ships	Pleasure Craft	Tanker Ships	Tugs/ Barges	Other	Total (All Vessel Types)
1990	72930	17539	100728	89966	0.00	16557	3492	50099	12863	0.00	364179
1991	66572	23166	119191	109209	354	17914	1654	56444	44573	0.00	439081
1992	72598	34792	89288	100793	0.00	11373	1203	47611	57183	0.00	414845
1993	61682	15155	102492	137922	445	17283	7191	49994	46635	0.00	438803
1994	66953	23699	79768	99791	387	27923	7226	48273	52166	0.00	406190
1995	59733	27708	93905	121606	0.00	59511	3082	54009	68081	0.00	487639
1996	81147	22646	88581	120212	0.00	30572	0.00	47069	60699	0.00	450929
1997	86655	14563	99135	100616	0.00	39423	0.00	45009	90792	0.00	476197
1998	68606	12576	87612	110310	0.00	58573	0.00	50121	58631	0.00	446432
1999	83580	10439	112072	137546	0.00	52111	205	52419	72365	0.00	520741
2000	139083	7691	106118	114592	0.00	32866	8464	58942	80077	0.00	547839
2001	84313	32560	124297	106238	0.00	48186	1168	56654	71347	0.00	524766
2002	68030	15486	107690	131428	0.00	45771	0.00	55892	78914	0.00	503214
2003	78849	11554	106397	132883	325	41310	1582	62381	81997	0.00	517284
2004	59248	10407	90790	127030	0.00	46786	2034	71204	58598	0.00	466101
2005	61552	4531	102319	114680	1510	74775	11553	55276	67092	0.00	493291
2006	53221	7467	108681	141131	202	87674	0.00	71779	97592	0.00	567750
2007	78930	11833	128941	182296	3239	82118	6464	83138	171648	0.00	748610
2008	72803	48490	152527	183594	4344	89981	27894	98203	130413	4759	813012
2009	67514	33318	125725	167995	0.00	63259	37521	76273	147094	0.00	718703
2010	85351	82807	167165	157508	0.00	92677	35346	111776	137032	0.00	869666
2011	73501	105966	163532	189340	228	46633	54962	130033	65490	0.00	829689
2012	68569	79190	164457	130730	619	37085	70695	113454	103476	0.00	768281
2013	94105	92950	184287	144993	4389	68384	75373	115534	69278	0.00	849298
Average Distance (km/year)	188	2427	***3193***	***2899***	88.2	***2427***	***2400***	***3083***	***3369***	NA	***20102***

*Bolded italic values are significant at the 95% confidence level or higher.

Overall, total cumulative shipping distance more than doubled from an average of 401,630 km yr^{-1} for the first 2 years of the record (1990–1991) to an average of 808,790 km yr^{-1} for the last 2 years of the record (2012–2013) (Figure 9a). This equates to a mean annual increase of 20,102 km yr^{-1} (Table 3). However, the change was not gradual. There was a step increase over the period 2006–2008. When broken down by vessel category, the patterns are generally similar, but much noisier (Figure 9b). Over the past decade, Pleasure Craft showed the biggest change, increasing from an average of 917 km yr^{-1} between 2001 and 2003 to 67,010 km yr^{-1} between 2011 and 2013, for a total increase of over 7000%.

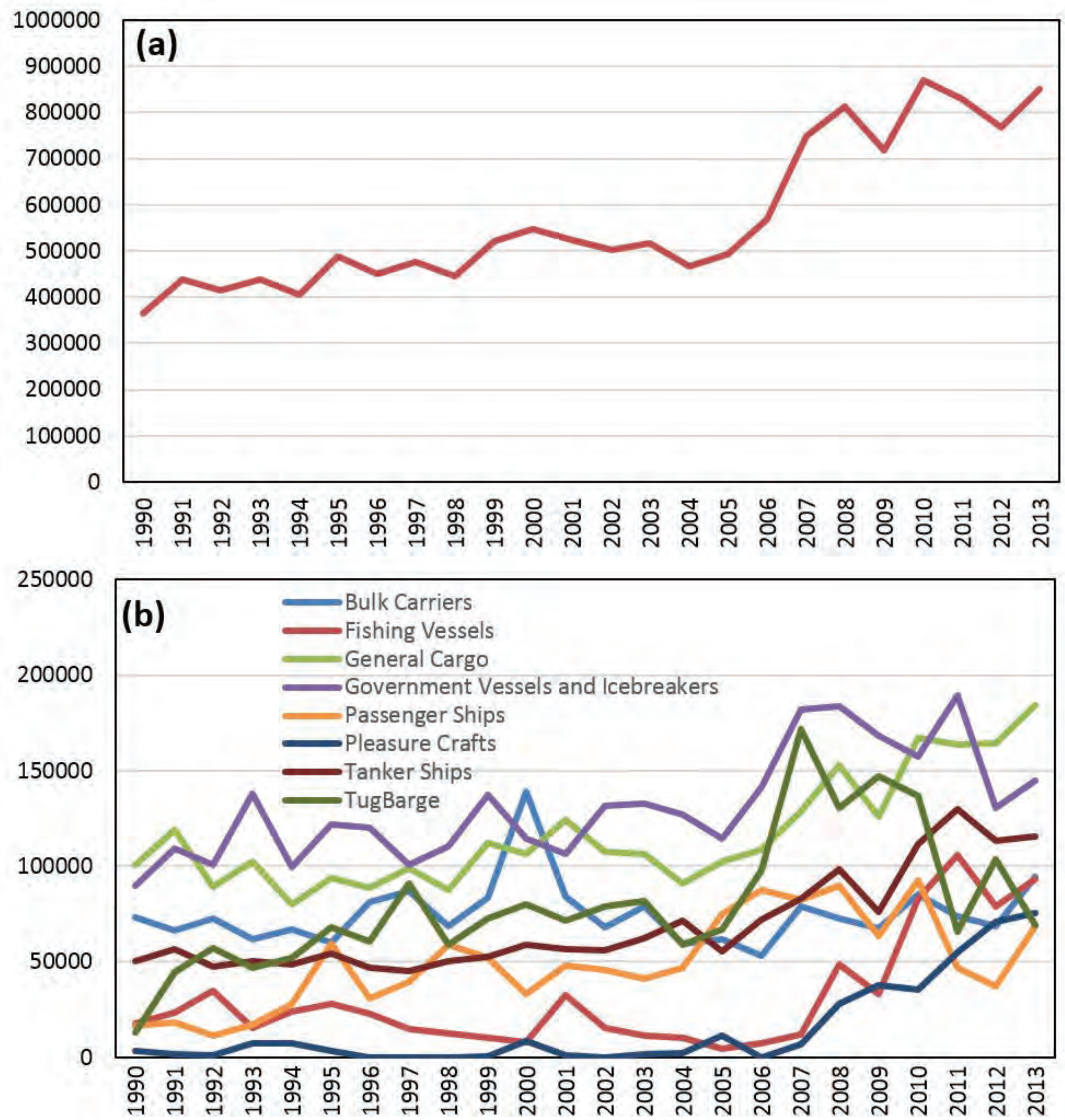


Figure 9

Trends in annual distance travelled over 1990–2013 for: (a) All ship types combined; (b) Individual ship types (Oil & Gas and Other not shown due to low numbers)

Proportionally, there has been a shift in the importance of different vessel types over time. In 1990/91, the three most common vessel types (Bulk Carriers, General Cargo and Government Vessels & Icebreakers) made up a total of 70% of all ship distance in the Canadian Arctic (Figure 10a). However, by 2012/13 these three vessel types only accounted for 49% of all activity (Figure 10b), as three other vessel types grew in importance: Pleasure Craft (an increase from 1% to 9% of all activity), Fishing Vessels (from 5% to 11%), and Passenger Ships (from 4% to 6%).

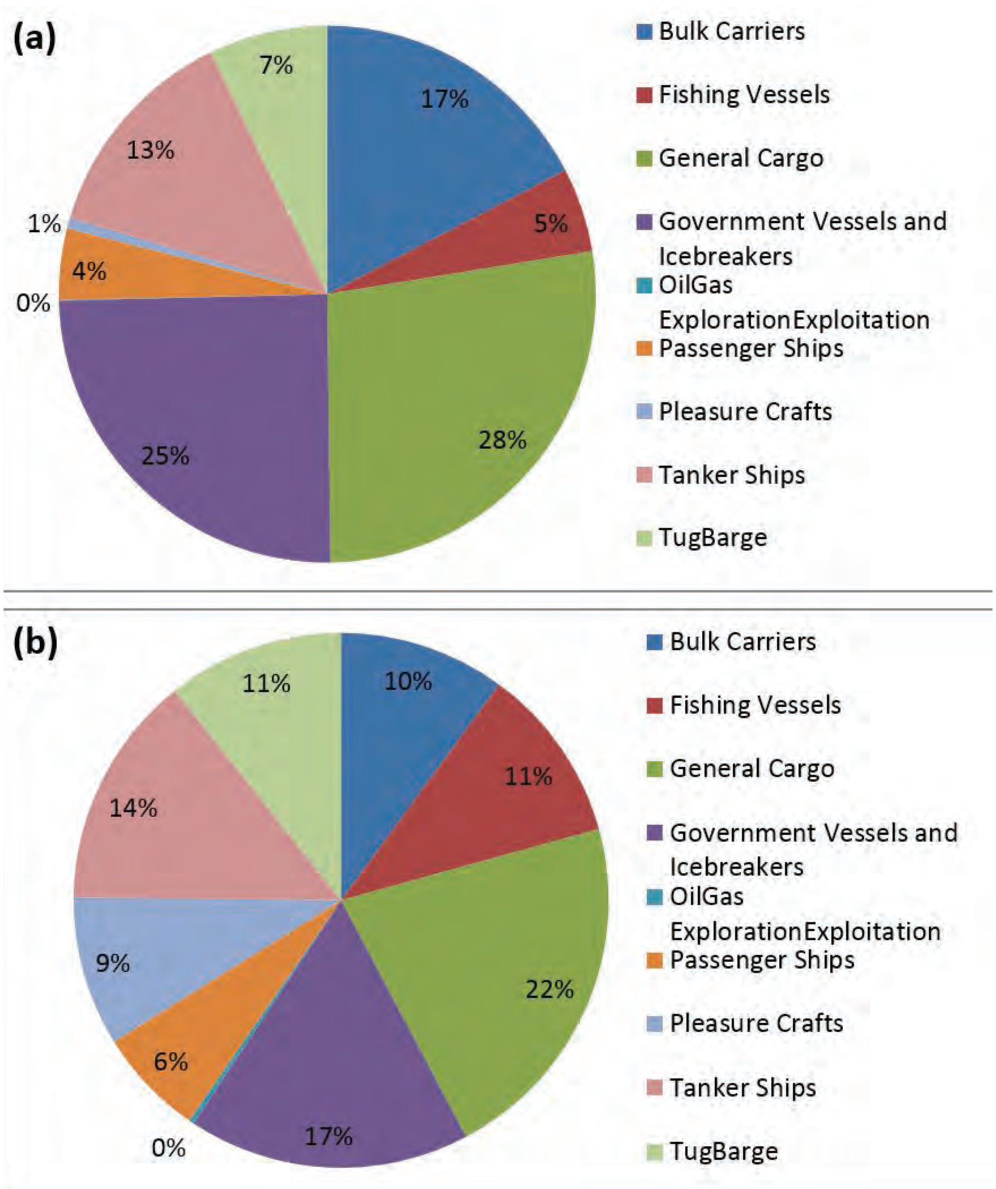


Figure 10

Relative importance of different ship types in accounting for total shipping activity in: (a) 1990/91; (b) 2012/13

By differencing the mean shipping distribution in 2012/13 from the distribution in 1990/91, it is possible to determine where most changes have occurred (Figure 11). This indicates that shipping increases have been predominantly focused in the Eastern Arctic, particularly around southwest Baffin Bay and in Hudson Bay and Hudson Strait (e.g., Deception Bay, Iqaluit, Pangnirtung). Changes in the Western Arctic have been generally minor (e.g., Cambridge Bay, Sachs Harbour), and changes in the High Arctic have been slightly negative (e.g., Resolute, Eureka). Based on shipping activity within 50 kms of communities, a total of 49 communities experienced an increase in shipping over this period, 6 experienced a decrease, and 1 did not change, as no ships transited in either period (Table 4).

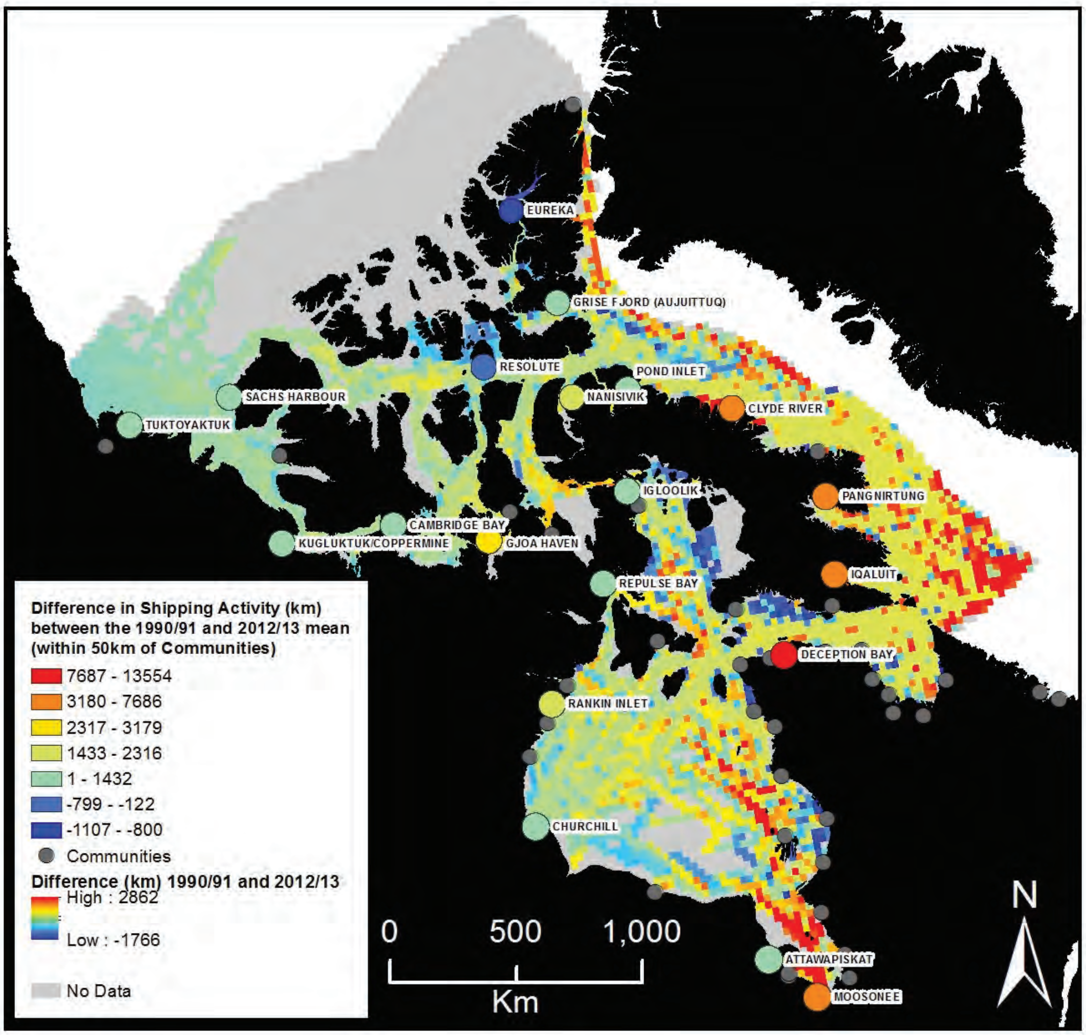


Figure 11

Spatial distribution of changes in shipping activity between 1990/91 and 2012/13 across the Canadian Arctic

Table 4

Relative Changes in Shipping Activity within 50 km of Communities, 2012/13 vs. 1990/91

Rank	Community Name	Change (km yr^{1})
1	DECEPTION BAY	13,554.00
2	KASHECHEWAN	13,348.00
3	MOOSONEE	7,686.00
4	PANGNIRTUNG	7,474.00
5	FORT ALBANY	7,176.00
6	CLYDE RIVER	6,567.00
7	MOOSE FACTORY	5,784.00
8	CHISASIBI	5,737.00
9	IQALUIT	5,680.00
10	BROUGHTON ISLAND (QIKIQTARJUAQ)	5,261.00
11	SALLUIT	4,954.00
12	SANIKILUAQ	4,791.00
13	KANGIRSUK (GEORGE BAY)	4,540.00
14	PUVIRNITUQ	4,298.00
15	CAPE DORSET	3,660.00
16	ARCTIC BAY	3,466.00
17	PELLY BAY (KUGAARUK)	3,256.00
18	GJOA HAVEN	3,179.00
19	EASTMAIN	3,069.00
20	AUPALUK	2,922.00
21	HALL BEACH	2,848.00
22	INUKJUAK	2,780.00
23	IVUJIVIK	2,579.00
24	FORT SEVERN	2,362.00
25	LAKE HARBOUR (KIMMIRUT)	2,321.00
26	CORAL HARBOUR	2,320.00
27	NANISIVIK	2,316.00
28	KUUJJUARAPIK AND WHAPMAGOOSTUI	2,177.00

29	RANKIN INLET	1,833.00
30	KANGIQSUJUAQ (WAKEHAM BAY)	1,635.00
31	IGLOOLIK	1,432.00
32	WHALE COVE	1,221.00
33	GRISE FJORD (AUJUITTUQ)	1,130.00
34	CHURCHILL	1,129.00
35	ARVIAT	1,071.00
36	POND INLET	1,058.00
37	TALOYOAK (SPENCE BAY)	1,013.00
38	ATTAWAPISKAT	852
39	HOLMAN (ULUKHAKTOK)	771
40	CHESTERFIELD INLET	756
41	REPULSE BAY	685
42	SACHS HARBOUR	664
43	CAMBRIDGE BAY	599
44	QUAQTAQ (KOARTAQ)	563
45	TUKTOYAKTUK	561
46	KUGLUKTUK/COPPERMINE	328
47	KUUJJUAQ	304
48	WASKAGANISH	208
49	INUVIK	177
50	ALERT	0
51	RESOLUTE	-122
52	AKULIVIK	-576
53	UMIUJAQ	-709
54	EUREKA	-1,107.00
55	KANGIQSUALUJJUAQ (GEORGE RIVER)	-1,702.00
56	TASIUJAQ	-3,818.00

To understand the causes of the spatial variability in shipping activity through time, it is useful to analyze the patterns of changes in individual ship types. As discussed above, the greatest relative changes occurred in Pleasure Craft, those vessels used by marine adventurers but without paying passengers. In the first decade of the study period, there were virtually none of this vessel type found anywhere in the Canadian Arctic, but over the past decade they have been relatively common, particularly in more northerly areas. It is clear that the Southern NWP route has become a preferred destination for private expeditions, and recently Pleasure Craft have also started entering Hudson Bay. In 1990, there was one Pleasure Craft that passed through the study area, none in 1998, but several in 2008 and many in 2013 (Figure 12).

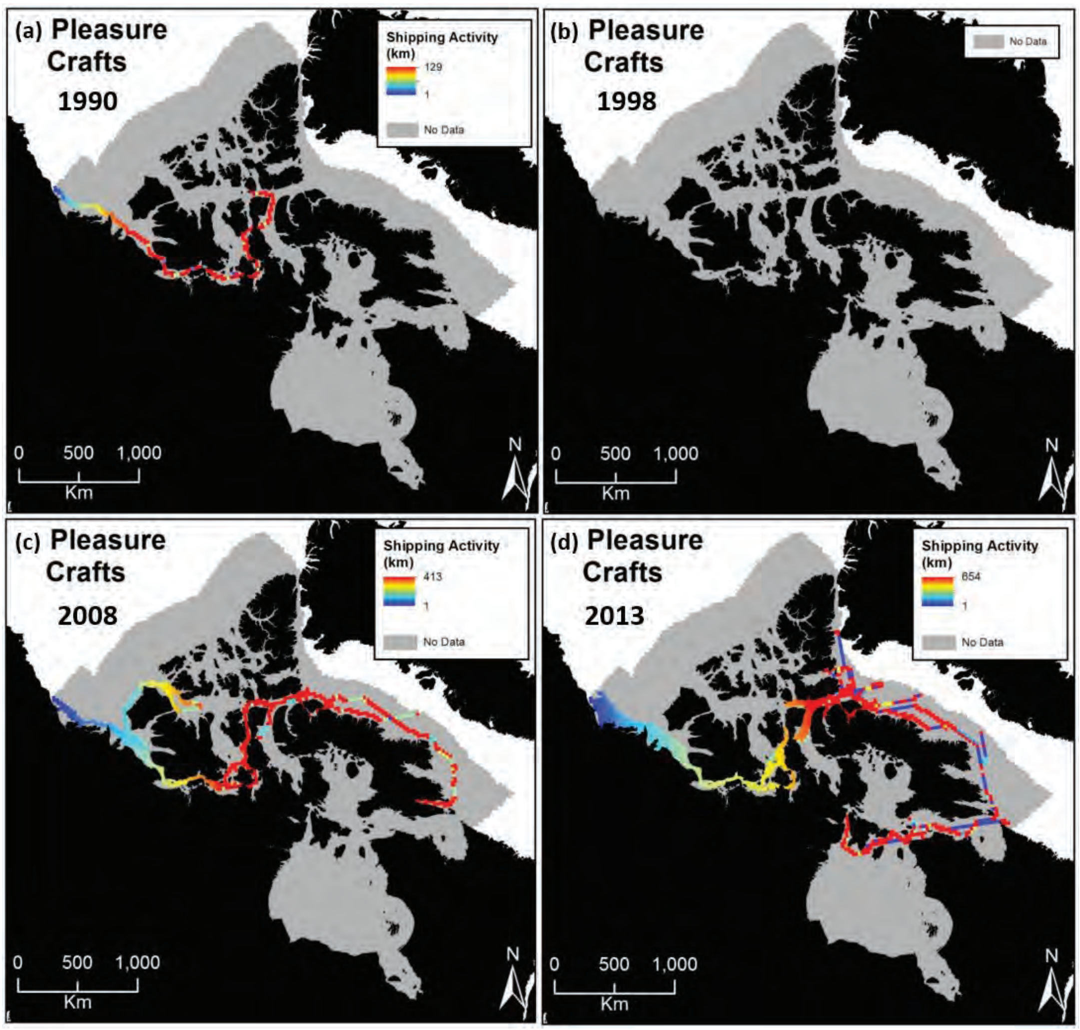


Figure 12

Comparison of Pleasure Craft activity in (a) 1990; (b) 1998; (c) 2008; and (d) 2013

Passenger Ships (i.e., cruise ships) have also demonstrated a significant increase over time, albeit at a lower rate than Pleasure Craft. In 1990–1991, they undertook an average cruise distance of 17,235 km yr $^{-1}$ in Canadian Arctic waters, which more than tripled to an average of 52,735 km yr $^{-1}$ in 2012/2013 (Table 3). In the first two years of the study period, no Passenger Ships transited through the NWP (Figure 13a). However, by the end of the study period, the S-NWP was a relatively common route (Figure 13d). What is also clear from the Passenger Ship traffic is that many vessels start or finish their trips in Greenland, rather than undertake a complete voyage in Canadian waters.

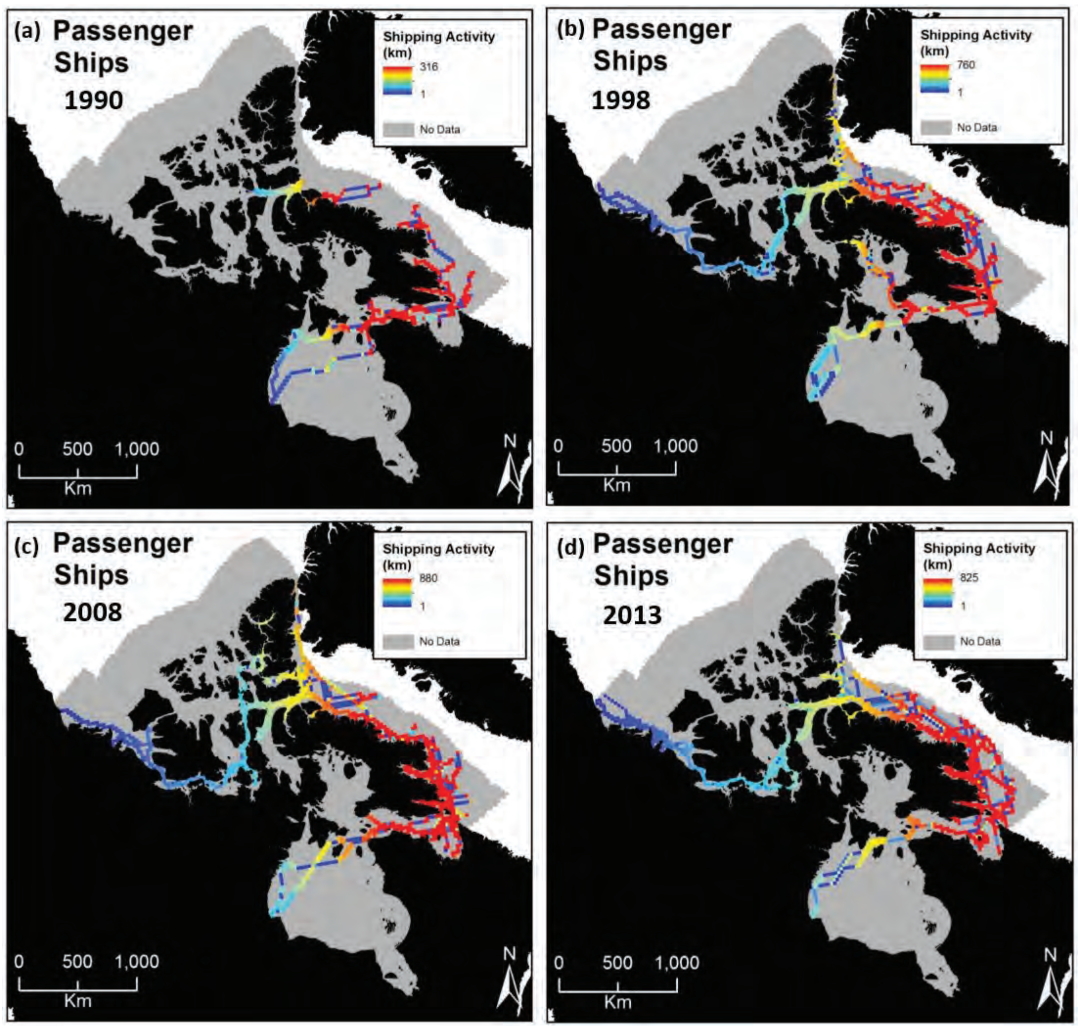


Figure 13

Comparison of Passenger Ship activity in (a) 1990; (b) 1998; (c) 2008; and (d) 2013

For Fishing Vessels, activity was generally low between 1990 and the mid-2000s. However, their activity has increased dramatically over the last 8 years, with an increase from an average track distance of 5,999 km yr^{-1} in 2005–2006 to 86,070 km yr^{-1} in 2012–2013, despite the fact that their changes over the entire 24-year record were not statistically significant (Table 3). This increase has been strongly focused around southeast Baffin Island, with almost no Fishing Vessels recorded in the Western Arctic between 1990 and 2013, and only a few reaching northern areas such as the area around Grise Fiord in 2013 (Figure 14).

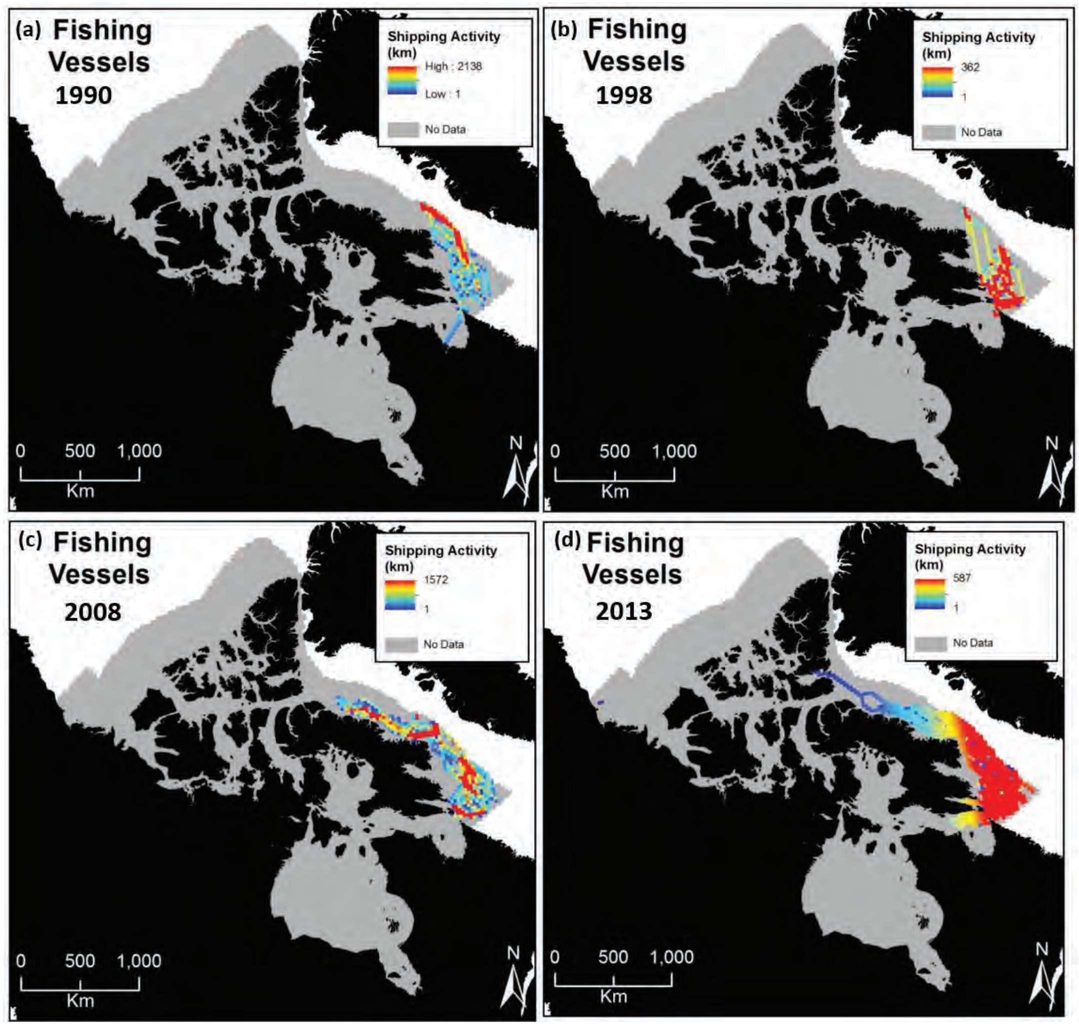


Figure 14

Comparison of Fishing Vessel activity in (a) 1990; (b) 1998; (c) 2008; and (d) 2013

The location of Bulk Carrier activity shows a dichotomous pattern, but with no long-term trend (Table 3). In the 1990s, activity of this ship type was focused in northern regions, primarily due to the servicing of the Polaris Mine near Resolute (Figures 15a, b). Activity across the AB route to Churchill also occurred through this period for the movement of products such as grain. However, the Polaris Mine closed in 2002, and by 2004 there was no Bulk Carrier activity in northern regions (Figure 15c). Instead, activity became focused on the carrying of ore from Deception Bay (which opened in the mid-1990s), along with continued activity on AB (Figure 14d). In the last few years, a few Bulk Carriers have passed through the S-NWP, although this activity is currently quite limited.

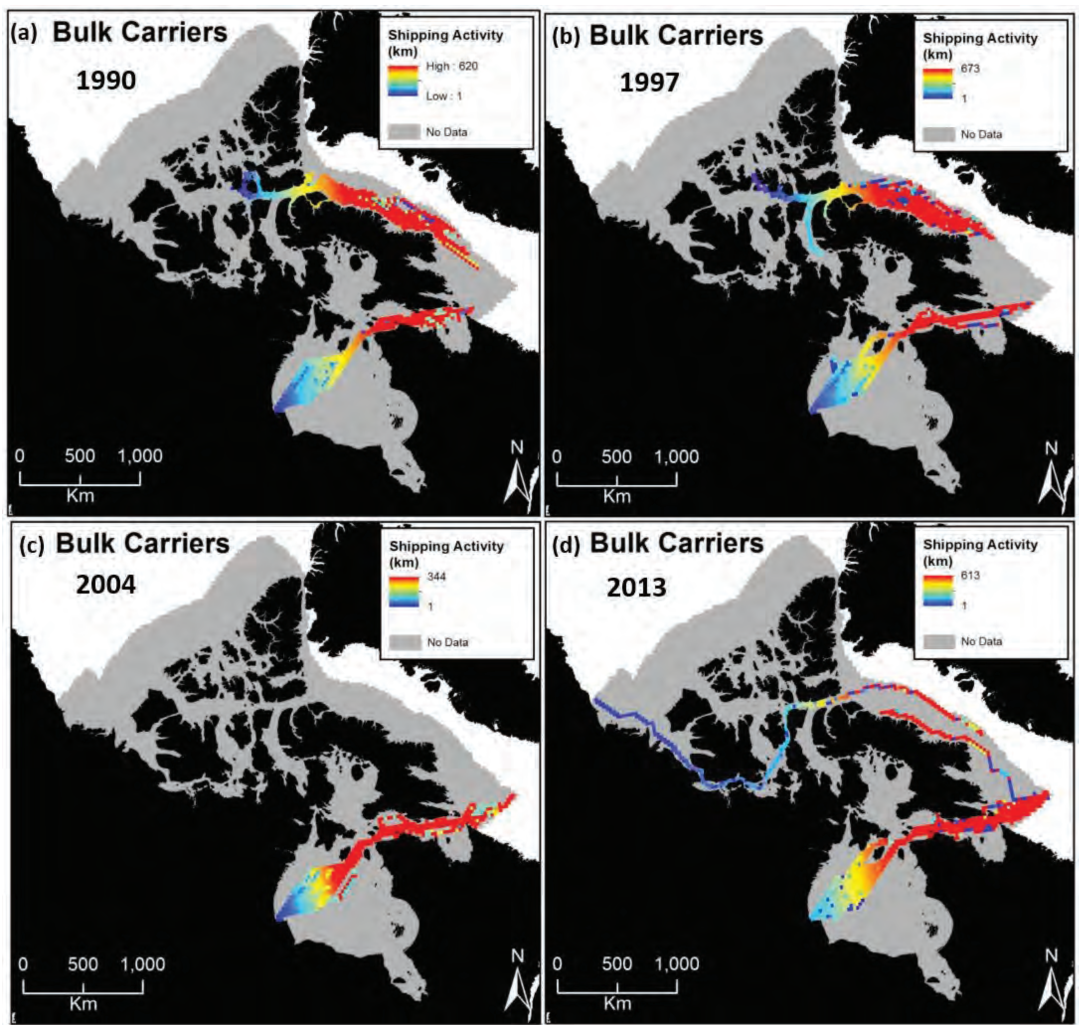


Figure 15

Comparison of Bulk Carrier activity in (a) 1990; (b) 1997; (c) 2004; and (d) 2013

General Cargo and Tanker Ships have shown similar trends over time, with generally little variability until the mid-2000s (Figure 8). During this period, these vessels re-supplied communities in the Eastern Arctic and there was little spatial variability between years (Figures 16a, c). However, starting in 2008, these ship types reached the Western Arctic for the first time (transiting the whole way from eastern Canada), resulting in a marked increase around this period (Figure 8; Table 3). This expansion to the Western Arctic has intensified up to the present day (Figures 16b, d).

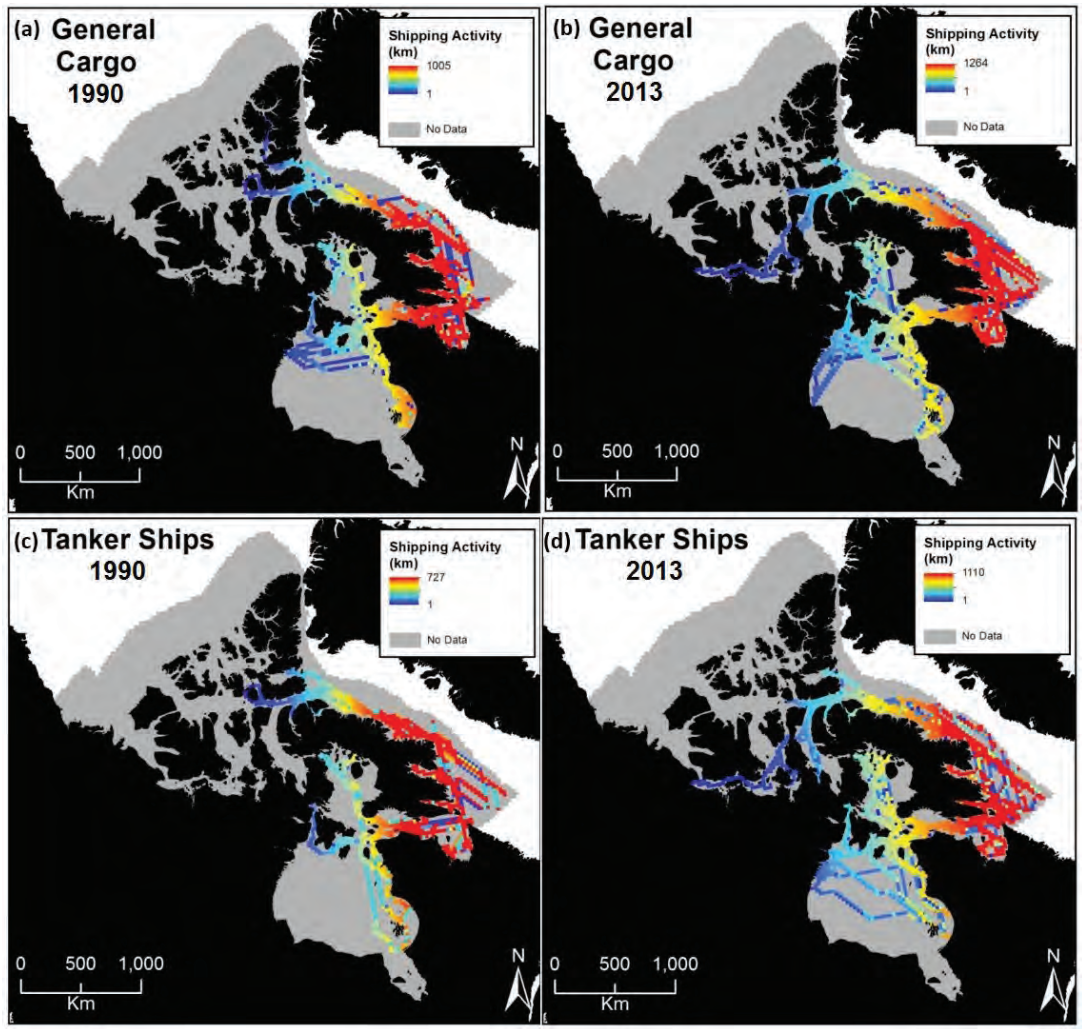


Figure 16

Comparison of General Cargo activity in (a) 1990 and (b) 2013; Tanker Ship activity in (c) 1990 and (d) 2013

2.5 Sea Ice Trends and Variability in the Region

Over the shipping season, sea ice within the NORDREG zone is characterized by statistically significant declines of total ice, MYI, and FYI area at 30 x 10^3 km^2 year $^{-1}$, 19 x 10^3 km^2 year $^{-1}$, and 11 x 10^3 km^2 year $^{-1}$, respectively (Figure 17).

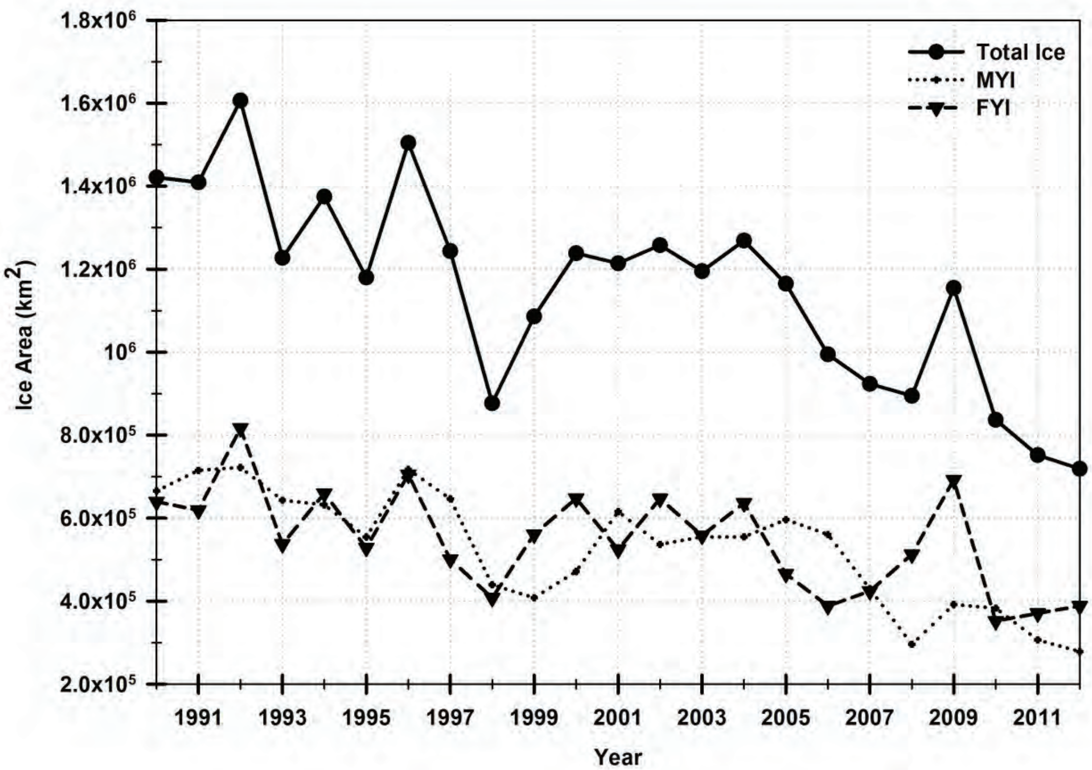


Figure 17

Time series of shipping season mean total ice, MYI, and FYI area (km^2) in the NORDREG zone, 1990–2012

This is an important result for shipping activities, especially in relation to MYI, the most hazardous ice type for vessels. Significant decreases in summer FYI from 1990 to 2012 (-19 x 10^3 km^2 year $^{-1}$ for July, -13 x 10^3 km^2 year $^{-1}$ for August, and -6 x 10^3 km^2 year $^{-1}$ for September, respectively) indicate greater FYI melting in the summer months. This melting results in less MYI area in the subsequent shipping season because less FYI survives the melt season (Table 5). Recent increases in open water in the lower latitudes of the CAA facilitates the southward import of MYI from the Arctic Ocean into the CAA, and subsequently into the channels of the NWP, thus still posing a navigational hazard for shipping operations (Howell et al., 2013). Monthly mean total sea ice area in the NORDREG zone is declining significantly in all months of the year except April. The greatest losses are from June to December, with each month's loss exceeding -19 x 10^3 km^2 year $^{-1}$ to a maximum of -34 x 10^3 km^2 year $^{-1}$ in July (Table 5). Mean MYI is experiencing a significant decline in all months of the year in excess of -10 x 10^3 km^2 year $^{-1}$ in June, to a maximum of -23 x 10^3 km^2 year $^{-1}$ in October (Table 5). Declining total ice, MYI, and FYI area in the NORDREG zone from 1990 to 2012 is in agreement with current model simulations (Stephenson, Smith, Brigham, & Agnew, 2013; Stephenson et al., 2011; Sou & Flato, 2009).

Table 5

Sen's Slope Trends for Mean Monthly and Shipping Season (25 June–15 October) Sea Ice Area within the NORDREG Zone, 1990–2012a (Pizzolato et al., 2014)

	Trend Ice Area (x 10^3) km^2 year $^{-1}$				Trend Ice Area (x 10^3) km^2 year $^{-1}$		
Month	**Total Ice**	**MYI**	**FYI**	*Month*	**Total Ice**	**MYI**	**FYI**
January	**-8**	**-14**	3	August	**-29**	**-17**	**-13**
February	**-7**	**-13**	3	September	**-28**	**-22**	**-6**
March	**-5**	**-13**	5	October	**-27**	**-23**	-3
April	-1	**-13**	4	November	**-24**	**-21**	-9
May	**-9**	**-11**	1	December	**-15**	**-18**	-6
June	**-19**	**-10**	-5				
July	**-34**	**-14**	**-19**	Shipping Season	**-30**	**-19**	**-11**

a Bold values are significant at the 95% confidence level or higher.

2.6 Connection Between Sea Ice Change and Shipping Trends

The relationships between shipping season mean total ice, MYI, and FYI area and annual vessel counts revealed weak correlations (at the 95% confidence level or higher) for some vessel types for total ice area: Government Vessels and Icebreakers (-0.34), Passenger Ships (-0.34), and General Cargo (-0.30). MYI area relationships also revealed weak significant correlations for: General Cargo (-0.40), Government Vessels and Icebreakers (-0.30), and Passenger Ships (-0.30) (Table 6). Similarly, correlations between monthly mean total ice and MYI area, and monthly vessel counts in the NORDREG zone revealed significant correlations for some vessel types in the months of July through October, which fall within the traditional shipping season, 25 June–15 October (Table 6). Outside the typical shipping season, stronger correlations were identified between total ice area and Pleasure Craft in March and February at 0.30 and 0.34, respectively, as well as relationships between total ice area and Bulk Carriers and the total for all vessel types in November at -0.30. No additional correlations were discovered between monthly sea ice area and monthly vessel counts from January to June and November to December, signifying ice conditions alone are not contributing to the observed monthly vessel count increases outside the traditional shipping season. The only exception is for tourism vessels, which are the most directly influenced by sea ice change, meaning that sea ice does represent a driver of change for tourists, especially Pleasure Craft.

Table 6

Kendall's Tau Correlations for Mean Monthly Sea Ice Area (km^2 year^{-1}) and Monthly Vessel Counts in the NORDREG Zone for July through October, 1990–2012[a,b] (Pizzolato et al., 2014)

	Ice Area (km^2 year^{-1})									
	Total					MYI				
Vessel Type	Jul	Aug	Sep	Oct	Shipping Season	Jul	Aug	Sep	Oct	Shipping Season
All Vessel Types	-0.22	-0.23	-0.19	0.00	**-0.31**	-0.32	-0.44	-0.19	-0.15	-0.26
Bulk Carriers	-0.01	-0.04	0.08	**-0.30**	0.04	-0.16	-0.23	-0.02	0.19	-0.07
Fishing Vessels	-0.23	-0.22	-0.09	-0.02	-0.19	-0.13	-0.38	-0.08	0.00	-0.14
General Cargo	-0.29	-0.26	**-0.30**	-0.15	**-0.30**	-0.28	-0.38	-0.37	-0.34	-0.40
Government Vessels and Icebreakers	0.14	-0.14	**-0.31**	-0.15	**-0.34**	0.18	-0.14	-0.36	-0.27	-0.30
Passenger Ships	-0.11	-0.19	-0.17	0.09	**-0.34**	-0.10	-0.29	-0.12	-0.08	-0.30
Pleasure Craft	-0.14	-0.12	0.04	-0.04	-0.07	-0.38	-0.23	-0.02	0.21	-0.10
Tugs/Barges	0.00	0.01	-0.01	-0.03	-0.21	-0.25	-0.19	-0.01	-0.08	-0.10
Tanker Ships	-0.23	-0.01	-0.15	-0.01	-0.19	-0.26	-0.23	-0.15	-0.04	-0.19

a Bold values are significant at the 95% confidence level or higher.
b No correlation is identified by "-".

Successively stronger correlations between total ice area and annual vessel counts have occurred over the entire time series at the 95% confidence level or higher (Figure 18), with the strongest correlation reported during the 2002–2012 time period. Between 1992 and 2012 and between 2002 and 2012 (with the exception of 1998–2012 and 1999–2012), correlations between mean MYI area and annual vessel counts also exhibited an increasingly strong trend towards present, with the strongest correlation reported during the 2002 to 2012 time period. These correlations indicate that the relationship between total ice area/MYI area and annual vessels in the NORDREG zone has become progressively stronger over the 1990–2012 time period. The increasingly strong relationship between annual vessel counts and mean total sea ice area/MYI area over the entire time series suggests that climate change is, over time, playing a more influential role in driving shipping demand and could influence future trends.

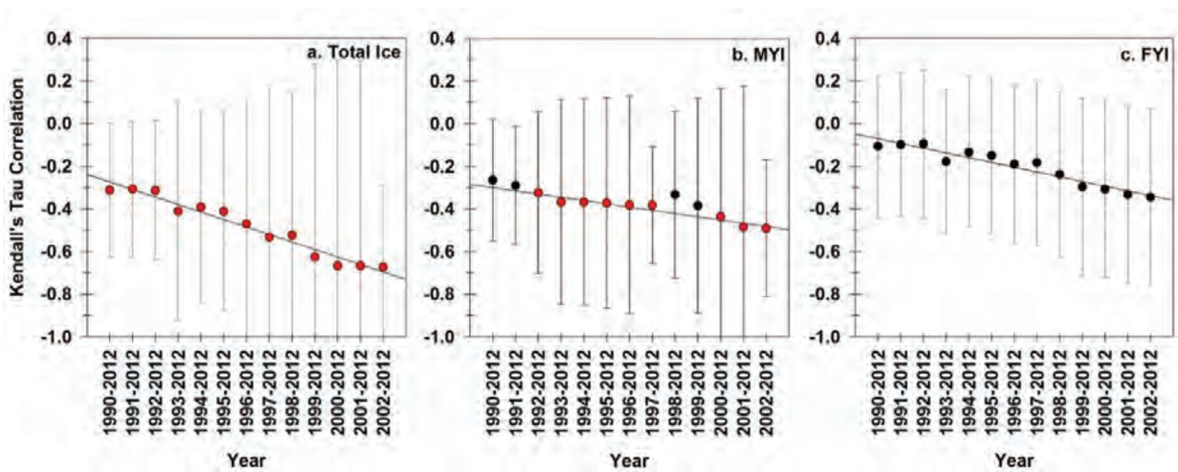


Figure 18

Moving window Kendall's Tau correlation analysis to measure the relationship between shipping season mean ice area (a. Total, b. MYI, c. FYI) and annual vessel counts in the NORDREG zone. Red markers denote significant correlations at the 95% confidence level or higher. Confidence intervals become increasingly larger as the time series shortens because we become less confident in the correlations due to the smaller sample size (Pizzolato et al., 2014).

The shipping season appears to be getting longer, consistent with an increasing mean annual melt season length of 11 days per decade-1, and a delay in the mean freeze onset date (as determined from the satellite passive microwave record) of 8 days per decade-1. This relates to significant correlations (at the 95% confidence level or higher) between shipping season total sea ice area and melt season length (-0.51), melt onset (0.53), and freeze onset (-0.31). Extensions of the shipping season are most prominent in the fall season, but are also apparent in the spring.

A lengthened shipping season in the NORDREG zone has an influence on Passenger Ships volume annually (-0.46) and all vessel types in May (-0.32). This provides evidence that earlier melt onset may be directly related to an increase in vessel traffic in the NORDREG zone early in the shipping season (spring).

No relationships were discovered between lag correlations (i.e., previous year conditions) of freeze onset and melt season length (1990–2010) preconditioning September and shipping season mean total, MYI or FYI sea ice area (1991–2011). This is not surprising considering that most shipping operators are planning their voyages more than 6 months in advance of operations. Therefore, recent ice conditions do not influence traffic volume. In summary, the lack of strong significant correlations between decreasing sea ice and increasing shipping activities over the 1990–2012 shipping season provide some evidence to support the hypothesis that shipping activities are not planned solely based on the condition of the sea ice, but rather are more influenced by other external factors likely relating to resource development, shipments to communities, cargo delivery, and improvements in vessel design (e.g., Arctic Council, 2009; Lasserre & Pelletier, 2011; Rompkey & Cochrane, 2008). The only vessel type that seems to be somewhat influenced directly by sea ice change is tourism vessels, particularly Pleasure Craft.

Emma Stewart

Chapter 3: Projected Future Shipping Trends

3.1 Forecast of Future Marine Shipping Activity for the Canadian Arctic

Maritime traffic in the Canadian Arctic is anticipated to increase in volume and variety in the coming decades. Reductions in sea ice due to climate change is producing larger areas of open water in the Arctic during the summer months, longer navigation seasons in some areas, and a generally thinner and younger ice cover. As marine navigability in the North improves, consequent economic opportunities arise, notably those associated with resource extraction (e.g., development of new mines), tourism (e.g., cruise ships), and community re-supply.

Given recent increases in Arctic marine traffic, as described in Chapter 2, it is useful to try to anticipate the future traffic picture in the Canadian Arctic, especially since improvements in infrastructure, regulations, traffic services, and environmental or safety response all have long lead times. Forecasting is an inherently difficult but not impossible task. It involves exploring plausible futures, bringing to bear the most recent, comprehensive estimates of all relevant factors, and converting this knowledge into scenarios that can be used for planning purposes.

One common way to construct scenarios is through thought experiments that consider possible combinations of future driving factors, yielding a description of the resulting traffic (see Hodgson et al., 2013; Brigham, 2007; Smith & Stephenson, 2013). Although useful to understand basic patterns, a significant drawback of this approach is that each scenario is constructed using a single instance of each of a multitude of uncertain driving factors, but does not then portray the broad and complex range of traffic scenarios that are possible, nor does it explicitly emphasize more likely states of the input variables over less likely conditions. However, a traffic simulation model addresses these limitations and was used to analyze future trends. The approach incorporates a broad range of input factors, both physical and economic, translates them into corresponding traffic levels, and then combines the uncertainty of these factors using Monte Carlo analysis to generate probabilistic ranges of traffic levels by type and location. A case study simulation for the year 2020 is presented here (see also Étienne, Pelot, & Engler, 2013; Mohrdieck, Pelot, & Ulmke, 2014).

3.2 Modeling Method

The first version of the model relied on ship-tracking information collected through the Long Range Identification and Tracking (LRIT) system. This comprises an international ship position reporting system established by the International Maritime Organization (IMO) and operated through agreements between Maritime nations (Hammond et al., 2006). Current model developments incorporate data from the Automatic Identification System (AIS), which uses a transponder to electronically exchange identity and location information between nearby ships, shore-based stations, or satellites. The International Maritime Organization's International Convention for the Safety of Life at Sea (IMO, 2016) makes an AIS transponder mandatory for international voyaging ships weighing 300+ gross tons and all Passenger Ships. Thus, there are limitations to this approach when attempting to model smaller vessel types (i.e., Pleasure Craft, some fishing boats) that are not as well captured in LRIT and AIS datasets.

For this study, LRIT data from the year 2011 were acquired from the Canadian Coast Guard and AIS data from the Marine Environmental Observational, Prediction, and Response Network (MEOPAR). These data were categorized by primary vessel type, with the number of tracks for each type provided in Table 1. Each track represents the connection of contiguous tracking records from LRIT for a given trip, from origin to destination. The area of interest for the analysis encompasses the region defined by the Arctic Waters Pollution Prevention Act (Transport Canada, 1985), with the addition of Hudson Bay, James Bay, and a 300 nautical miles (nm) buffer zone around Canada's northern shoreline (Figure 19). This region includes marine zones in the NORDREG zone and compares well with the study area used in Chapter 2.

Table 7

Number of Tracks per Vessel Type (2011)

Vessel type	ID	Number of tracks (2011)
Cruise/Passenger	C	5
Fishing trawler	F	2
Merchant (General Cargo)	M	17
Research/survey	R	1
Supply ships & Tugs	S	5
Tankers	T	14
Unknown	U	32
	TOTAL	**76**

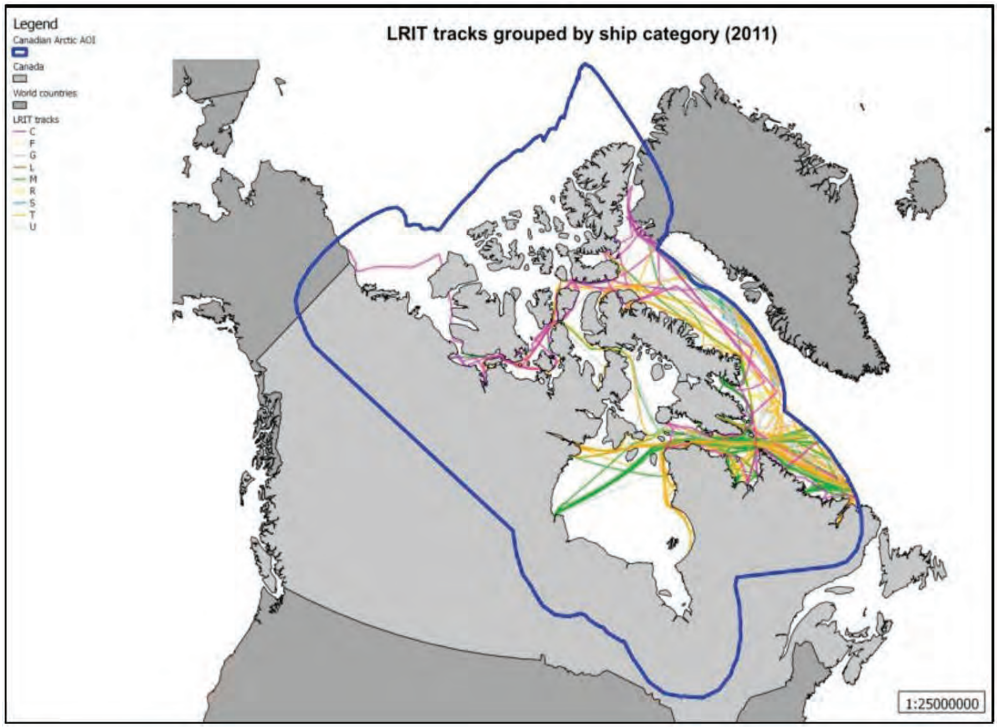


Figure 19
LRIT (2011) tracks by vessel category within the Area of Interest (NAD83 projection)

The simulation model must allow vessels to proceed along any feasible path in the Arctic, so a graphical node-network was created to allow future forecasted traffic to follow additional paths in addition to the currently used routes. The nodes on the network were constructed on the basis of Zones of Interest (ZOI), an approach that can encompass several types of origins and destinations: focused areas such as ports and communities; spatial areas associated with specific types of activity, such as fishing areas or offshore exploration leases; and gateways on the east and west sides of the AOI through which traffic enters or leaves the vessel traffic network. To allow the maximum possible flexibility for traffic to move between the ZOI, arcs were created to link the nodes. As most types of traffic would move as directly as possible between their origin and destination ZOI, an optimization algorithm was applied to link the ZOI efficiently, subject to constraints such as land avoidance and shallow water restrictions. The next step in completing a realistic and feasible network model involved incorporating into the model ice projections for the year 2020, affecting traffic in terms of where it can go as a function of the ice coverage, ice type, and vessel type. The final step was the development of a temporal traffic-spreading algorithm, since, as the ice restrictions change, the model must allow for ships to travel outside of the months that are currently feasible.

The ZOIs were determined using the Canadian Geographical Name Database (Natural Resources Canada, 2003) as an indicator of inhabited settlements, vessel stops indicated in the LRIT database, and manual zones added to the list. Two manual zones, named EAST and WEST ZOI, were added to represent the "portals" where ships usually enter or leave the Arctic AOI. Two other areas related to Greenland Oil and Gas exploitation were also added to the network, as presented in Figure 20. Fishing and Pleasure Craft traffic data come from different data sources and thus are not simulated using the ZOI graph in this first iteration, although the network structure could include them as needed.

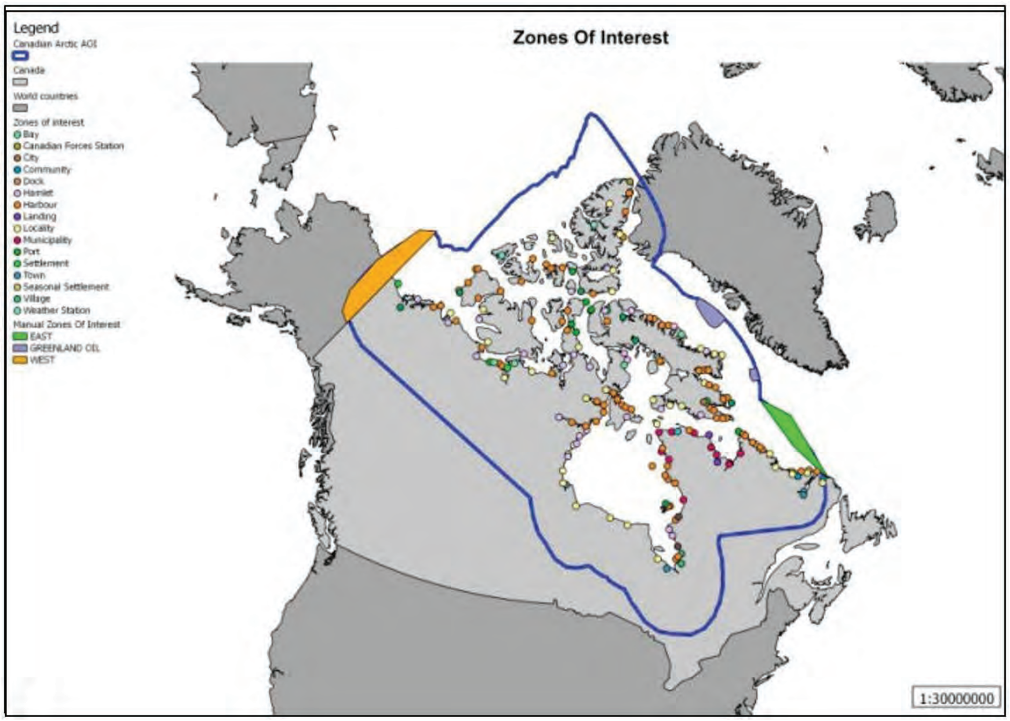


Figure 20

Zones of Interest (ZOI) in the Canadian Arctic

Sea ice charts created by the Canadian Ice Service (CIS, 2009) provide information about the location, concentration, stage of development, and form of ice. These datasets can be downloaded from the National Snow and Ice Data Center website (nsidc.org). Transport Canada's Arctic Ice Regime Shipping System (AIRSS) (Transport Canada, 1998) assists navigation by providing a numerical estimate, called the Ice Numeral (IN), of whether a given vessel type may navigate safely through an area characterized by a consistent "ice regime," which is determined by ice concentration and type, and vessel ice class. While only an indicator, it is assumed that a positive IN corresponds to a navigable area for a given ship at that time, while a negative IN suggests it is impassible. We adopt this go/no-go condition in our model with the following extensions.

• The entire AOI is gridded with cells of 0.1° x 0.1°, so that sea ice conditions can be considered in each cell.

• When inconsistent ice conditions occur in a cell where sea ice charts overlap (see Figure 21), we conservatively assume the worst condition.

• The ice conditions that may be encountered in any given grid cell are estimated over a month, which serves as the resolution for our model. Thus, for each grid cell we calculate the minimum Ice Numeral and the Maximum Ice Numeral over the month.

• Ice Numeral values can range from 10*(+2) = +20 for 100% Ice-Free areas, to 10*(-4) = -40 for Type E ships in 100% multi-year ice. As an indicator of general "passability" for all our categories of ship types combined, an Ice Numeral Sum (INS) was calculated for each grid, each month, for all vessel types (see Figure 22), where green is a high IN (safer) and red is a low IN (dangerous).

• Based on the Ice Numeral grid for 2011 and an ice prediction for the year 2020 from literature, we computed an Ice Numeral Prediction Grid using the following assumptions: the Ice Type will decrease by 1 from 2011 levels, and ice concentration will drop by 20%. See Figure 23 (and compare with Figure 22) for the projected average IN across months and ship categories.

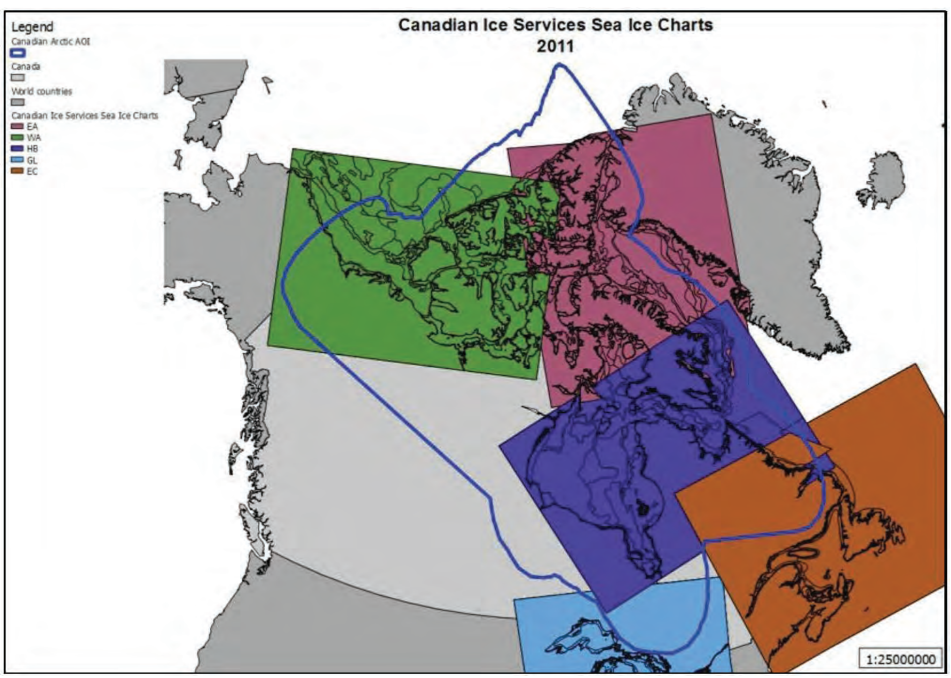


Figure 21

Coverage provided by Canadian Ice Service sea ice charts (2011)

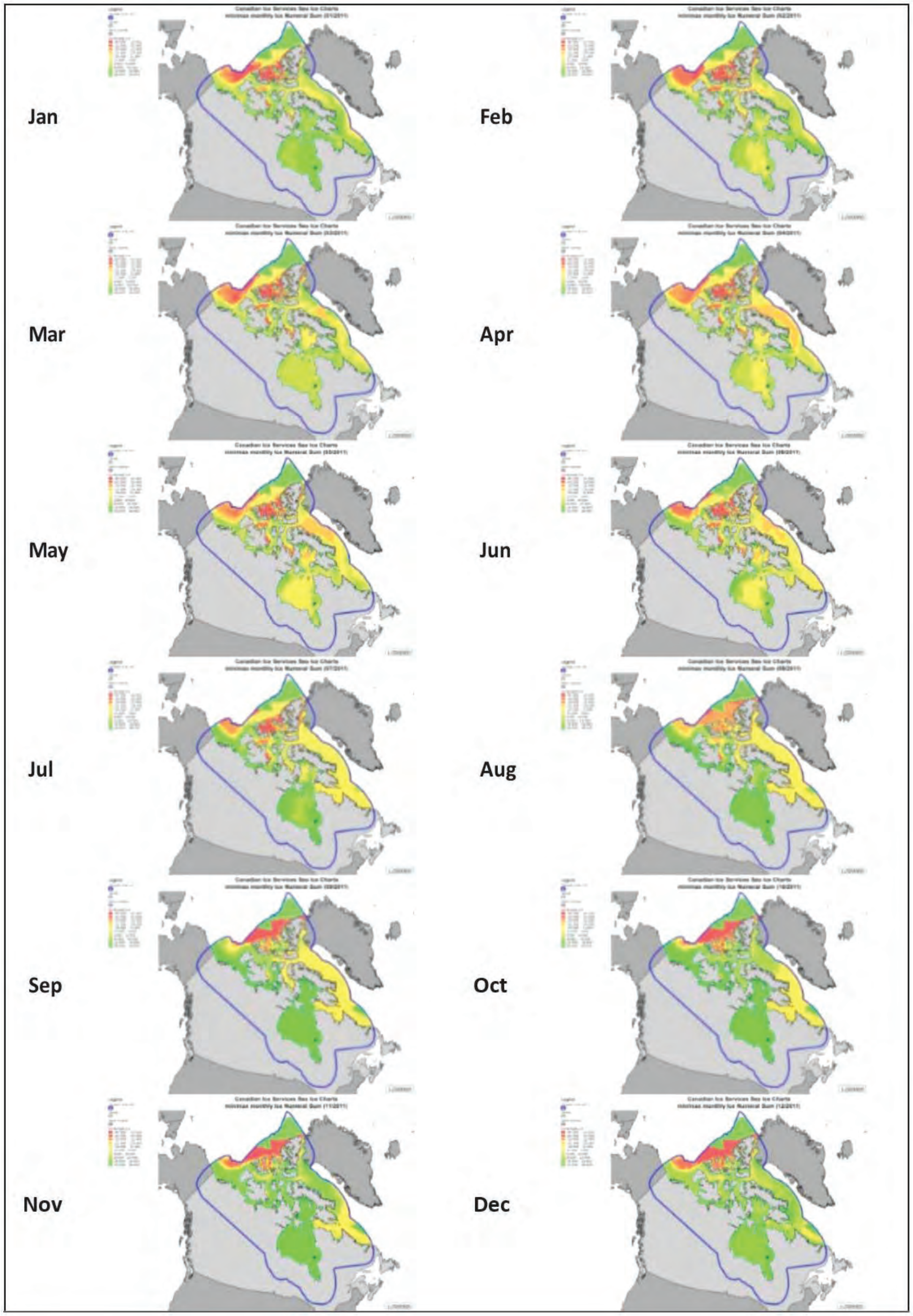


Figure 22

Monthly evolution of Ice Numeral Sum aggregated by grid cell for 2011

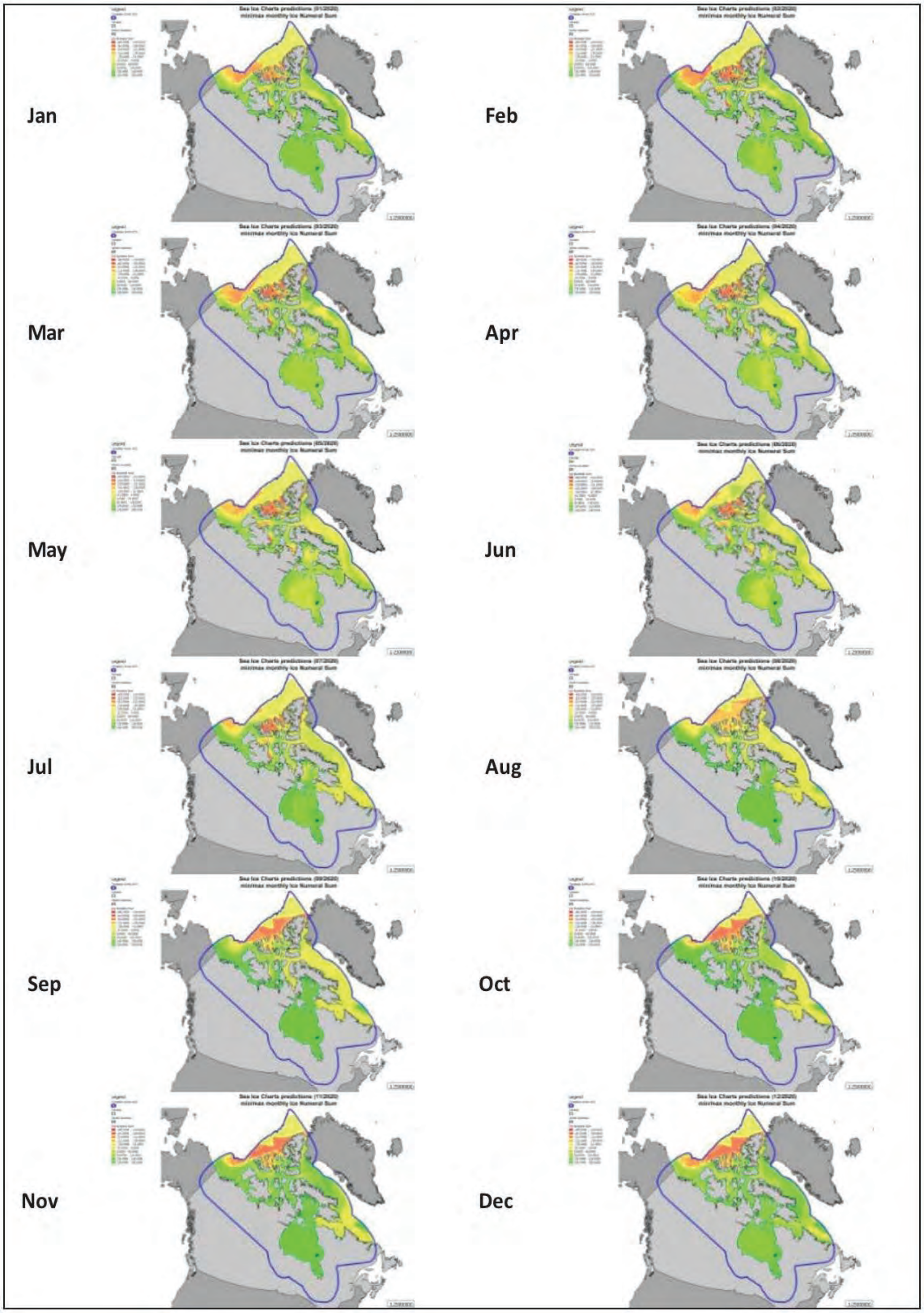


Figure 23

Monthly evolution of Ice Numeral Sum aggregated by grid cell for 2020

3.3 Projecting Future Navigable Ice Areas

Having completed the ice model and year 2020 ice prediction for the Arctic AOI grid, the model can be used to simulate the feasible paths between every ZOI pair depending on the Arctic Class of the ship. For illustrative purposes, the lowest-rated Ice Class vessel category (Type E) and the highest ice-class vessel (CAC 3 Canadian Arctic Category ships) will be used. Note that stronger CAC 2 and CAC 1 vessels are not operating in the Canadian Arctic, and so were not used in the simulation (also see Laliberté, Howell, & Kushner, 2016).

A comparison of the evolution of the navigable area in March between 2011 and 2020 is presented in Figures 24 and 25, respectively, for the Arctic CAC 3 and Type E ship categories. Red cells are areas that are not navigable in either 2011 or 2020. Brown cells show areas that were not navigable in 2011, but will be navigable in 2020. Green cells are areas already navigable in 2011, and which are expected to remain so in 2020. Note that Arctic CAC 3 category vessels will be able to navigate everywhere in the Artic in 2020 under this prediction simulation.

3.3.1 Navigation Route Optimization

Along with the ice restrictions, the model takes into account three other factors to determine the likelihood of routes being chosen in future scenarios. The model uses the shortest path to simulate a ship route between two ZOI, but the choice of routes is weighted by the cost of these factors:

- **Bathymetry:** Since ships try to navigate in deep water to avoid grounding, we integrated the arctic bathymetry into the shortest path cost function. Publicly available bathymetric data from GEBCO (General Bathymetric Chart of the Oceans) was used to calculate the minimum water depth for every 0.1° grid cell of the AOI (Figure 8). The shallower the water, the greater the cost function assigned (with the option of exclusion zones for very shallow water).
- **Cell traffic density:** Ships are generally inclined to follow existing routes, as it is safer based on historical activity. However, cruise ships may be motivated to explore new areas and Fishing Vessels to pursue stocks into less familiar regions. The cost function reflects historical density in each cell, with previously unused or lower density traffic grids assigned a higher penalty.
- **Cell distance to shore:** Based on historical LRIT trajectories, vessels do not normally venture closer than 30 km from shore while travelling, undoubtedly to lessen grounding likelihood. Hence, a penalty is applied for cells within 30 km from shore.

Thus, the network model is completed. All possible origins and destinations are represented using ZOI, vessels can travel on routes between points that are feasible in terms of ice coverage during the relevant period, and the choice of routes is fundamentally based on a shortest path algorithm, tempered by the above three factors.

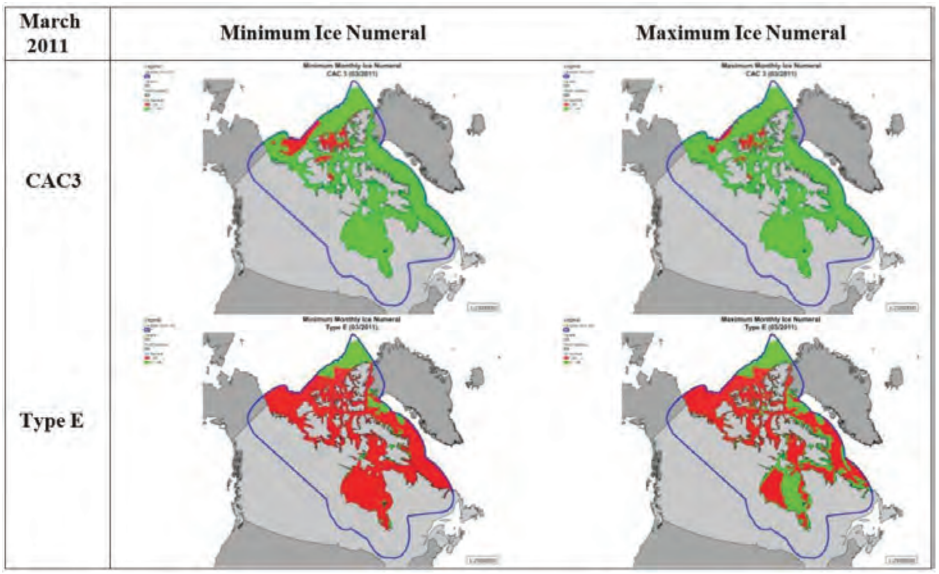


Figure 24

March 2011 Ice Numeral comparison for Type E and CAC 3 ships

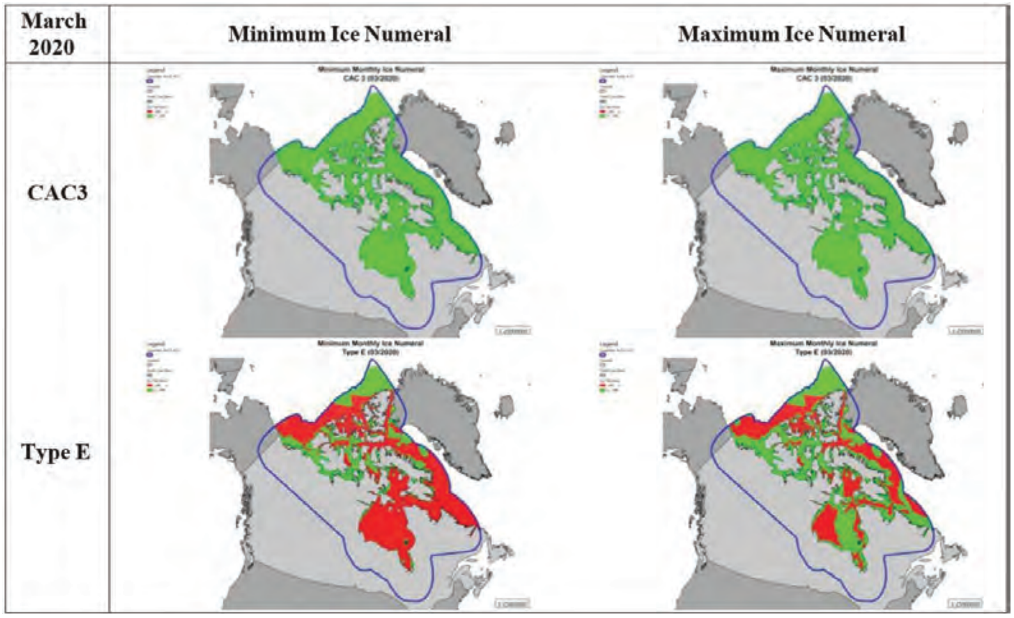


Figure 25

March 2020 Ice Numeral comparison for Type E and CAC 3 ships

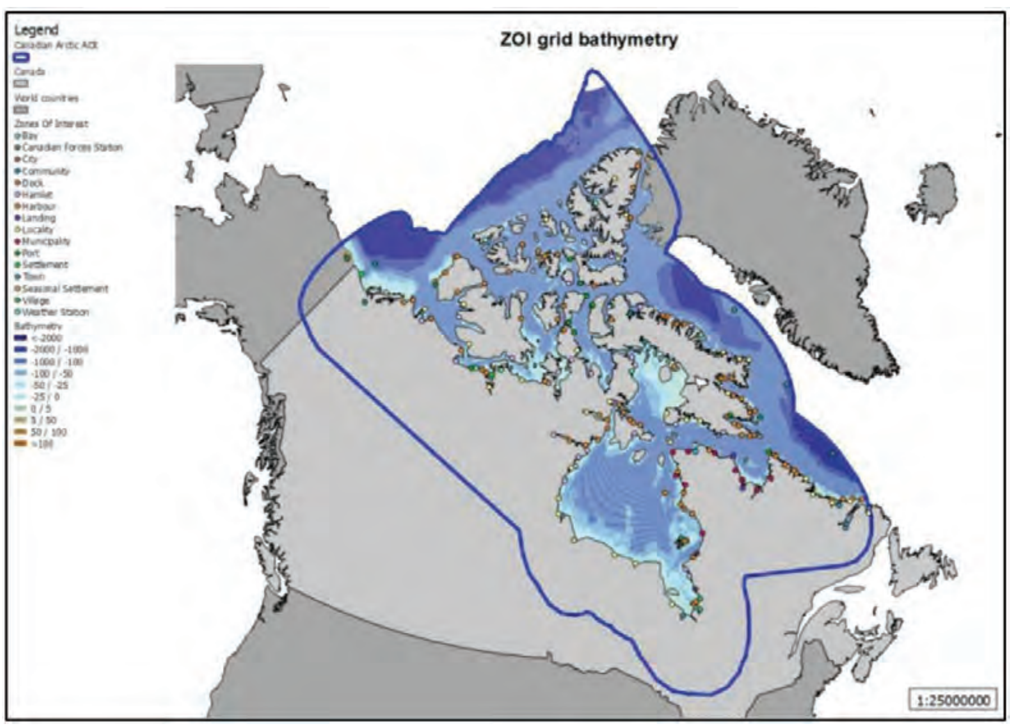


Figure 26

Arctic bathymetry (0.1 degree grid) derived from General Bathymetric Chart of the Oceans

3.4 Generation of Future Traffic Projections by Vessel Type

Simulating future traffic scenarios for 2020 using the network model involves several steps. As the rate of development in Northern Canada is expected to vary significantly amongst economic sectors, the following five activities are distinguished in the model: Community Re-supply, Natural Resource Exploration/Exploitation, Tourism, Fisheries, and Pleasure Craft. While transarctic shipping through the Northwest Passage is technically feasible, the great uncertainty and lack of infrastructure provide significant barriers that preclude such regular activity in the near future. This type of shipping is therefore not included in our model, although the model structure allows easy later insertion of such scenarios if needed. The following subsections highlight some key elements used in the projections for each sector, with details provided in Étienne et al. (2013). Since there is uncertainty in all projections, a probability distribution is generated using high, likely, and low estimates. Monte Carlo simulation is then used to combine the possible values of all the inputs to calculate future traffic scenarios using multiplicative or additive factors. Fractional vessel trips are permitted in the model, as the purpose is to estimate aggregate traffic levels and trends.

3.4.1 Community Resupply

Community resupply is highly related to the location of population centres in the Canadian Arctic. The ZOI were cross-referenced with the Canadian Geonames database to identify network links that terminate in communities and other habituated areas. The categories of ship impacted by these resupply activities are Merchant, Tankers, Tug, and Government vessels. Population growth predictions for each province and territory from Statistics Canada (2010) were used to project community growth for the year 2020. To account for uncertainties in these predictions, low, medium, and high growth multiplicative factors were determined. Parameters obtained from an Organisation for Economic Co-operation and Development report (OECD 2012) were also taken into account to simulate the impact of Canada-wide growth in Gross Domestic Product (GDP) on community re-supply. As a key port of export for Canada's grain industry, the anticipated traffic through the Port of Churchill on Hudson Bay is modeled separately from other northern communities, as the economic drivers there are distinct.

It is expected that community re-supply will increase, but not significantly and not rapidly. Construction projects will drive demand, and these will depend on infrastructure decisions that are made over the next five years, as well as other unknown factors. Population increases are expected, but these will not drive significant increases in re-supply until after 2020. Grain and other shipments out of Churchill are highly dependent on land infrastructure and other regulations that are currently inhibiting any rapid increase in traffic, and so only minor growth is expected for shipping related to the Port of Churchill.

3.4.2 Natural Resource Exploration/Exploitation

An important spacial-temporal factor taken into account in the 2020 model simulations is the exploitation of natural resources in the Canadian Arctic. This factor provides the greatest impact on the results because there are many new activities planned in this sector, although there are major uncertainties as to which projects will be operating in 2020. That is why the Monte Carlo simulation, using triangular distributions, provides a useful method to model the possible range of impacts of these scenarios on maritime traffic levels.

As the annual sea ice extent progressively shrinks, and if oil and gas prices rise, exploitation of Arctic oil and gas fields will become increasingly attractive. Using digital spatial boundaries of existing leases, and examining a large set of reports projecting future development in the Beaufort Sea, a new Zone of Interest was created in that area. Simulated traffic around that ZOI was estimated based on traffic counts and ship categories from the archetypical Greenland oil and gas activities, for which we have existing traffic patterns. Traffic in and out of the area was also simulated between the ZOI and the West Gate entry portal into the Canadian Arctic.

Another major resource in the Canadian Arctic is minerals. The following projects were included in the model based on existing operations or anticipated activity by the year 2020: Voisey's Bay, Raglan mine, Nunavik nickel project, Hopes Advance project, Izok Lake Corridor, Bathurst Inlet port, Sabina's Back River project, Hackett River project, Meadowbank mine, Kiggavik project, Meliadine project, Mary River project, and Roche Bay project.

The traffic associated with each of these projects is estimated using a probability distribution based on the anticipated type of ship, level of activity, and likelihood that extraction is occurring at that location. Of course, the volatile nature of this sector means that regular updates should be conducted for this part of the model to reflect improved or changed activity projections.

In general, it is anticipated that the level of resource-based shipping will remain relatively stable into 2020 with only some minor variation. However, resource-based shipping is expected to increase over longer time periods, but will be highly correlated to commodity prices and demand.

3.4.3 Tourism

Tourism activity has a direct impact on maritime traffic for the category of Cruise/Passenger ships in the Arctic. Based on our literature review, we do not expect any new Canadian Arctic tour companies to be established between now and 2020 due a lack of availability of ice-strengthened ships and due to current market saturation. However, tourism activity is expected to increase slightly through existing companies and via one-off voyages from existing operators that typically travel to other regions (generally the global south). We simulated this increase by multiplying the 2011 traffic counts by a maximum of 1.5 over the entire year (a 50% increase). However, the mode's (most likely value) expected change was simulated using a 25% increase. There has already been a ~20% increase in cruise traffic between 2011 and 2015, and thus a 25% increase in the 2020 time period is highly plausible.

Overall, a small increase in cruise traffic volume is expected by 2020 through companies that already operate in the Canadian Arctic. Although no new companies are anticipated to emerge, it is expected that operators that have not visited the Canadian Arctic over the past few years, but which have visited in the past, will return to the region as a result of climate change. The Northwest Passage is the most popular cruising route, and as that route becomes increasingly accessible it will draw more tourist vessels to the region. It is also expected that the region will experience some new entrants from existing operators of larger cruise vessels than we have previously witnessed in the region. Although the region does not have the infrastructure to support extremely large cruise vessels that carry thousands of passengers, it is anticipated that the region will see an increase in the size of cruise ships operating in the region. Therefore, the biggest increases will be the total number of passengers, not necessarily the total number of vessels. An example of this is the Crystal Serenity, a luxury yacht with capacity to carry over 1000 passengers and is planning a Northwest Passage tour in 2016. The non-ice strengthened vessel operated by an American company is the first of several larger vessels to visit the Canadian Arctic, particularly the Northwest Passage.

3.4.4 Fisheries

Based on the literature review, fisheries are not expected to generate more traffic in the Canadian Arctic by 2020. The gridded average traffic density month overlay simulation for Fishing vessels is presented in Figure 27. New fisheries infrastructure around Pangnirtung, Nunavut, will influence some increases in intensity, but overall fisheries will remain relatively stable.

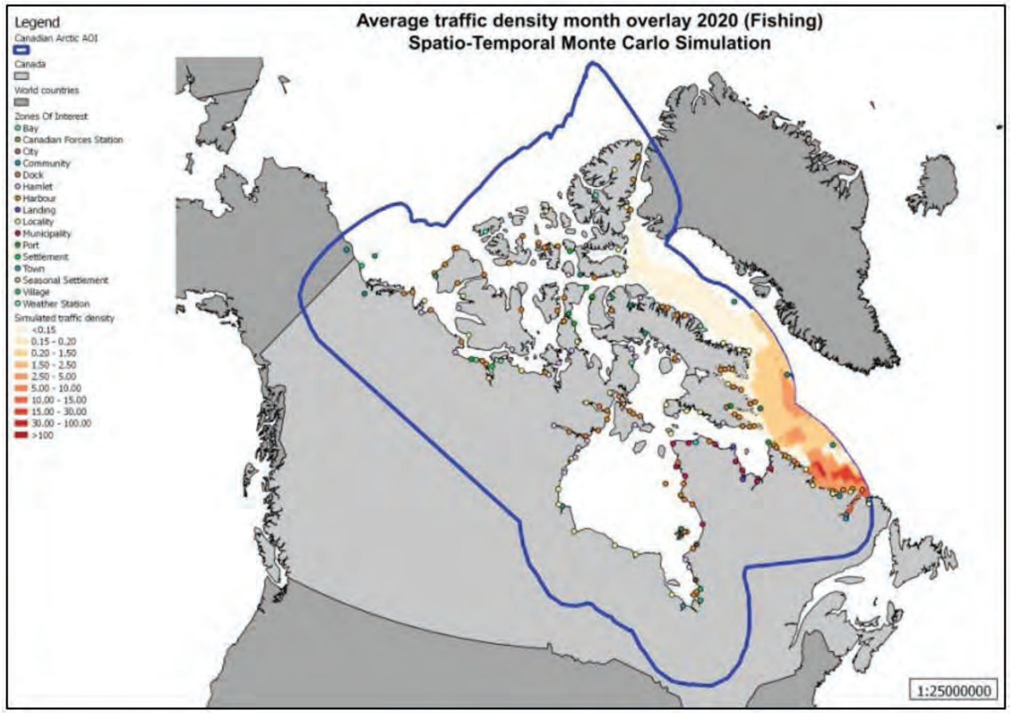


Figure 27

Gridded average traffic density month overlay (Fishing 2020)

3.4.5 Pleasure Craft

Modeling Pleasure Craft projections is especially challenging considering that this type of vessel is not well monitored. We have limited reliability in our model of Pleasure Craft, but did attempt to estimate future change based on historic incident rates recorded by the Canadian Coast Guard Search and Rescue Program Information Management System incident reporting database, and noted the relationships between these incidents and populated areas at the national level. Additional effort is needed to more reliably estimate future Pleasure Craft numbers. However, because this category of vessel is currently the fastest growing sector, it is likely that some level of growth will continue into the future. However, the total number of Pleasure Craft in the region remains relatively low compared to other regions. Thus, despite expected growth in this vessel type, total numbers will remain low into 2020.

3.4.6 Other

Icebreaker, military, and research activity will increase by 2020, but, again, the increase will be slow and moderate. Perhaps scientific research thrusts over the past decade caused increases in research vessel activity, and this focus is expected to continue but not to increase significantly from current volume. Military activity is also expected to continue. Icebreaking activity is limited to the number of vessels available, but it is anticipated that the season length in which vessels operate will increase, and so the same volume of vessels will remain into 2020, but that these vessels will operate with increased intensity and over a longer period of time. Once the off-shore patrol vessels become operational (beyond 2020), there will be increased traffic resulting from their operation.

3.5 Monthly Traffic Spreading

As arctic sea ice melts, it is expected that the duration of the annual shipping season will increase. The Ice Numeral predictions for 2020 can be used to compute which network links would be navigable for each ship type in each month. We used the following assumption to simulate this “monthly traffic spreading.” If there is some traffic on a given link during one month, then this traffic is expected to spread out across previous and subsequent months (up to two months before and two after), as long as the link is also navigable during those preceding and following months. However, in this part of the simulation we did not increase the total amount of traffic on the link; we only spread it temporally across the months. Changes in the total traffic levels on that route were conducted as a separate step, as described above.

Once the simulations are completed for every link and ship category, they can be visualized using histograms. Histograms of traffic numbers were generated by month and ship category. The monthly overall traffic simulation for all types of ships is presented in Figure 28. The blue line corresponds to the monthly normalized traffic count for 2011. Depending on the location of this blue line, 3 different scenarios can be observed:

Case 1: When the histogram is fully on the right side of the blue line, the month encounters a significant traffic increase. This is usually the case when traffic for that month is low or zero and precedes or follows other months with a relatively high traffic count. This arises when the link in the current month becomes accessible due to ice melt, hence some traffic is spread from an adjacent month (i.e., the current month is at the limit between cold and warm season, generally March, April, May, June–November, December).

Case 2: When the histogram minimum and maximum values are located on either side of the blue line, it means that traffic can spread both into and out of that month, or that ice conditions are too strong to allow any spreading. These scenarios usually happen in the middle of the warm or cold seasons (January, February–July).

Case 3: When the histogram is fully on the left side of the blue line, the month has a significant traffic decrease. This is usually the case when the traffic for that month is high and precedes or follows another month with a low traffic count. This means that the traffic will spread to the other month, which has had more sea ice loss over time (i.e., a month falling in the warm season—August, September, October).

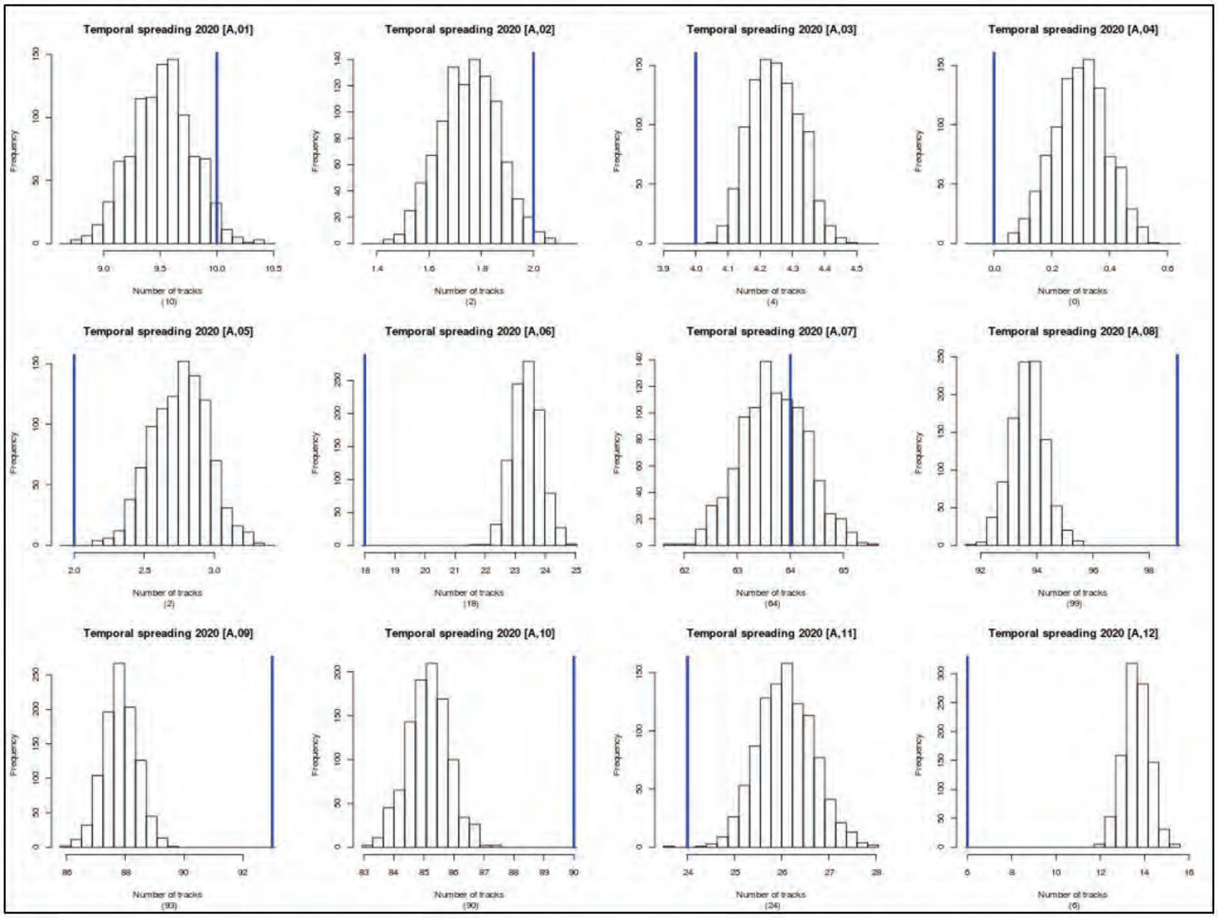


Figure 28

Monthly temporal spreading histograms (A=all ships; 1-12 indicates months starting in January)

The histograms are useful to understand the global distribution of the simulated traffic for a specific category of ship. In order to visualize traffic spatial density, the values on each network link that intersect a grid cell were summed to determine monthly traffic statistics per grid cell, while ship category illustrates the yearly gridded and aggregated average of the simulated traffic in the Canadian Arctic for 2020.

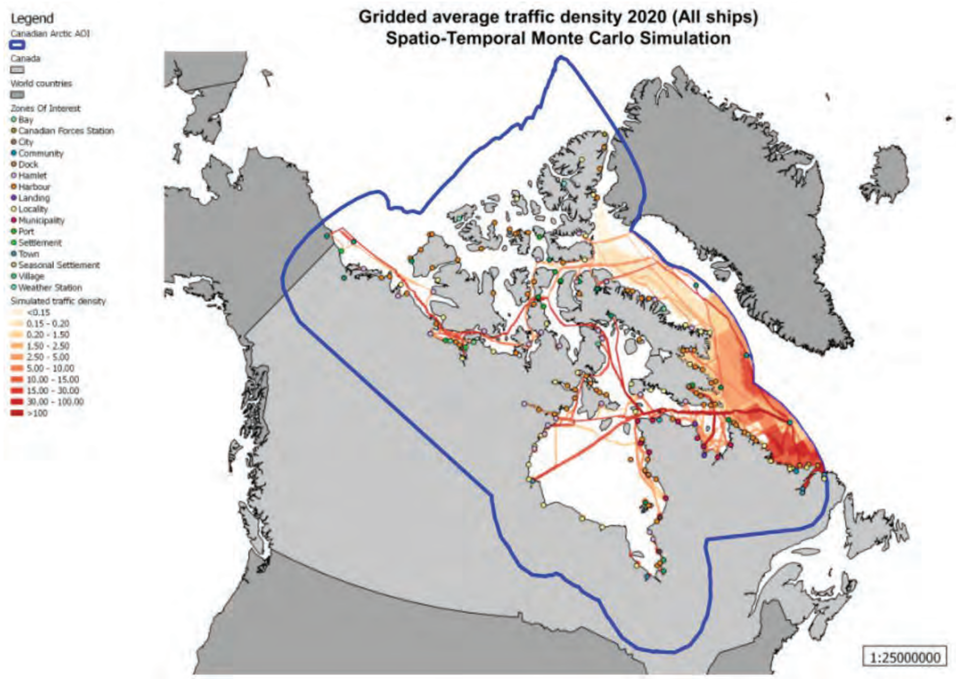


Figure 29

Average yearly gridded simulated traffic density for 2020

Such results can be generated by month and by vessel category. Another useful perspective is to generate maps with coloured cells to illustrate the range between the projected minimum and maximum traffic in each cell, which is a good indicator of variability. Results show that for some vessel categories in some areas and some months the range is much higher than other scenarios. Ultimately, the simulation model results are most valuable when used dynamically, to generate scenarios based on the most updated parameters, and the results viewed with dynamic maps that illustrate the variability across the year.

3.6 Summary of Future Shipping Projections

The traffic simulation approach taken to model future traffic volumes produced multiple possible outcomes based on the sliding scale of input variables. These input variables can be altered over time as socio-economic and environmental conditions become more clear (e.g., a mine opens, commodity prices stabilize, ice projections improve, etc.), and thus the model can be refined to pinpoint the most likely future scenarios within different timeframes. As a result, there is no single modeled outcome for future ship traffic at this time. However, there are generalizable trends that can be observed within the various modeled outcomes. We have more confidence in the outputs of projected shipping trends for shorter future time periods (2020) considering the extreme challenges of predicting socio-economic factors over longer time periods (e.g., 2050 or 2100), which is more common within climate science, but less common in socio-economic science. Thus, our focus in this study was the 2020 time period. This is also a very relevant time period for decision-making. Based on generalizable model outcomes, extensions from current trends outlined in Chapter 2 and expert opinion, it is expected that there will be an increase in overall traffic volume across Arctic Canada by 2020, with further increases expected beyond that timeframe. Increases in 2020 will not be uniform across ship types, and rapid increases are not anticipated for any ship type except perhaps Pleasure Craft vessels, which are projected to continue to increase as a result of climate change. Because tourism vessels are the only vessel types that

Olivia Mussells

are directly influenced by reductions in ice concentrations, it is this sector that will be the most influenced by climate change. Continued decreases in sea ice will influence some increases in tourism demand, but other factors—such as the global economy, the availability of tourism vessels, and social trends—will limit potential increases. Despite only limited increases in total tourism traffic volumes, it is expected that larger cruise vessels and Pleasure Craft will begin arriving in Arctic Canada, meaning that the number of visitors to the region will increase.

In terms of spatial distributions in future shipping traffic, certain regions are anticipated to see greater increases than others. The northeast coasts of Labrador, Newfoundland, and Quebec are expected to see increases related to resource development traffic. Similar trends are anticipated for the transit route between Churchill Harbour, through Hudson Strait, and into international waters. Resource traffic is also expected to increase along the western side of Baffin Bay and through Hudson Strait (although this may change to the eastern side of Baffin Island) related to the now-operational Mary River mine. Tourism traffic increases, as well as some other vessel increases related small increases in resource and cargo transport, are expected through the southern route of Northwest Passage. Variable ice conditions will limit ship traffic through the northern route of the Northwest Passage, which is not expected to be a reliable or viable route until well past the 2020 time period, if ever. Even the southern route of the Northwest Passage continues to be extremely variable, as ice conditions will continue to limit traffic in some years and not in others.

Chapter 4: Drivers of Shipping Change & Identifying Climate Related Risks and Opportunities

4.1 Drivers of Shipping Change

An extensive analysis of historic shipping trends has resulted in a better understanding of ship traffic patterns since 1990. We also have an understanding of the role that changing sea ice conditions are playing in influencing those shipping trends. Section 2.5 demonstrated that changing sea ice has played a relatively minor role in influencing shipping patterns in the past, but that this influence has increased over time. To enhance our understanding of the relative role of climate change (i.e., changes in temperature, ice extent, wind, season length) as a driver of current and future shipping traffic, 57 interviews and a follow-up survey (n=30) were undertaken. The selection of interview participants followed the broad guidelines set out by Smit et al. (2000) for such studies, and was based on a number of considerations, including: a) experience working directly on Arctic shipping issues, b) involvement of mariners and individuals with experience on Arctic-faring vessels, and c) involvement of individuals with experience in decision-making and regulatory processes in the Arctic. The group of respondents included a mix of government representatives, shipping operator stakeholders, ship captains, ship insurers, scholars, and representatives from relevant non-governmental and not-for-profit agencies. All participants are known experts in the field of Arctic shipping and brought various perspectives and expertise to the project.

The overall major driver of the use of the NWP and the waters of the Canadian Arctic is natural resource development and the movement of those resources to global markets. Sea ice retreat provides greater marine access and potentially longer seasons of navigation.

– Ship operator of 40 years

The result is the development of a relative importance index of drivers of shipping change. Experts consistently ranked Economic factors (such as fuel use, commodity prices, and cost of insurance) as the most influential driver of ship traffic, followed by Infrastructure-related factors (such as telecommunications, port facilities, and other services) and Technological factors (such as access to satellites, Internet, and digital charting). Climate change ranked higher than Social factors (such as human resources, regional demographics, community issues, and cultural practices) and Political factors (such as regulatory framework, guidelines, and incentives). None of the experts consulted ranked climate change as having no importance in driving shipping trends, indicating a strong level of belief that changing sea ice conditions do play a role in the development of maritime activity. Climate change is also expected to play a larger role in driving shipping trends in the future as sea ice continues to melt (Figure 30). For the present day, it may be more appropriate to discus climate change as an *enabler* of Arctic shipping rather than a direct *driver*. For example, with the exception of tourism vessels, ships are not traveling to Arctic Canada simply because they can. Rather, they are traveling in the region for other reasons, but may do so with increased frequency or with increased ease because of reduced sea ice. The only sector where climate change is playing a very direct role in driving an increase in ship traffic across Arctic Canada is in the tourism sector. More particularly, it is Pleasure Craft that are most influenced. Tourists are attracted to the allure of the Northwest Passage and to the idea that the region is changing. Studies have shown that some tourists have a desire to see changing landscapes before they "disappear" or are significantly altered (Lemelin, Dawson, & Stewart, 2014). Pleasure craft are also the fastest growing marine sector in Arctic Canada, and so we can expect a continued upward trend of tourism vessels into the future as the climate continues to change (also see Johnston, Dawson, Stewart, & De Souza, 2013).

Climate change is attracting more yachts and adventurers to the region because they think the Northwest Passage is now open and safe to transit.
– Expert

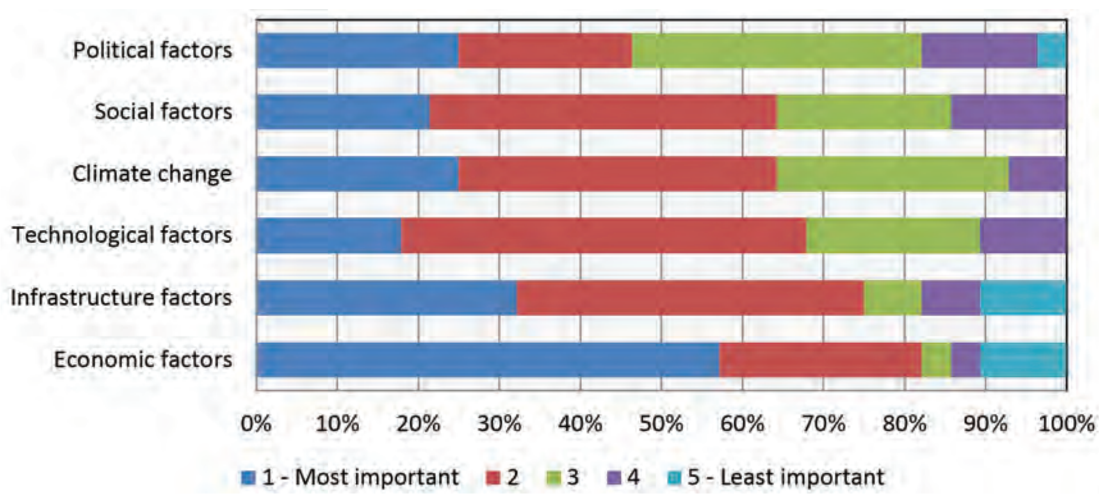


Figure 30

Relative importance of different drivers of Arctic shipping activity based on survey with key informants (n=30)

4.2. Risks and Opportunities of Climate Change for Arctic Shipping

Climate change poses both risks and opportunities for Arctic shipping in Canada. Conducting a risks and opportunities assessment is an important initial step in conducting a full climate change adaptation assessment, which will enable the identification and evaluation of effective response options to climate change (see Figure 31 in Chapter 5). The interviews with key-informant experts helped to identify the major challenges and opportunities that climate change presents for shipping in Arctic Canada. Participants in the study were asked to identify the major risks and major opportunities associated with climate change for the Arctic shipping sector and to outline how they thought risks could be reduced and opportunities enhanced. The interview results were analyzed using constant comparison and thematic coding methodologies (see Auberbach & Silverstein; 2003; Saladana, 2009), and supplemented by a comprehensive review of relevant literature, including scholarly articles, policy and parliamentary reports, and other articles.

During the interviews, respondents were asked to discuss how best to deal with any of the risks and opportunities they identified. These responses provided the basis for the evaluation of potential adaptation strategies that are outlined in detail in Chapter 5. Below is a discussion on the identified risks and opportunities associated with Arctic shipping.

4.2.1 Risks of Climate Change to Arctic Shipping

The risks of climate change to Arctic shipping could be significant and include both direct risks and compounding risks. Direct risks include the potential negative impacts that a changing climate has directly related to shipping safety, national security, sovereignty, environmental sustainability, and local culture and economy. Compounding impacts include the geographic and socio-political challenges that exist within Canada that can accentuate direct risks, such as weaknesses in institutional, regulatory, or policy structures, insufficient information provision or lack of data availability, and/or inadequate infrastructure and services. The following section outlines both the direct and compounding risks that climate change collectively poses for shipping in Arctic Canada.

4.2.1.1 Direct Risks

Safety. Despite a reduction in sea ice and thickness that has increased access to the Canadian Arctic, the region remains dangerous to navigate, especially to new entrants and mariners inexperienced in ice-infested waters. A changing climate means that there are more small- and medium-sized icebergs, bergy

Ice is melting but this doesn't translate into clear sailing in the Arctic. The biggest risk of climate change is variability. Shipping companies don't want to buy a more expensive ship just in case…container companies want predictability not variability.

– Ship operator

bits, and other ice hazards that previously presented as thick, impassable ice islands or other ice barriers that were easier to avoid and arguably less dangerous to mariners. The increase in ice hazards causes safety concerns related to possible hull strikes and sinkings. Key informants generally agree that the sinking of a cruise ship is the most likely major ice hazard event and would be a devastating incident for response agencies and the industry, as well as, perhaps, communities.

Security. Increased access to the region has inherently increased security risks related to illegal entry into Canada via the new Arctic routes, as well as risks related to drugs, firearms, and human trafficking.

We should not underestimate the possibility of small vessels illegally entering Canada from the Arctic.

– Government representative

Sovereignty. An accessible Arctic, including enhanced trade routes and newly accessible natural resources, has brought issues of sovereignty to the forefront of global politics. Although it is unlikely that the Northwest Passage will become a viable trade route in the near future, sea ice reductions expected over the next century may create geopolitical challenges for Canada due to debate concerning sovereignty of the route as inland waters rather than an international strait.

Environment. The Arctic is warming at twice the rate of the global average, and as a result is experiencing significant impacts to local flora and fauna. As climate change alters habitats and influences a northward migration of wildlife, tourist vessels are increasingly traveling into uncharted waters in search of polar bears, walrus, and other iconic species. Increased shipping activity is accentuating these impacts and increasing the potential for a major fuel or oil spill in the region, which could be environmentally devastating. According to a government representative, "Given the relatively low levels of traffic the risk of a major spill is low" compared to other regions in Canada. However, the consequence of a spill in Arctic Canada is much higher considering the sensitivity of the environment and its limited biodiversity. The threat of invasive species to the Arctic is also increased by both climate change and related increases in shipping. Increased ship activity further poses risks for marine animals via noise pollution, habitat alterations, and other contaminants. Although ecologically and biologically significant areas (EBSAS) have been identified, a changing climate means that these environmentally sensitive areas are not stable and slowly migrating, often northward, and are not protected. Finally, increased icebreaking and increases in winter shipping to newly accessible mines is disrupting wildlife migration patterns (e.g., caribou, walrus).

It's still remote, foggy and cold all the other navigational hazards will remain into the future with climate change …

– Shipping Company Representative

Cultural and economy. Icebreaking and winter shipping also pose risks to local hunters who could become stranded or caught in risky ice conditions as ice breakers and winter resource ships transit the region with increased frequency. An oil spill or other contamination would have severe implications for food security and food safety in local communities where a traditional harvest comprises an important part of household food sources. It is widely understood that local communities will be forced to deal with a range of climate- and shipping-related impacts, but will gain limited benefits considering the transiting nature of ships operating in the region. Higher winds and extreme events are creating increasingly hazardous boating conditions, especially for smaller community vessels.

4.2.1.2 Compounding Risks

Limited monitoring and enforcement. The Canadian Coast Guard (Iqaluit MCTS office) has been collecting daily position points for ships operating in Arctic Canada's NORDREG zone since the 1980s, and more systematically since 1990. However, daily location data is relayed to the MCTS office by ship captains and was done so on a voluntary basis up until 2011, when reporting became mandatory for large vessels (over 300 gross tonnes) and those involved in towing with a combined weight of 500 gross tonnes. Given that smaller vessels present the highest probability of safety and security risks, it is problematic that there is not a better monitoring system for all vessels operating in Arctic Canada. Automatic Information System (AIS) and Long Range Identification and Tracking (LRIT) satellite tracking in Arctic Canada have been available since 2011 and provide more refined position data at a sub-minute time scale, but typically only capture larger vessels. The efforts made in this study to better understand historic ship patterns help to reduce the risks related to poor monitoring, but do not entirely eliminate them. Poor monitoring capabilities and limited ship location data make it challenging for various agencies and local communities to plan for infrastructure, services, and supplies, including placement of ice breakers and other search and rescue equipment. Where this data is not available or is limited, the ability to plan and forecast possible incidents is obviously limited. Lack of monitoring also increases the risk to sensitive ecological, cultural heritage, and archeological sites from Pleasure Craft and other tourism vessel users who may or may not understand their impact.

There is a need develop statistics [on ship traffic] to see what's going on.
– Other expert

Its not the number of ships that worries me, the issue is where these ships are going.
– Government representative

Monitoring and enforcement emerged as a major concern for management agencies, in part because improved regulation is meaningless without effective monitoring and enforcement mechanisms. Enforcement in the Arctic is very challenging given the size and geography of the region. The lack of enforcement capabilities among the RCMP, Transport Canada, and other regulatory organizations presents important risks to the region from less-responsible or less-ethical shipping companies that could easily take advantage of limited enforcement. For example, there are risks related to illegal discharge of waste water and other pollutants, there is increased opportunity for drug and human trafficking, and tourist vessels can easily travel to sensitive sites without proper permits and cause damage to the ecology or to culturally significant sites.

Poor information provision and limited capacity. The misperception that the Canadian Arctic is fully accessible due to climate change and that the Northwest Passage is "open for business" is misleading and risky. The region today continues to be hazardous to navigate even for experienced mariners. There is consensus among experts that new entrants into Arctic Canada, particularly Pleasure Craft vessels, pose a significant risk for safety and security considering the type of vessels and their lack of knowledge and experience in the region. There is currently no single source or portal where new entrants can obtain important and comprehensive information on best practices or risks. The lack of information provision stems partly from poor coordination and communication among different federal departments and between the federal and territorial governments. To be fully prepared, mariners must consult information on multiple government websites and gather information from disparate sources. Inefficient information provision enhances the risk that mariners will not be as prepared as possible. The risks related to poor information provision and lack of experience extends beyond new entrants. One ship captain noted, "I believe that it [climate change] has also diminished the skill and/or readiness of mariners who do venture into the ice with ships because there is a lower level of experience in dealing with the heavy arctic ice."

When people read these statistics about climate change they think the change is linear. But it's not. There are peaks and valleys ... passages are flooded with multi-year ice one year and totally open the next. This misperception about the role of climate change is dangerous.
– Researcher

The biggest risk is having people operating there that don't know what they're doing. You can't regulate incompetence.
– Retired Ship Captain

Risks related to climate change are also compounded by a limited direct capacity in the region to respond to emergencies. The Canadian Rangers play an important voluntary role in search and rescue and some communities have been outfitted and trained with oil spill response kits. However, it is common that key positions within communities such as those trained to use oil spill response kits are often left vacant and/or these individuals are not always available. According to a local expert, "not all the communities have spill kits …. [S]ome are stored at the co-op stores… but some don't have it, it's lost …. Eight communities don't know where their kit is."

Lack of infrastructure and services. Related to the risks associated with lack of capacity are those from limited infrastructure and limited services in the region. The limited charts and soundings and the absence of e-navigation or GPS-referenced charts in the region present significant safety risks to mariners. As climate change has increased the areas available for transit, the need for increased charting has become even more urgent. At most risk are tourism vessels, Fishing Vessels, and Pleasure Craft, which purposefully travel away from charted corridors into more dangerous and uncharted areas. The limited infrastructure and services in the region, including the absence of a high Arctic deep water port, salvage capabilities, refueling areas, and boat maintenance or repair services, all enhance the risks to vessels operating in Arctic Canada. As the Arctic shipping season becomes longer due to climate change and technological improvements in ship design, the need for icebreaking will increase. There is concern that the current Canadian icebreaking fleet is old and may not be able to meet future demand. The lack of icebreaking services will increase the risk to mariners if the fleet is not updated and expanded. Furthermore, the increasing demand that Pleasure Craft and adventurers are placing on it will mean even more limited service for commercial operators. Finally, Search and Rescue (SAR) capabilities are highlighted as one of the greatest challenges for marine transportation in the Canadian Arctic. In the event of an incident, the closest icebreaker could be days away. Other services are deployed from southern bases (i.e., Victoria, Goose Bay, Halifax), meaning that there could be significant delays to a rescue.

When the Clipper Adventurer became grounded they brought up a company from Florida to assist.
– Other expert

The problem is SAR [search and rescue] is measured in days, not hours.
– Other expert

Data and information challenges. The absence of current and "real-time" weather and climate data poses significant risks to Arctic mariners. Given increasingly variable weather conditions, accurate and timely weather and ice forecasts are essential to ensure safety. The presence of icebergs or ice along shorelines creates very strong local weather conditions that are not captured in existing regional models (e.g., the presence of a large iceberg can change the direction of the wind in that area). In addition, regions that were previously ice-covered year-round are now subject to long periods of open water, which has profoundly changed ocean-atmosphere interactions and made tactical predictions of sea-ice dynamics more difficult. Climate change has enhanced the risks of

Over the past decade the CIS has had to create ice charts for increasingly broad areas. As vessels are less constrained by multi-year ice, they can now reach a wide range of destinations. This means that the CIS now has to produce more charts, for a wider range of areas, on the same operating budget.
– Government Representative

A big challenge is to improve ocean current understanding, as well an understanding of wind. Wind isn't well forecast beyond 3 days.
– Other expert

There is a lack of accurate and reliable weather information. By the time the navigator gets the ice chart it can be 12 hours old …. [W]e need real time data.
– Ship Captain

wind to ships operating in the Arctic region as smaller icebergs and bergy bits can be highly mobile, with increased intensity and frequency of wind events, causing choke points and creating mobile hazards. The lack of wind forecast data increases this risk. Additionally, with increased accessibility, vessels now operate in new regions across the North, putting a strain on the capacity of ice forecasters who are now required to forecast larger areas on the same operating budget. As a result, the forecasts are often not at a scale that would be useful for ship operators and are not provided in the timeframe required.

4.2.2 Opportunities of Climate Change to Arctic Shipping

There are a number of opportunities related to the impact of climate change on Arctic shipping. In particular, increasing access and volumes of ship traffic could have positive economic development opportunities, including increased employment in a region with the lowest employment rate in the country. The shipping season in Arctic Canada is getting longer, which could lead to important trade and transport opportunities. For example, with the support of icebreaking services that would ensure reliability, even during variable ice seasons, the shipping season out of the Port of Churchill could be expanded beyond its current 14-week operating season. The tourism sector is also well placed to benefit from a longer operating season. Additional and longer tours can now be planned, and itineraries through the Northwest Passage can now be reliably sold and executed because of changes in ice conditions (see Stewart, Dawson, & Johnston, 2010, 2015; "Crystal Serenity," 2014). There are also opportunities associated with resource development as climate change has increased access to previously inaccessible resource areas that can now be serviced by ship.

We have the opportunity to do this right for once.
– Ship Captain

Importantly, there are opportunities for the development of local businesses that can serve developments in the growing maritime sector. For example, there is likely to be demand for local boat repair businesses, tourism service businesses, recycling services, and others. The current federal focus on the development of Northern Marine Transportation Corridors (NMTC), which prioritize infrastructure development and services, presents an important opportunity for local communities to position private businesses and services in locations known to service ships now and in the future. Climate change and the increase in Arctic shipping also create opportunities for the assertion of sovereignty and the sharing of Canadian culture, including Indigenous culture, and increased opportunities for cross-cultural dialogue, communication, and understanding. Considering the increasing number of vessels operating in the Arctic and their mutual need for navigational information and better charts and depth soundings, there is an opportunity for crowd sourcing information and data that would benefit all mariners. Related to this is the opportunity to create a culture of sharing, responsibility, and integrity among mariners in the Arctic as the number of players operating in the region is currently small enough to influence. While the number of vessels remains relatively low, we have the opportunity to address our specific challenges and create a policy and regulatory framework aimed at both supporting and managing Arctic shipping in Canada.

Jackie Dawson

Table 8

Summary of Climate Change Risks and Opportunities for Arctic Shipping

Direct Risks	Compounding Risks	Opportunities
• Increased ice hazards result in increased navigation difficulties and greater potential for hull strikes, sinkings • Improved access increases potential for illegal entry, human and substance trafficking • Increased access to NWP draws into question sovereignty over Arctic waterways • Changes in climate alter species distribution, migration patterns, and population health of flora and fauna; introduction of new species • Increased shipping activity increases potential for environmental degradation through ongoing and extreme pollution events • Impacts on health of individual residents and communities through shipping, and pollution impacts on food security • Increased prevalence of wind, fog, and extreme weather events has implications for safety of local vessels and all shipping activities • Increased instability and unpredictability of safe ice conditions affects safety of travel on ice • Increased extreme events and erosion lead to destruction of shipping infrastructure	• Limited monitoring and enforcement reduce opportunities for planning and responding • Limited monitoring and enforcement increase risk of illegal behaviour, damage to environment, damage to cultural artifacts • Limited monitoring and enforcement increase risk of illegal behaviour, damage to environment, damage to cultural artifacts • Poor information provision, especially for new entrants, affects their ability to be fully prepared for conditions • Limited capacity to respond to incidents increases the cost and damage from those incidents • Lack of infrastructure limits capacity for response to incidents • Lack of services to meet changing demand spatially, temporally, vessel categories, and in numbers leads to increasing delays and conflicts in scheduling and capacity • Lack of data with "real-time" access presents additional potential for incidents, stresses capacity of system to provide data	• Incrased season improves reliability of shipping • Increased season enables tourism operators to expand offerings • Increased accessibility creates new routes and destinations for shipping • Spatial changes and new concentrations provide incentives for improved charting and other services • Increased shipping can lead to economic development for vessel and mariner service businesses • Infrastructure development can address the needs of several vessel categories and community needs • A made-in-Canada approach can support numerous policy goals related to shipping and traffic increases, economic development, and cultural sharing

Chapter 5: Assessment of Adaptation Strategies & Response Options

5.1 Climate Change Adaptation Assessment Approach

The climate change adaptation assessment was based on a framework developed by the United Nations Environment Program and involved collecting information and policy solutions, analyzing those solutions, and examining consensus among an expert group (UNDP, 2005; UNEP, 2008) (Figure 31). The specific method chosen for analyzing the 82 identified response options from the interview stage was a policy Delphi (see Donohoe & Needham, 2009; Lemieux & Scott, 2011; Lemieux et al. 2011; Dawson, Stewart, Johnston, & Lemieux, 2016). A policy Delphi is an iterative research tool used to establish the strongest possible solutions to a defined policy problem through a series of consultations with key informant experts (de Loë, 1995; Linstone & Turoff, 2002; Donohoe & Needham, 2009; Lemieux & Scott, 2011). A policy Delphi makes effective use of the diverse judgments, opinions, and experiences of a group of experts in order to achieve a degree of consensus on adaptation strategies so as to identify the most appropriate ways forward. The policy Delphi approach used here involved 30 of the most highly knowledge experts from the original group of 57 experts who were previously interviewed for this study. This group of 30 people made up the "expert panel" for the study and responded to an electronic survey asking them to evaluate the 82 identified adaptation strategies that emerged via the interview process. The policy Delphi process also included a final verification step following analysis of the survey results, which involved in-depth discussions with representatives from Transport Canada and four shipping companies that represent different transport modes (i.e., cargo, resource, re-supply, and tourism). The verification step facilitated the final recommendations emerging from the study and is discussed in more detail in Chapter 6.

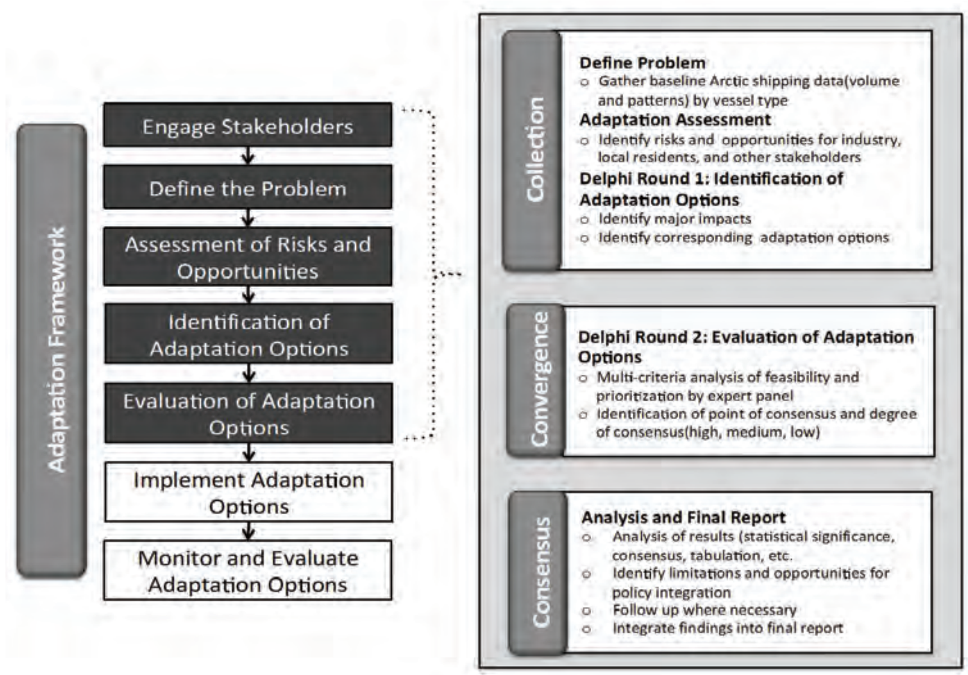


Figure 31

Adaptation framework & policy Delphi approach (adapted from UNDP, 2005; UNEP, 2008; Donohoe & Needham, 2009)

For ease of analysis and organization, the adaptation strategies evaluated through the electronic survey were divided into four categories: a) Regulation and Policy; b) Planning, Preparedness, and Enforcement; c) Infrastructure, Services, and Training; and d) Research. The expert panel consisted of 11 (37%) government representatives (federal, territorial, and municipal), 8 ship operators (27%), and 11 (37%) other experts from academia or non-governmental-organizations. Ten of the 30 expert panel members were experienced Arctic mariners with an average of 22 years of operating experience in ice-infested waters (i.e., over 200 years of total on-ship experience). The survey required panel members to individually evaluate the proposed adaptation strategies based on three factors: a) level of desirability, b) affordability, and c) ease of implementation (Table 9). Level of desirability was used to indicate priorities of panel members, while affordability and ease of implementation are measures of "feasibility." This approach is important because, for example, a strategy may be highly desirable but not feasible, whereas another strategy may be less desirable but feasible. Therefore, certain suggestions may be prioritized for implementation despite lower desirability. Panel members were provided with specific evaluation criteria to help them assess the strategies across a 4-point Likert scale. These criteria were provided to participants to ensure some consistency in understanding the task, and to facilitate prioritization of options (Table 9).

Table 9

Evaluation Criteria for Expert Panel Members

Evaluation Criteria	Rating 1	Rating 2	Rating 3	Rating 4
Cruise/Passenger	**First-order priority;** a most relevant point; has direct bearing on major issues; must be resolved, dealt with, or treated.	**Second-order priority;** is relevant to the issue; significant impact but not until other items are treated; does not have to be fully treated.	**Third-order priority;** insignificantly relevant; has little importance; not a determining factor to major issue.	**No priority relevance;** no measurable effect; should be dropped as an item to consider.
Feasibility: Affordability	**Definitely affordable;** can be implemented with current fiscal realities; and/or high cost sharing possibilities.	**Some indication adaptation is affordable;** possibility that adaptation can be implemented with current fiscal realities; and/or some cost sharing opportunities.	**Some indication adaptation is unaffordable;** additional monetary resources or reallocation required to implement; and/ or low cost sharing opportunities.	**Definitely unaffordable;** adaptation cannot be implemented within current fiscal realities; and/ or no cost sharing opportunities.
Feasibility: Ease of Implementation	**No identifiable internal or external barriers** (e.g., legal, political, institutional, social, etc.); definitely can be implemented.	**Some identifiable internal or external barriers** (e.g., legal, political, institutional, social, etc.); barriers most likely can be overcome.	**Some identifiable internal or external barriers** (e.g., legal, political, institutional, social, etc.); barriers may be too significant to overcome.	**Obvious significant internal and external barriers** (e.g., legal, political, institutional, social, etc.); definitely cannot be implemented.
Timeframe	**Short term;** within 2 years	**Medium term;** 2 to 7 years from now	**Long term;** More than 8 years from now	–

Aapted from Lemieux & Scott, 2011; Dawson et al., 2016.

The results of the survey were analyzed using a multi-stage analysis in order to interpret and synthesize survey results, and to establish levels of consensus and points of agreement among respondents. For each recommended adaptation strategy, the "level of consensus" (i.e., the extent to which respondents agreed with one another) was determined through statistical analysis of responses, and then nominally categorized as high, medium, low, or none. Although it is not necessary to have complete consensus on suggested adaptation strategies, if there is low or no consensus on a particular item, this is an indication that that suggestion may be contentious or may require additional consideration. However, interpreting consensus must be done carefully considering that expert respondents can be self-interested and may respond based on what a particular adaptation strategy may mean for them. Thus, it is important to scrutinize consensus results and assess why there may be lower levels of consensus on some items (see section 5.8 for additional discussion on consensus and potential stakeholder bias). A "point of agreement" was identified where a majority of scoring occurred around a particular category. For example, the point of agreement for an adaptation strategy may be "very desirable" or "definitely feasible," depending on the rankings of a majority of respondents (see Table 10 for an example of how data were evaluated). Respondents were also given the option to provide comments on specific items. The aim of the analysis was to determine priority and feasibility for each proposed adaptation strategy and to use this information to determine which strategies should be more seriously considered for implementation. Table 10 provides an example recommendation and outlines the analytical approach, including level of consensus and point of agreement.

Table 10

Example Analysis of an Adaptation Strategy

Example Recommendation
Update the zone/date system to reflect changes in ice conditions and improvements in accessibility

PRIORITY

	FO	SO	TO	NP	CONSENSUS	POINT OF AGREEMENT
responses	**8**	**11**	**9**	**1**	Low	Second- to third-order priority
% with opinion	**28%**	**38%**	**31%**	3%		
% like categories	**66%**	**69%**	**34%**			

FO=First order; SO=Second order; TO=Third order; NP=No priority

AFFORDABILITY

	DA	MA	MU	DU	CONSENSUS	POINT OF AGREEMENT
responses	**15**	**12**	**1**	**0**	High	Definitely affordable
% with opinion	**54%**	**43%**	**4%**	0%		
% like categories	**96%**	**46%**	**4%**			

DA=Definitely affordable; MA=May be affordable; MU=May be unaffordable; DU=Definitely unaffordable

EASE OF IMPLEMENTATION

	NB	SBO	SBN	SB	CONSENSUS	POINT OF AGREEMENT
responses	**15**	**12**	**1**	**0**	High	Some barriers (likely overcome)
% with opinion	**14%**	**79%**	**7%**	0%		
% like categories	**93%**	**86%**	**7%**			

NB=No barriers; SBO=Some barriers, likely overcome; SBN=Some barriers, likely not overcome; SB=Significant barrier

Note: *The following criteria were used to evaluate recommended strategies. Consensus is a measure of the degree to which the group agreed on the importance of the statement (e.g., first-order priority, definitely affordable, no barriers, etc.). The following categories are used: High is 70% of ratings in 1 agreement category or 80% in two related categories, Medium is 60% of ratings in 1 agreement category or 70% in 2 related categories, Low is 50% of ratings in 1 agreement category or 60% in*

2 related categories, None is less than 60% of ratings in 2 related categories. Related agreement categories for descriptors include: Priority (First- to second-order priority, second- to third-order priority, third-order to no priority); Affordability (Definitely affordable to may be affordable, may be affordable to may be unaffordable, may be unaffordable to definitely unaffordable); and Ease of Implementation (No Barriers to Some Barriers [Likely Overcome], Some Barriers [Likely Overcome] to Some Barriers [Likely Not Overcome], Some Barriers [Likely Not Overcome] to Significant Barriers). When consensus is "None," agreement is based on majority voting, whereby there is more than 50% in a single category. If there was no majority voting in a single category, then the point of agreement is based on the highest percentage in two related categories.

5.2 Regulation and Policy Adaptation Strategies

Twenty-five strategies related to Regulation and Policy were assessed by the expert panel (Table 11). Ten of these achieved high or medium consensus as first-order priorities. Improvements to the monitoring system, greater protection of environment and cultural sites, and risk reduction are the areas with the highest consensus for first-order priority. Within this group of ten, the only two that received medium consensus rather than high consensus were related to views on monitoring smaller vessels (voluntary reporting, carrying AIS). Given the high consensus on making NORDREG mandatory as a first-order priority, this appears to be the preferred option. Clearly, there is a desire for increased monitoring capacity and agreement in general on how to proceed. Protection strategies received high consensus as first-order priorities, particularly in relation to site guidelines, sensitive areas, and responding to pollution infringements. An additional grouping that had high consensus as either first-order priority or first- to second-order priority includes specific risk reduction strategies, such as enabling Transport Canada to restrict vessels from operating in certain areas, standardizing risk assessment criteria, requiring an ice pilot or ice navigator, and establishing a mandatory bond or insurance system. Table 11 displays the Regulation and Policy strategies grouped by priority order, but also by consideration of feasibility and consensus score. The timeframe for suggested implantation is also provided (short term to long term). The timescale in general for the first-order priorities in the Regulation and Policy theme is short term.

Table 11

Regulation and Policy Adaptation Strategies

Regulation and Policy					
		Priority			
Suggested adaptation strategy		Point of agreement	Consensus	Feasibility	Timescale
RP-25	Establish site guidelines for access to and use of sensitive tourism sites (i.e., protected areas, cultural heritage areas)	first-order priority	high	probably feasible	short term
RP-13	Require all vessels to report to Canadian Coast Guard (i.e., NORDREG) regardless of size	first-order priority	high	probably feasible	short term
RP-12	Develop an expedited decision-making and approvals process within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems conflict / are not clear	first-order priority	medium	probably feasible	short term
RP-14	Maintain current reporting requirements to NORDREG and implement a voluntary tracking program for Pleasure Craft (i.e., sailboats, motor yachts) and local vessels	first-order priority	medium	probably feasible	short term
RP-4	Standardize the risk assessment criteria for obtaining insurance for ships operating in Arctic waters	first-order priority	high	probably feasible	short to medium term
RP-11	Extend the authority of Transport Canada so that it may restrict vessels from operating in unsafe or uncharted waters	first-order priority	high	neutral	short to medium term
RP-22	Enhance the protection of identified ecologically sensitive areas that are now more accessible	first-order priority	high	neutral	short to medium term

RP-21	Provide dedicated resources to enhance monitoring and enforcement for non-compliance with environmental regulations and shipping regulations (i.e., sewage, grey water, ballast discharge)	first-order priority	high	neutral	medium to long term
RP-19	Include the Arctic as an emission control area to reduce harmful emissions (SOx, NOx, VOCs)	first-order priority	high	neutral	long term
RP-16	Require all vessels, regardless of size, to carry Automatic Identification System (AIS) transponders	first-order priority	medium	neutral	short to medium term
RP-23	Implement voluntary speed reductions in ecologically sensitive areas that are now becoming increasingly accessible	first- to second-order priority	medium	probably feasible	short to medium term
RP-15	Require that all smaller vessels be fitted with corner reflectors so they can be tracked by satellite radar	first- to second-order priority	low	probably feasible	short term
RP-10	Require an ice pilot or ice navigator for all vessels over 300 gross tonnes, including Government Vessels	first- to second-order priority	high	probably feasible	short to medium term
RP-2	Establish a mandatory bond and/or insurance system to recover costs for search and rescue incidents and salvage	first- to second-order priority	high	neutral	medium term
RP-18	Require that all personnel on a vessel carry an Emergency Position-Indicating Radio Beacon (EPIRB)	first- to second-order priority	medium	neutral	short to medium term
RP-17	Require all vessels, regardless of size, to be equipped with Global Maritime Distress and Safety System (GMDSS) equipment when operating in Arctic waters	first- to second-order priority	medium	neutral	short to medium term
RP-3	Establish a user pay system to recover costs for search and rescue incidents and salvage	first- to second-order priority	low	neutral	medium to long term

RP-6	Charge a fee for icebreaking service requests	first- to second-order priority	none	neutral	medium to long term
RP-9	Require double hulled ships in the Arctic at all times	first- to second-order priority	low	probably not feasible	medium to long term
RP-20	Ban the use of heavy fuel oils (HFOs) in Arctic Canada	second-order priority	high	probably not feasible	long term
RP-1	Update the zone/date system to reflect changes in ice conditions and improvements in accessibility	second- to third-order priority	low	probably feasible	short to medium term
RP-7	Charge a fee to all vessels for transiting the Northwest Passage	second- to third-order priority	none	neutral	medium to long term
RP-24	Establish and enforce strict noise level standards for vessels operating in the Canadian Arctic	second- to third-order priority	medium	probably not feasible	medium to long term
RP-8	Implement a pay per use structure for Canadian Ice Service (CIS) ice charts	third-order to no priority	low	neutral	medium term
RP-5	Establish an insurance system for ships that is operated through the federal government (similar to car insurance in some provinces)	third-order to no priority	none	neutral	medium to long term

5.3 Planning, Preparedness, and Enforcement

Twenty-one strategies were evaluated under the theme of Planning, Preparedness, and Enforcement (Table 12). Ten of these were ranked as first-order priority, with high consensus for all but one. A major focus in these high consensus strategies is preparation for spill responses. Other notable first priorities are adapting the Marine Transportation Corridors to include sensitive ecological sites and cultural sites, and creating new ways of solving resourcing issues for SAR, passport control, and a strategic marine transportation plan. The timescale for the first-order priorities in this theme area is the medium term (Table 12).

Table 12

Planning, Preparedness, and Enforcement Adaptation Strategies

Planning, Preparedness, and Enforcement					
		Priority			
Potential adaptation strategy		Point of agreement	Consensus	Feasibility	Timescale
PPE-17	Establish partnerships and protocols with commercial ship operators to support equipment transport in case of a major spill	first-order priority	high	probably feasible	short to medium term
PPE-2	Adapt the Northern Marine Transportation Corridors in consideration of sensitive ecological sites	first-order priority	high	probably feasible	medium term
PPE-3	Adapt the Northern Marine Transportation Corridors in consideration of sensitive cultural sites	first-order priority	high	probably feasible	medium term
PPE-8	Allow local RCMP to act as customs and immigration officers for Passenger Ships and Pleasure Craft (i.e., check passports)	first-order priority	high	probably feasible	short to medium term
PPE-21	Build contingency plans into the Arctic pollution prevention certificate	first-order priority	medium	probably feasible	medium term
PPE-4	Establish an official intergovernmental Marine Transportation Strategy with an implementation plan	first-order priority	high	neutral	short term
PPE-13	Expand the Canadian Ranger program for search and rescue (SAR)	first-order priority	high	neutral	short to medium term

PPE-15	Develop a spill response and disaster risk management plan for each community and ensure that all communities have accessible spill response kits and proper training for their use	first-order priority	high	neutral	short to medium term
PPE-18	Create specific disaster management plans for the cruise tourism industry	first-order priority	high	neutral	medium term
PPE-14	Ensure spill response kits are placed along identified Northern Marine Transportation Corridors	first-order priority	high	neutral	short to medium term
PPE-19	Provide a free program to local vessels to borrow Emergency Position-Indicating Radio Beacon (EPIRB) equipment	first- to second-order priority	medium	probably feasible	short term
PPE-1	As part of the Northern Marine Transportation Corridors establish dedicated "tourism" corridors with east and west entry points	first- to second-order priority	low	probably feasible	medium term
PPE-9	Allow trained local residents to act as customs and immigration officers for Passenger Ships and Pleasure Craft (i.e., check passports)	first- to second-order priority	none	probably feasible	medium to long term
PPE-11	Incorporate climate change projections into the National Research Council's (NRC) Canadian Arctic Shipping Risk Assessment System (CASRAS)	first- to second-order priority	high	neutral	short to medium term
PPE-12	Implement "flexible" or "mobile" boundaries to Marine Protected Areas (MPAs) to account for changing climate and related biodiversity	first- to second-order priority	medium	neutral	medium term
PPE-10	Establish a Transport Canada enforcement, verification, and audit team in the Arctic for the duration of the shipping season	first- to second-order priority	medium	neutral	short to medium term

PPE-5	Establish an Arctic Port Authority	first- to second-order priority	low	neutral	medium to long term
PPE-6	Establish a mechanism whereby Canada can implement port state control in the Arctic, without actually having an official Arctic port	first- to second-order priority	medium	neutral	medium to long term
PPE-16	Establish an Arctic coast oil response corporation (similar to what is on the east and west coasts)	first- to second-order priority	medium	neutral	medium to long term
PPE-7	Restructure the Canadian Coast Guard to be under Transport Canada (vs. DFO) in order to enhance CCG's regulatory and enforcement authority	first- to second-order priority	none	probably not feasible	medium to long term
PPE-20	Provide subsidies to help Canadian vessels transition away from heavy fuel oils (HFOs)	second- to third-order priority	low	probably not feasible	medium to long term
RP-7	Charge a fee to all vessels for transiting the Northwest Passage	second- to third-order priority	none	neutral	medium to long term
RP-24	Establish and enforce strict noise level standards for vessels operating in the Canadian Arctic	second- to third-order priority	medium	probably not feasible	medium to long term
RP-8	Implement a pay per use structure for Canadian Ice Service (CIS) ice charts	third-order to no priority	low	neutral	medium term
RP-5	Establish an insurance system for ships that is operated through the federal government (similar to car insurance in some provinces)	third-order to no priority	none	neutral	medium to long term

5.4 Infrastructure, Services, and Training Adaptation Strategies

Twenty-four strategies were evaluated under this theme and 11 are ranked as first-order priorities. Of these, 9 have high consensus, with particular emphasis on enhancing services to reflect a longer shipping season, providing more reliable environmental and weather information, and improving charting through various means. There was also strong support for increased investment in the Canadian Coast Guard fleet and operations. The majority of strategies in this theme were recommended for implementation within a short- to medium-term timescale (Table 13).

Table 13

Infrastructure, Services, and Training Policy Adaptation Strategies

Infrastructure, Services, and Training					
		Priority			
Recommended adaptation strategy		**Point of agreement**	**Consensus**	**Feasibility**	Timescale
IST-16	Install multi-beams on all Canadian Coast Guard (CCG) vessels to relay bathymetric information to the Canadian Hydrographic Service (CHS)	first-order priority	high	probably feasible	short to medium term
IST-9	Include future climate change and sea ice scenarios in the prioritization of ice breaking services during the shipping season	first-order priority	medium	probably feasible	short term
IST-5	Keep the Northern Canadian Coast Guard offices open longer to reflect lengthening of shipping season	first-order priority	high	neutral	short term
IST-19	Improve seasonal ice thickness and extent forecasting (e.g., provide real-time ice charts, improve forecasting of shear, pressured ice, and ridging zones)	first-order priority	high	neutral	short to medium term
IST-6	Provide additional icebreaking services in the shoulder seasons to reflect the lengthening shipping season	first-order priority	high	neutral	short term

IST-14	Establish additional capacity and resources for bathymetric charting	first-order priority	high	neutral	short term
IST-20	Establish a reliable method for relaying weather and ice information to vessels in order to address issues related to bandwidth, latitude, and black-out areas	first-order priority	high	neutral	short term
IST-15	Develop public-private partnerships for charting new areas	first-order priority	medium	neutral	short to medium term
IST-2	Develop a system of small ports and safe harbours	first-order priority	high	neutral	medium to long term
IST-7	Expand and upgrade the Canadian Coast Guard Arctic marine fleet	first-order priority	high	probably not feasible	long term
IST-25	Appoint a local marine transportation coordinator in each community (i.e., to provide a single point of contact for tourism, re-supply, fishing, or other vessels)	first- to second-order priority	medium	probably feasible	short to medium term
IST-21	Establish a formal mechanism for ice chart users to report back to the Canadian Ice Service (CIS) on ice conditions during a voyage and provide real-time positioning data (e.g., Twitter or other mechanism)	first- to second-order priority	high	probably feasible	short term
IST-23	Provide training opportunities for industry to understand the Polar Operational Limit Assessment Risk Indexing System (POLARIS)	first- to second-order priority	low	probably feasible	medium term
IST-4	Re-institute the designated infrastructure fund for harbours to address effects of climate change	first- to second-order priority	high	neutral	medium to long term
IST-24	Develop comprehensive information resources for tourism operators and adventurers that outlines regulations, standards, and expectations	first- to second-order priority	high	neutral	medium term

IST-22	Establish/enhance northern education/ training programs for marine navigation, small business operation, search and rescue, oil spill response and recovery, emergency response, and tourism and hospitality	first- to second-order priority	medium	neutral	medium term
IST-17	Partner with industry to install government supplied multi-beams to relay bathymetric information to the Canadian Hydrographic Service (CHS)	first- to second-order priority	low	neutral	medium to long term
IST-10	Establish mobile search and rescue (SAR) platforms on board re-supply vessels through partnerships between the Canadian Coast Guard (CCG) and industry	first- to second-order priority	medium	neutral	medium to long term
IST-11	Establish small search and rescue (SAR) bases in all communities adjacent to key shipping routes (NMTC) (run and operated by local community members)	first- to second-order priority	medium	neutral	medium to long term
IST-13	Require a minimum of one Tug stationed in the Arctic	first- to second-order priority	low	neutral	medium to long term
IST-18	Establish a system for commercial and private vessels to relay bathymetric information to CHS (e.g., establish a crowd sourcing program)	second-order priority	medium	neutral	short to medium term
IST-12	Establish a minimum of 3 search and rescue (SAR) bases in the Canadian Arctic where military search and rescue (SAR) crews would be positioned	second-order priority	high	probably not feasible	medium to long term
IST-8	Maintain investment in the offshore patrol vessels	second- to third-order priority	low	neutral	medium to long term
IST-3	Establish mobile refuelling stations for ships UNDER a certain tonnage, such as Pleasure Craft and small commercial vessels	second- to third-order priority	low	neutral	medium to long term

5.5 Research Adaptation Strategies

Eleven strategies were evaluated under the Research theme and 6 of these were first-order priority, all with a high level of consensus (Table 14). The strategies with the highest desirability reflected a need for enhanced data sharing among operators, scholars, and government, and a need to engage in more focused research on the implications of shipping for northern communities. The most consistent timeframe for strategies within this theme was medium term.

Table 14

Research Adaptation Strategies

Research					
		Priority			
Recommended adaptation strategy		Point of agreement	Consensus	Feasibility	Timescale
RS-2	Facilitate data sharing partnerships between government, academics, and other stakeholders to obtain and share real-time, standardized, meteorological, and oceanic data	first-order priority	high	probably feasible	medium term
RS-4	Improve understanding of Arctic indigenous marine use and the impact that increased shipping will have on local communities	first-order priority	high	probably feasible	short term
RS-10	Conduct a needs assessment for each community to determine minimum infrastructure needs for increased shipping activity (i.e., mooring bollards, dock cranes, discharge ramps, dock lighting, fences, breakwaters, marshalling areas, floating docks, community docks)	first-order priority	high	probably feasible	short to medium term
RS-5	Develop a decision support system to help navigators to make sound decisions (when to proceed, when to take evasive action based on weather and ice data)	first-order priority	high	neutral	short to medium term
RS-7	Dedicate specific resources to improve Arctic wind forecasts	first-order priority	high	neutral	medium term

RS-8	Increase weather and ocean current instrumentation and analysis (current meters, meteorological stations), especially near communities and on the Northern Marine Transportation Corridors	first-order priority	high	neutral	medium term
RS-6	Continue to fund the Network of Experts for Transportation in Arctic Waters (NEXTAW) (i.e., government working group)	first- to second-order priority	medium	probably feasible	short term
RS-9	Hire local Arctic weather observers for Environment Canada to record observational weather data	first- to second-order priority	high	probably feasible	short to medium term
RS-3	Develop a searchable database of all completed and ongoing Arctic Marine Transportation research	first- to second-order priority	medium	probably feasible	medium term
RS-11	Conduct a climate change assessment during the proposal stage of all new maritime infrastructure	first- to second-order priority	medium	probably feasible	short to medium term
RS-1	Prioritize focused research on changing ice conditions and their implications for Arctic marine traffic	first- to second-order priority	high	neutral	medium term

5.6 Desirability-feasibility Plots for Adaptation Strategies

Prioritizing recommendation options is a function of both desirability and feasibility (i.e., affordability plus ease of implementation), and so desirability-feasibility plots are a useful tool in determining which strategies should be considered for implementation. Results are displayed as a scatter-plot on a four-quadrant grid, with mean desirability ratings across the x-axis and mean feasibility ratings across the y-axis. The location of the x- and y-axes were determined based on mean score of all desirability ratings (x-axis) and feasibility ratings (y-axis) for each theme. All variables that fall to the left of the y-axis have been rated as having a higher than average desirability within that theme, and the variables that are found below the x-axis have been rated to be above average in terms of feasibility. Thus the more desirable and more feasible options are located in the lower left quadrant of the scatter plot (Figure 32).

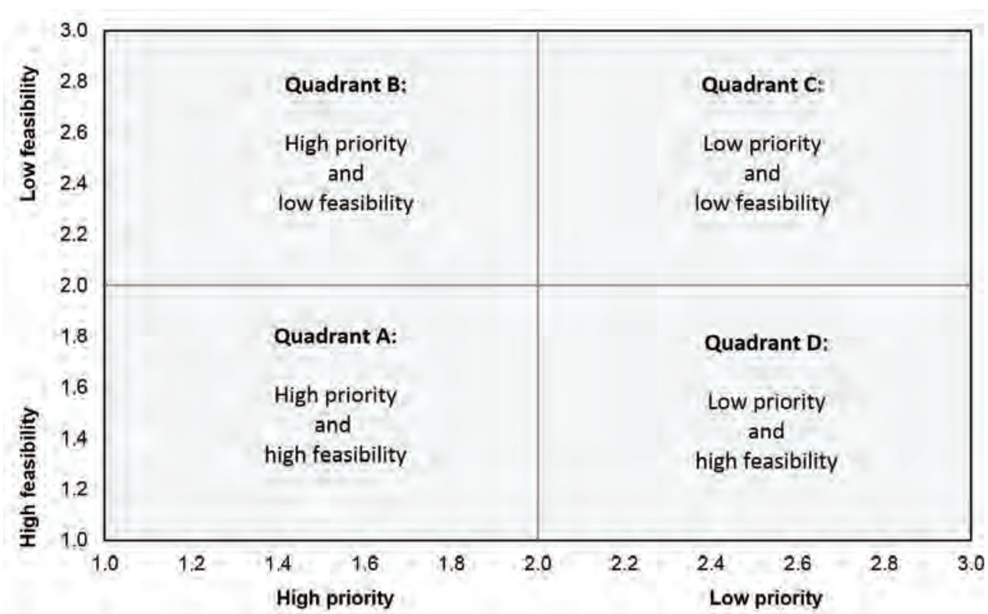
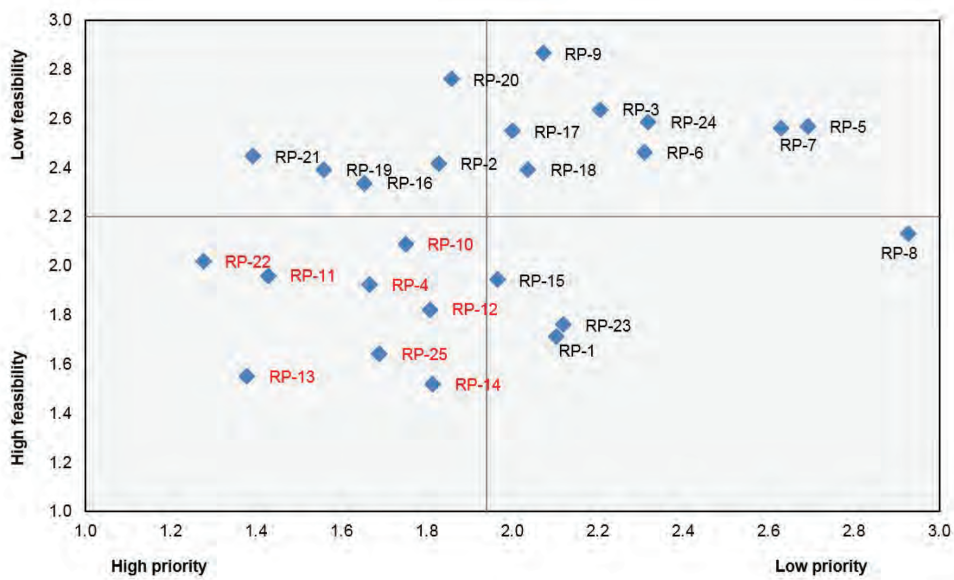


Figure 32

Priority-feasibility plot

Figure 33 displays the priority-feasibility plot for strategies in the Regulation and Policy theme. Eight strategies fall within Quadrant A, suggesting that these should be the initial focus of adaptation efforts. Items in Quadrant C are low priority and low feasibility, suggesting they should not be considered in adaptation efforts unless there is another compelling reason to do so.

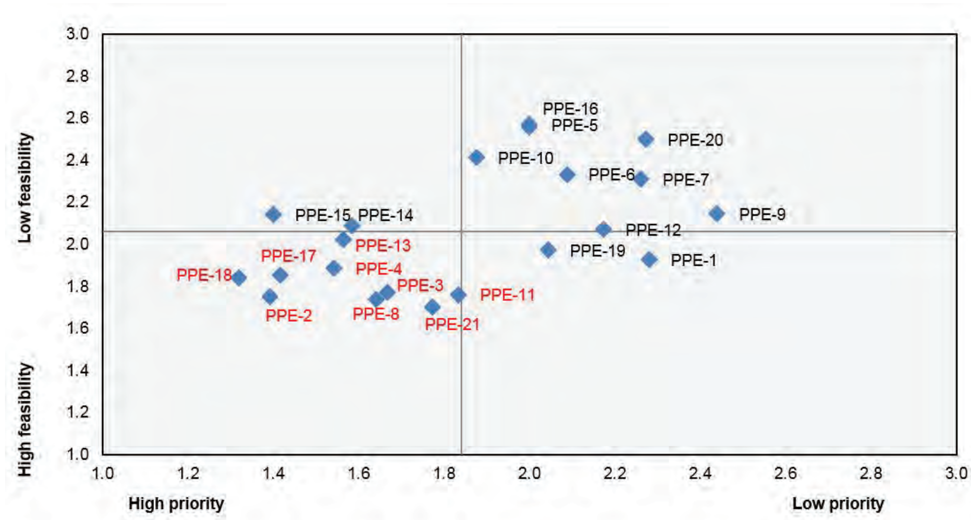


Legend	
RP-4	Standardize the risk assessment criteria for obtaining insurance for ships operating in Arctic waters
RP-10	Require an ice pilot or ice navigator for all vessels over 300 gross tonnes, including government vessels
RP-11	Extend the authority of Transport Canada so that it may restrict vessels from operating in unsafe or uncharted waters
RP-12	Develop an expedited decision-making and approvals process within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems conflict/are not clear
RP-13	Require all vessels to report to Canadian Coast Guard (i.e., NORDREG) regardless of size
RP-14	Maintain current reporting requirements to NORDREG and implement a voluntary tracking program for pleasure craft (i.e., sailboats, motor yachts) and local vessels
RP-22	Enhance the protection of identified ecologically sensitive areas that are now more accessible
RP-25	Establish site guidelines for access to and use of sensitive tourism sites (i.e., protected areas, cultural heritage areas)

Figure 33

Desirability plot for Regulation and Policy strategies

Figure 34 displays the priority-feasibility plot for Planning, Preparedness, and Enforcement strategies (refer to Table 11). This theme received nine high priority–high feasibility items. These strategies are more closely grouped, with several sitting on or near the line between categories. These particular items should be examined closely to see whether there is a good reason to move them into Quadrant A.

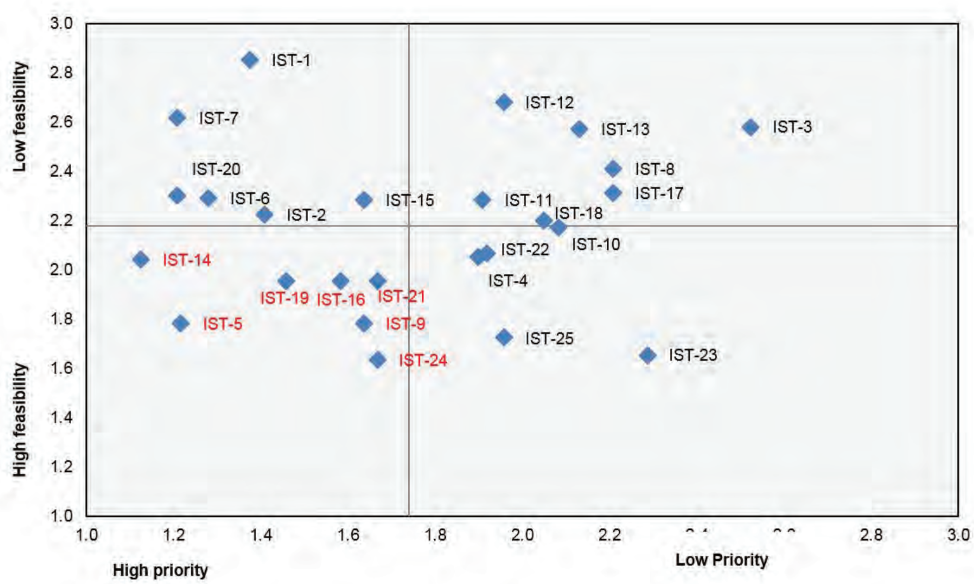


Legend	
PPE-2	Adapt the Northern Marine Transportation Corridors in consideration of sensitive ecological sites
PPE-3	Adapt the Northern Marine Transportation Corridors in consideration of sensitive cultural sites
PPE-4	Establish an official intergovernmental Marine Transportation Strategy with an implementation plan
PPE-8	Allow local RCMP to act as customs and immigration officers for passenger ships and pleasure craft (i.e., check passports)
PPE-11	Incorporate climate change projections into the National Research Council's (NRC) Canadian Arctic Shipping Risk Assessment System (CASRAS)
PPE-13	Expand the Canadian Ranger program for search and rescue in marine areas (SAR)
PPE-17	Establish partnerships and protocols with commercial ship operators to support equipment transport in case of a major spill
PPE-18	Create specific disaster management plans for the cruise tourism industry
PPE-21	Build contingency plans into the Arctic pollution prevention certificate

Figure 34

Priority vs. feasibility plot for the Planning, Preparedness, and Enforcement recommendations

Figure 35 shows the strategies in the Infrastructure, Services, and Training category to be spread across the four quadrants, with seven in Quadrant A (refer to Table 12). Several items are close to the line and these should be examined further.

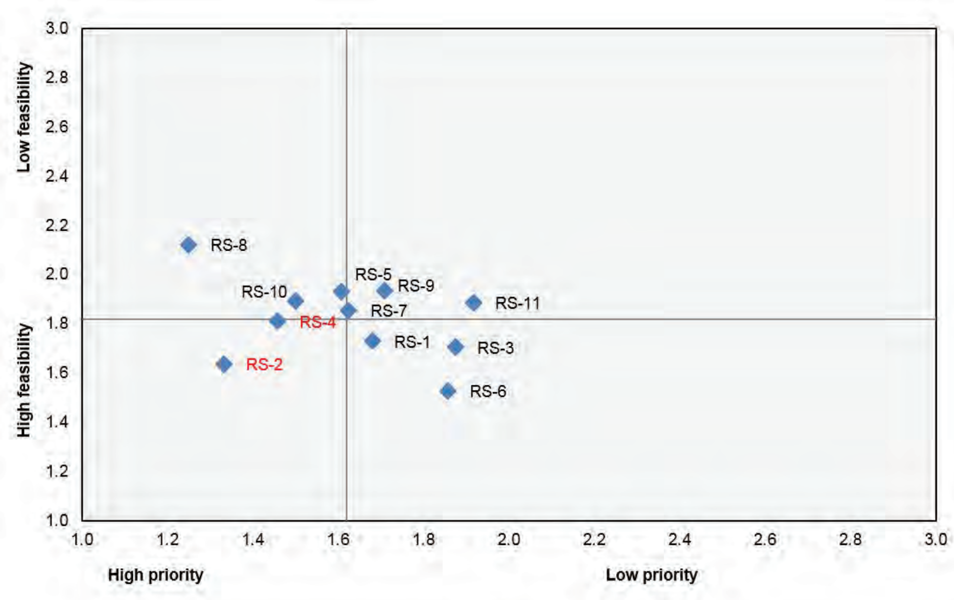


Legend	
IST-5	Keep the Northern Canadian Coast Guard offices open longer to reflect lengthening of shipping season
IST-9	Include future climate change and sea ice scenarios in the prioritization of ice breaking services during the shipping season
IST-14	Establish additional capacity and resources for bathymetric charting
IST-16	Install multi-beams on all Canadian Coast Guard (CCG) vessels to relay bathymetric information to the Canadian Hydrographic Service (CHS)
IST-19	Improve seasonal ice thickness and extent forecasting (e.g., provide real-time ice charts, improve forecasting of shear, pressured ice, and ridging zones)
IST-21	Establish a formal mechanism for ice chart users to report back to the Canadian Ice Service (CIS) on ice conditions during a voyage and provide real-time positioning data (e.g., Twitter or other mechanism)
IST-24	Develop comprehensive information resources for tourism operators and adventurers that outlines regulations, standards, and expectations

Figure 35

Priority vs. feasibility plot for the Infrastructure, Services, and Training recommendations

Only two research strategies fall in Quadrant A of the priority-feasibility plot (refer to Table 13). Despite this finding, strategies within the Research theme received the highest general support, with no suggested strategies receiving lower than second-order priority scores (Figure 36). This figure demonstrates the weakness of the box-plot approach when there is a high rating for most items.



Legend	
RS-2	Facilitate data sharing partnerships between government, academics, and other stakeholders to obtain and share real-time, standardized, meteorological, and oceanic data
RS-4	Improve understanding of Arctic indigenous marine use and the impact that increased shipping will have on local communities

Figure 36

Priority vs. feasibility plot for the Research recommendations

5.7 Ranking Adaptation Strategies (Desirability and Feasibility)

The priority-feasibility plots are useful to quickly and visually determine which strategies may be considered for implementation within each of the thematic categories. However, as was seen in the Research theme area, there are some limitations with the approach that could lead to the elimination of some strategies that should be considered for implementation and that rank higher than strategies occurring within in different themes. Therefore, an additional step was taken in the analysis of the survey results to “rank” all of the strategies, regardless of themes.

The method used to rank adaptation strategies involved assigning numeric values to represent points of agreement for priority and feasibility (Table 15). A single score for feasibility was determined by taking the sum of the scores for affordability and ease of implementation. Consideration was then given to the level of consensus among respondents whereby low-consensus items were lowered in priority compared to higher-consensus recommendations.

Table 15

Categories for Points of Agreement (Desirability, Affordability, Ease of Implementation) (assigned numeric value in brackets)

Desirability	Affordability (value)	Ease of Implementation (value)
First-order priority (1)	Definitely affordable (1)	No barriers (1)
First- to second-order priority (2)	Definitely affordable to may be affordable (1.5)	No barriers to some barriers (likely overcome) (1.5)
Second-order priority (3)	May be affordable (2)	Some barriers (likely overcome) (2)
Second-order priority to third-order priority (4)	May be affordable to may be unaffordable (2.5)	Some barriers (likely overcome) to some barriers (likely not overcome) (2.5)
Third-order priority (5)	May be unaffordable (3)	Some barriers (likely not overcome) (3)
Third-order priority to no priority (6)	May be unaffordable to definitely not affordable (3.5)	Some barriers (likely not overcome) to significant barriers (3.5)
No priority (7)	Definitely not affordable (4)	Significant barriers (4)

Table 16 is a list of the highest-ranked adaptation strategies that emerged from the study. Also outlined is the timescale that the expert panel recommended for implementing the strategies. A complete ranked list of all 82 strategies is available in Appendix D. Following the ranking of all adaptation strategies, one final verification step was taken in order to better understand the highly ranked adaptation strategies and to refine a final list of recommendations that should be more seriously considered for implementation. Chapter 6 provides additional information on the verification step of the policy Delphi approach and outlines the final recommendations of the study.

Table 16

List of Highest Ranked Adaptation Strategies

Strategy code	Recommended adaptation strate	Point of agreement	Consensus	Feasibility	Timescale	Rank
RP-25	Establish site guidelines for access to and use of sensitive tourism sites (i.e., protected areas, cultural heritage areas)	first-order priority	high	probably feasible	short term	1
RP-13	Require all vessels to report to Canadian Coast Guard (i.e., NORDREG) regardless of size	first-order priority	high	probably feasible	short term	1
RS-4	Improve understanding of Arctic indigenous marine use and the impact that increased shipping will have on local communities	first-order priority	high	probably feasible	short term	1
PPE-17	Establish partnerships and protocols with commercial ship operators to support equipment transport in case of a major spill	first-order priority	high	probably feasible	short to medium term	1
RS-10	Conduct a needs assessment for each community to determine minimum infrastructure needs for increased shipping activity (i.e., mooring bollards, dock cranes, discharge ramps, dock lighting, fences, breakwaters, marshalling areas, floating docks, community docks)	first-order priority	high	probably feasible	short to medium term	1
RP-4	Standardize the risk assessment criteria for obtaining insurance for ships operating in Arctic waters	first-order priority	high	probably feasible	short to medium term	1
PPE-8	Allow local RCMP to act as customs and immigration officers for Passenger Ships and Pleasure Craft (i.e., check passports)	first-order priority	high	probably feasible	short to medium term	1

IST-16	Install multi-beams on all Canadian Coast Guard (CCG) vessels to relay bathymetric information to the Canadian Hydrographic Service (CHS)	first-order priority	high	probably feasible	short to medium term	1
RS-2	Facilitate data sharing partnerships between government, academics, and other stakeholders to obtain and share real-time, standardized, meteorological, and oceanic data	first-order priority	high	probably feasible	medium term	1
PPE-2	Adapt the Northern Marine Transportation Corridors in consideration of sensitive ecological sites	first-order priority	high	probably feasible	medium term	1
PPE-3	Adapt the Northern Marine Transportation Corridors in consideration of sensitive cultural sites	first-order priority	high	probably feasible	medium term	1
RP-12	Develop an expedited decision-making and approvals process within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems conflict / are not clear	first-order priority	medium	probably feasible	short term	2
RP-14	Maintain current reporting requirements to NORDREG and implement a voluntary tracking program for Pleasure Craft (i.e., sailboats, motor yachts) and local vessels	first-order priority	medium	probably feasible	short term	2
IST-9	Include future climate change and sea ice scenarios in the prioritization of ice-breaking services during the shipping season	first-order priority	medium	probably feasible	short term	2
PPE-21	Build contingency plans into the Arctic pollution prevention certificate	first-order priority	medium	probably feasible	medium term	2
PPE-4	Establish an official intergovernmental Marine Transportation Strategy with an implementation plan	first-order priority	high	neutral	short term	3
IST-5	Keep the Northern Canadian Coast Guard offices open longer to reflect lengthening of shipping season	first-order priority	high	neutral	short term	3

IST-6	Provide additional icebreaking services in the shoulder seasons to reflect the lengthening shipping season	first-order priority	high	neutral	short term	3
IST-14	Establish additional capacity and resources for bathymetric charting	first-order priority	high	neutral	short term	3
IST-20	Establish a reliable method for relaying weather and ice information to vessels in order to address issues related to bandwidth, latitude, and black-out areas	first-order priority	high	neutral	short term	3
RP-22	Enhance the protection of identified ecologically sensitive areas that are now more accessible	first-order priority	high	neutral	short to medium term	3
PPE-14	Ensure spill response kits are placed along identified Northern Marine Transportation Corridors	first-order priority	high	neutral	short to medium term	3
RP-11	Extend the authority of Transport Canada so that it may restrict vessels from operating in unsafe or uncharted waters	first-order priority	high	neutral	short to medium term	3
PPE-13	Expand the Canadian Ranger program for search and rescue (SAR)	first-order priority	high	neutral	short to medium term	3
PPE-15	Develop a spill response and disaster risk management plan for each community and ensure that all communities have accessible spill response kits and proper training for their use	first-order priority	high	neutral	short to medium term	3
IST-19	Improve seasonal ice thickness and extent forecasting (e.g., provide real-time ice charts, improve forecasting of shear, pressured ice, and ridging zones)	first-order priority	high	neutral	short to medium term	3
RS-5	Develop a decision-support system to help navigators make sound decisions (e.g., when to proceed, when to take evasive action based on weather and ice data)	first-order priority	high	neutral	short to medium term	3
PPE-18	Create specific disaster management plans for the cruise tourism industry	first-order priority	high	neutral	medium term	3

RS-7	Dedicate specific resources to improve Arctic wind forecasts	first-order priority	high	neutral	medium term	3
RS-8	Increase weather and ocean current instrumentation and analysis (current meters, meteorological stations), especially near communities and on the Northern Marine Transportation Corridors	first-order priority	high	neutral	medium term	3
RP-21	Provide dedicated resources to enhance monitoring and enforcement for non-compliance with environmental regulations and shipping regulations (i.e., sewage, grey water, ballast discharge)	first-order priority	high	neutral	medium to long term	3
IST-2	Develop a system of small ports and safe harbours	first-order priority	high	neutral	medium to long term	3
RP-19	Include the Arctic as an emission control area to reduce harmful emissions (SOx, NOx, VOCs)	first-order priority	high	neutral	long term	3
RP-16	Require all vessels, regardless of size, to carry Automatic Identification System (AIS) transponders	first-order priority	medium	neutral	short to medium term	4
IST-15	Develop public-private partnerships for charting new areas	first-order priority	medium	neutral	short to medium term	4
IST-1	Develop at least one multi-purpose deep water port facility in the Arctic (dedicated area for repair, fuelling, supplies, search and rescue)	first-order priority	high	probably not feasible	long term	5
IST-7	Expand and upgrade the Canadian Coast Guard Arctic marine fleet	first-order priority	high	probably not feasible	long term	5

5.8 Consideration of Stakeholder Bias in the Analysis of Adaptation Strategies

It is unusual to achieve complete agreement on any suggestions, but it is important that some consensus is achieved. The final ranking of suggested adaptation strategies took into consideration the level of consensus among expert panellists, which was generally high for first-order ranked strategies. The level of consensus was lower for second- and third-order priority strategies. This finding suggests that respondents agreed on the most important adaptation strategies and that these suggestions should be considered further for implementation.

Figures 37 and 38 go further and explore the similarities and differences in consensus among the different stakeholder groups (government, industry, and others, such as NGOs, academics, and consultants). This analysis was conducted to determine whether there were any biases among certain stakeholder groups. That is, certain stakeholder group may be biased against or toward certain strategies depending on how it may impact them and their activities directly.

Figure 37 shows the level to which stakeholder groups agreed with each other on the items ranked as first-order priority items (n=37). There was strong consensus between groups on the point of agreement. In general, there are strong similarities between groups on their consensus on first-order priority items (i.e., government figures tend to agree with government figures, and industry representatives tend to agree with industry representatives, and both groups tend to agree with each other). This finding suggests that respondents were not highly biased in their responses based on their stakeholder identity. However, there was lower consensus between groups on the level of feasibility, meaning that different stakeholder groups on the expert panel tended to agree on what is important, but they did not always agree on how easy or hard it would be to implement. This likely reflects the varying nature of the expertise within the group. For example, expert panellists who are involved in the development of bathymetric charts for the region have a better understanding of the technical and legal realities of generating official charts and therefore may rank the suggestion to improve charting as less feasible than someone with more limited understanding of government processes.

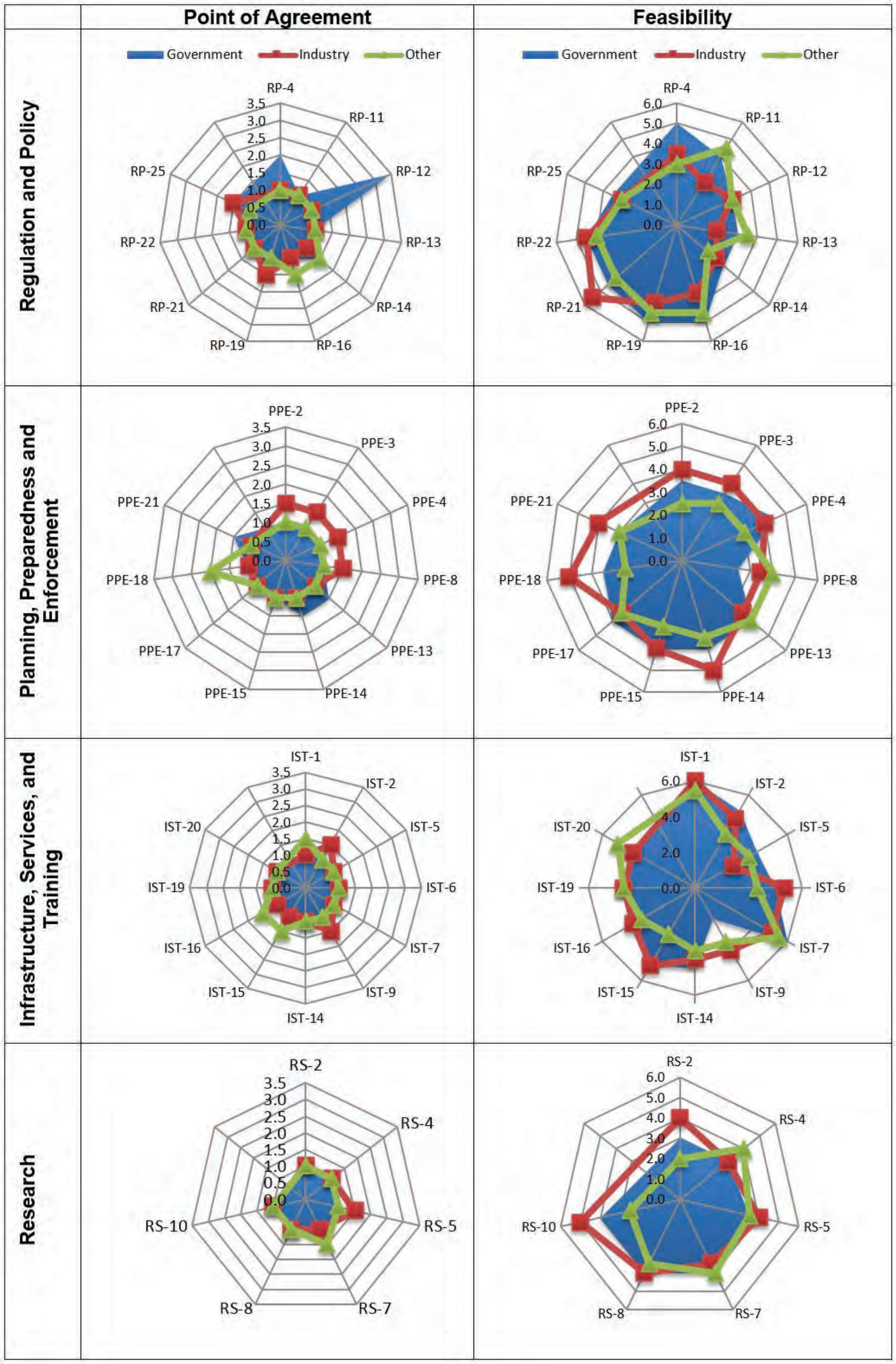


Figure 37

Comparisons between stakeholder groups for the first-order priority recommendations


Jackie Dawson

Figure 38 shows the level to which stakeholder groups agreed with each other on the items ranked as second-, third-, or no-priority items (n=45). There was lower consensus in general and also lower consensus among stakeholder groups on second-order and lower-priority items. This suggests that beyond the first-order priority items, expert panellists did not agree on what strategies should be considered for implementation. The lack of consensus could suggest that these strategies should not be considered for implementation or that they require additional attention to determine their net value in assisting with climate change adaptation for the sector.

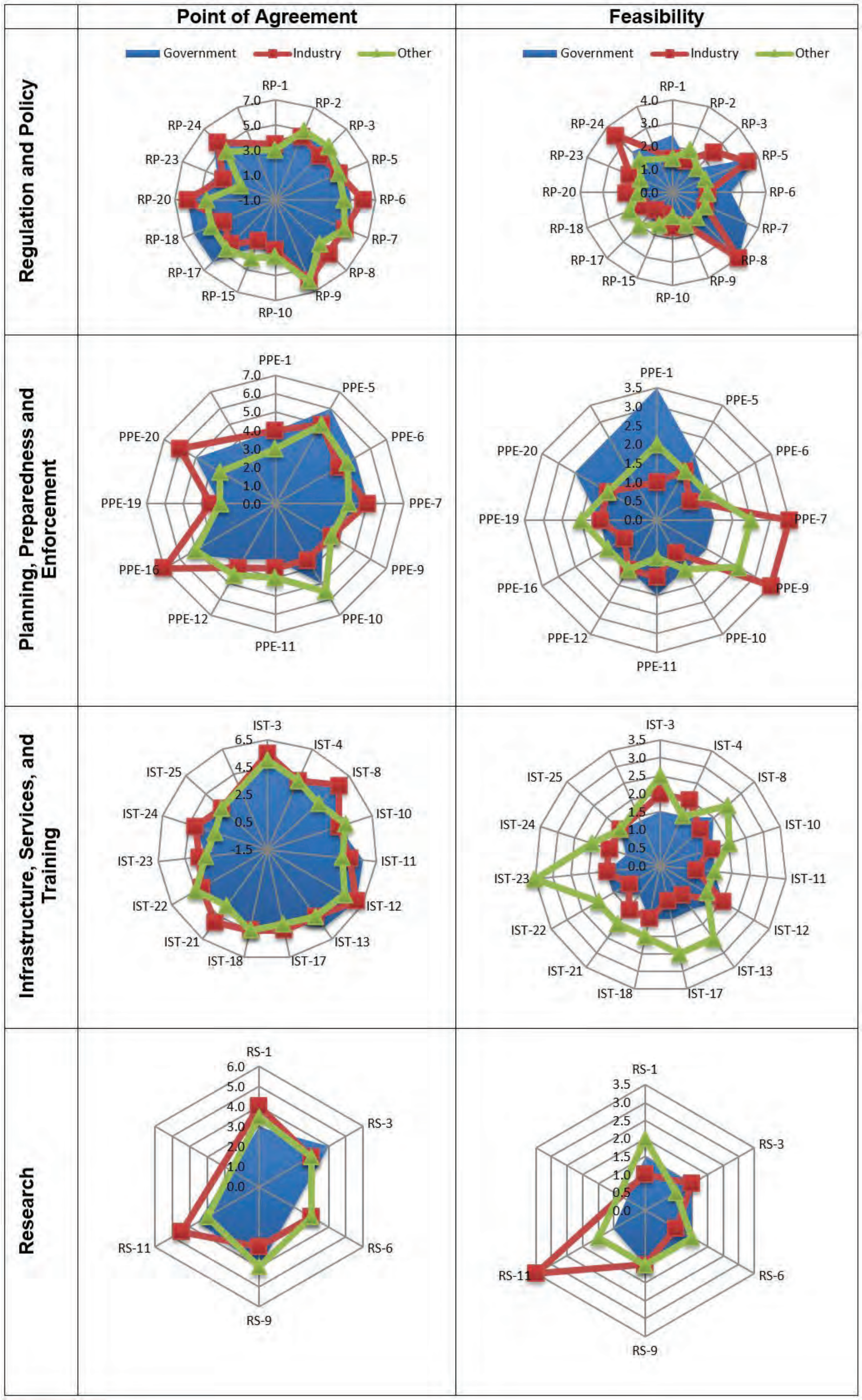


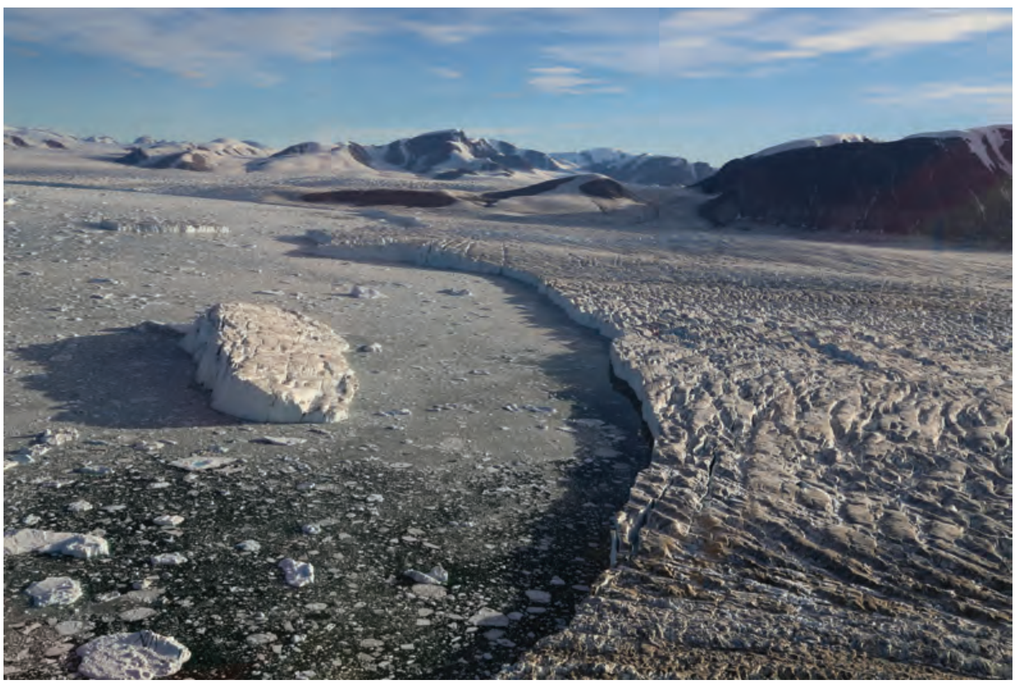
Figure 38

Comparisons between stakeholder groups for all recommendations other than first-order

Table 17

Number of Recommendations and their Level of Consensus within Each Stakeholder Group

	Government	Industry	Other	Overall
High	47	41	50	41
Medium	19	19	17	24
Low	9	10	13	12
None	7	12	2	5



Luke Copland

Chapter 6: Recommendations for Climate Change Adaptation

6.1 Introduction

The final step in the policy Delphi approach involved critically analyzing and verifying the list of ranked adaptation strategies in order to develop a set of final recommendations that should be considered for implementation. The verification step involved focused and lengthy discussions with four different ship operators representing different types of shipping activities in the Canadian Arctic (i.e., re-supply, tourism, resource, and project cargo). A verification meeting was also held with a selection of experts from Transport Canada. The objectives of the verification step were to: a) scrutinize the adaptation strategy suggestions and ensure that the most appropriate and needed strategies were highlighted; and b) identify and anticipate any possible undesirable "side effects" of adaptation strategy implementation (i.e., unintended consequences of decisions that can, in some instances, directly negate the original intention of the decision/strategy, or in other instances cause ripple effects and negative consequences outside the sector of focus).

The five in-depth verification interviews lasted between one and two-and-one-half hours each. The results of these interviews were used in conjunction with the complete findings of the study in order to establish a set of high-level recommendations for climate change adaptation within the marine transportation sector in Arctic Canada. A total of 12 high-level recommendations were established that reflect a convergence and, in some cases, extension of the strategies that were explicitly evaluated in Chapter 5. Consideration should be given to all the strategies outlined in this study, with the focus on these final recommendations presented in Chapter 6.

One of the overarching suggestions emerging from the verification interviews is the notion that the feasibility analysis in the study should not take precedence over the desirability analysis, considering that some extremely important but very expensive adaptation options were not highly ranked because of their low feasibility scores. Chapter 6 takes into account this perspective and outlines the collective strategies that should be most seriously considered by the federal government and other decision-making bodies for implementation because these are the strategies that would be of most value overall. It should also be noted that the feasibility analysis in this study is preliminary and that additional scrutiny is required on the part of the federal government and others to determine additional constraints and political appetite for the recommendations.

6.2 Recommended Strategies

The following 12 high-level recommendations have been divided into the four main categories used throughout this report:

1) Regulation and Policy
2) Planning, Preparedness, and Enforcement
3) Infrastructure, Services, and Training
4) Research

6.2.1 Recommended Strategies: Regulation and Policy

Overall, both key informant responses and survey data provide strong support for the Northern Marine Transportation Corridor (NMTC) approach that has been implemented by the Canadian Coast Guard and other agencies in the federal family. The corridors approach is an appropriate governance strategy and an effective response to the variety of pressures—including the implications of climate change—being experienced as a result of both the increased and projected further increases in shipping in the area. The corridors will enable, for example, the Canadian Ice Service to concentrate efforts to generate useful and enhanced ice analysis within a smaller, more focused and feasible area that can be available for any transiting vessels. The Canadian Arctic region is too large to service in its entirety, and so the corridors approach can help focus operational efforts in order to enhance safety and reduce ice and other related risks to vessels. Additional weather stations and other instrumentation along the corridors are recommended and would greatly enhance some of the weather and climate data gaps that currently exist in the region. However, despite the fact that the corridors approach is a good one, the existing routes were created based on only a few years of spatial ship-traffic data, and in some geographic regions these data do not reflect the longer-term traffic trends or the on-going and expected future traffic patterns. The corridor locations also do not currently consider sensitive cultural sites and local-use areas, as well as how these areas might change due to climate change. The corridor routes do consider some significant ecological sites but ignore their increased or decreased significance at certain times of the year (i.e., breeding or migration times), and how these crucial temporal periods are being altered with a changing climate. Corridor effectiveness will be limited until some of these data and other challenges are remedied.

The NMTC approach will help Canada provide an important standard of support for vessels transiting the established corridor routes, but does not provide any kind of support for tourism vessels that purposefully travel off these areas in search of icebergs and ice-dependent wildlife. Increasingly, tourism vessels are traveling into newly accessible and uncharted areas as ice cover decreases and recedes. The largest concern is for new entrants without past experience navigating in ice and other hazards in the region. There is also concern about smaller private yachts, which are not required to report their position to the Canadian Coast Guard or carry AIS transponders. Thus, there is a need to supplement the NMTC approach with a management strategy aimed at tourism vessels that regularly travel off the main transportation corridors in the region. There is a strong need to develop and implement tourism site guidelines across Arctic Canada that will serve to drive traffic to certain locations that can be better serviced and help focus operational efforts by the Canadian Ice Service, Meteorological Service of Canada (Environment and Climate Change Canada), and other organizations. Site guidelines are a published set of locations that typically include highly visited or attractive sites, as well as interpretative, navigational, and other safety information for visitors. The publication of these sites encourages traffic to these areas and conversely away from other, more dangerous regions. Currently, the complete lack of official information on shore sites across the Canadian Arctic means that private tourism vessels are traveling everywhere and anywhere. Site guidelines have been highly successful in other polar regions, such as Antarctica and Svalbard, in directing traffic to more serviced and less risky areas.

Luke Copland

A number of changes to the NORDREG requirements are recommended in order to increase the effectiveness of ship monitoring and regulatory enforcement. NORDREG is not sufficient as a voluntary regime, and the 2011 change to make reporting mandatory for ships over 300 gross tonnes was necessary and should be extended to include all commercial ships and non-local Pleasure Craft, regardless of size. Considering the now-low costs associated with purchase of boat-based AIS transponders, it is also recommended that it be mandatory for all commercial ships and non-local Pleasure Craft vessels to have AIS capabilities while traveling in the Canadian Arctic. In the context where limited search-and-rescue resources are available, increasing the CCGs' ability to monitor vessel traffic will also help them respond more quickly and effectively to distress calls.

Finally, an expedited decision-making and approvals process should be developed within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems are in conflict. Changing ice conditions have created some situations whereby vessels have been prohibited from entering areas that are completely ice free and have been forced to wait, sometimes days, to get permission to move forward despite the absence of ice-related risk. It is recommended that an experienced federal employee be accessible, perhaps on-call after hours and during weekends and holidays, to enable a more expedited approval for entry into ice regime areas that are free from risk, despite conflicts between the Zone Date and AIRSS systems.

Therefore, the following strategies are recommended for action and implementation.

Recommendation 1: The Northern Marine Transportation Corridors should continue to provide the main framework for shipping governance and decision-making in Arctic Canada. However, current placement of the corridors needs further consideration and additional research and consultation should be on-going in order to adapt the corridors in the future through the consideration of a changing climate and other secondary implications of climate change (RP-22; PPE-2; PPE-3; PPE-4).

Recommendation 2: Tourism site guidelines should be established and implemented as a companion to the NMTC in order to provide support and management of vessels that regularly transit off of the corridors (RP-25).

Recommendation 3: All commercial vessels and non-local Pleasure Craft, regardless of size, should be required to report to the Canadian Coast Guard NORDREG system, and all vessels (excluding local boats and non-motorized vessels) should also be required to carry Automatic Identification System (AIS) transponders. In general, dedicated resources and enhanced efforts should be made to improve monitoring of all vessel traffic (RP-13; RP-14; RP-16; RP-21).

Recommendation 4: An expedited decision-making and approvals process should be developed within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems conflict or are not clear. An experienced operations person should be on-call, including during holidays and weekends, for these more technical decisions (RP-12).

6.2.2 Recommended Strategies: Planning, Preparedness, and Enforcement

Emergency preparedness, specifically spill response readiness and search and rescue, figured prominently in the results of this study. Emergency preparedness is particularly important because the region is becoming increasingly accessible yet increasingly risky because of variable ice regimes and weather conditions. Experts in the study believed that the difficulties associated with responding to a spill is challenging in Arctic ice conditions, which means that prevention is of critical importance. It was also noted that in many other parts of the world spills have been catastrophic for up to 20 or 30 years after the incident. These timeframes could be even greater in the sensitive Arctic region.

Similarly, respondents felt that the consequences of a major marine incident involving a cruise tourism vessel have the potential to be catastrophic, thus meriting significant preventative action. The creation of site guidelines is one preventative action that should be implemented, but additional measures should also include the continuation of cruise ship disaster training, consideration of enhancing the Canadian Ranger program to cover marine search and rescue, and improved monitoring and data collection procedures for smaller Pleasure Craft vessels (i.e., yachts).

Jackie Dawson

Arctic shipping governance could be enhanced through the development of an official Arctic Marine Transportation working group that includes government, Inuit, shipping industry representatives, and other relevant experts. Other proponents have called this idea a "Corridors Commission" (see Pew Charitable Trusts, 2016), which is envisioned as being co-chaired by Inuit and federal government officials, and charged with developing a vision for Canadian Arctic shipping. The working group would develop the integrated corridors and then become the permanent management body responsible for overseeing the system, targeting resources, supportingsafe and responsible vessel traffic, monitoring performance, and adapting to change.

> **Recommendation 5:** Emergency preparedness and spill response capabilities should be enhanced in the region by ensuring that spill response kits are placed along the Northern Marine Transportation Corridors in noted locations, a spill response plan be prepared for each community along the corridors, appropriate and on-going training be provided to authorities in those communities for the use of the kits, preventative protocols be developed with commercial ship operators to facilitate the transportation of spill response equipment in the event of an incident, and other prevention strategies be established for dealing with cruise ship and tourism vessel disasters (PP-14; PP-15; PP-17; PP-18; PP-8; IST-24).

> **Recommendation 6:** An intergovernmental and inter-sectorial working group should be established to establish a Marine Transportation Strategy and Implementation plan that is focused on the NMTC and other foundational governance for shipping in Canadian Arctic waters (PPE-2; PPE-3; PPE-4).

6.2.3 Recommended Strategies: Infrastructure, Services, and Training

Investment in the Coast Guard fleet clearly emerged as a key recommended strategy despite the potentially high costs involved in building new icebreaker(s) and improving the existing vessel fleet. Investment in CCG marine assets ranked relatively low compared to other adaptation strategies in the study because the strategy might be unaffordable. However, during the verification stage of the study, it was unanimous among ship operators that investing in the CCG fleet was essential despite the costs involved and that this adaptation strategy should be placed much higher in the list of strategies for consideration of immediate implementation. The CCG plays a critically important role in preserving and protecting the Canadian Arctic marine environment by providing key services to mariners. Furthermore, Canada has signed the joint search-and-rescue agreement and has national and international responsibilities for SAR in the region. Some experts believe that Canada currently lacks the infrastructure to be able to effectively serve the region.

It is also recommended that additional resources be allocated to improve charting. Ships operating in the Canadian Arctic, especially CCG and Canadian military vessels, should be equipped with multi-beams and other sensors to improve charting and rescue abilities. Canada should also consider crowd-sourcing approaches to charting the region and might consider a multi-tiered system for communicating the data with end users (e.g., verified, sourced by ship operator, unverified).

Lastly, appropriate marine infrastructure is necessary to ensure safe travel and efficient commercial operations in the region. Any infrastructure investment should be multi-purpose and serve both marine operations and community needs. It may not be necessary to invest in large-scale infrastructure; instead, smaller-scale investments could make a significant difference.

> **Recommendation 7:** Investment should be made in the Coast Guard fleet, including: expanding and upgrading the vessel complement (in order to allow the CCG to expand ice-breaking services over a greater area and into the shoulder seasons), having multi-beams and other "SMART-ship" technologies installed on all CCG vessels (in order to allow them to chart the areas they are passing) and other technological upgrades as needed to ensure a world-class ice-breaking service, and continuing to extend the operational season of the northern Coast Guard office as the open water season continues to expand (IST-7, IST-6; IST-16; IST-5).

> **Recommendation 8:** Further investment should be made to improve charting, including additional human resources to address the backlog of data waiting to be charted; increasing new and focused charting efforts based on longitudinal ship-traffic patterns; and establishing and approving new approaches to charting, including crowd sourcing and developing incentive-based partnerships with ship operators. Additional investment should be made to improve ice and weather data interpretation, including improved communication to end-users (IST-14; IST-15).

> **Recommendation 9:** Investment in marine transportation infrastructure should be made in the North. The region is primarily serviced through marine access, and, as such, appropriate regional infrastructure is necessary, including at least one deep-water port, and a system of shallow water ports, as well as docking and other basic port infrastructure (IST-1; IST-2; RS-10).

6.2.4 Recommended Strategies: Research

The study revealed a need to improve the interpretation and provision of higher resolution and closer-to-real-time ice information, and to improve weather forecasts, including communication of these data with end users. Findings of the study revealed a much stronger need for investment in ice and weather

Olivia Mussells

forecasting, data interpretation, and data communication over investment in new science or new modeling techniques. Innovative and modern means of utilizing technologies to improve information interpretation and provision are necessary.

There is also a strong need for research to better identify and understand sensitive ecological and cultural sites that could potentially be impacted by increased ship traffic in the Arctic. Environmentally and biologically significant areas (EBSAs) have already been identified via Department of Fisheries and Oceans, but there is a lack of consolidated information on culturally significant sites, including areas of high local use that my be impacted by increased shipping or through the placement of the Northern Marine Transportation Corridors.

Finally, it is recommended that data-sharing partnerships and agreements be generated among different user groups, governments, and researchers. The development of effective data communication portals is also recommended, but this is challenging considering the varying needs of end users and the difficulty in creating a single, one-stop-shop data portal that would serve all end users. Additional investment is needed to better understand the needs of end users and to better communicate data with ship operators. The needs of end users and the social, cultural, and economic implications of shipping change in Arctic Canada should more often influence the natural science and modelling efforts that are currently underway in Canada. It is common for modelling efforts to be undertaken with the assumption that better modeling will lead to better outcomes (e.g., improved navigation, reduced risk), but this assumption is not true if the wrong questions are asked or if the new findings are not relevant for end users. Therefore, it is strongly recommended that modeling and other scientific endeavours are better linked to end users and that a better understanding of end-user needs, concerns, and decision-making patterns is generated.

> **Recommendation 10:** Action should be taken to improve data quality for marine weather forecasting (i.e., mariners need real-time weather information and higher resolution of information); weather and ocean current instrumentation should be increased, specifically around the Northern Marine Transportation Corridors; seasonal ice forecasting that includes real-time ice charts should be increased; and a reliable method should be developed for relaying weather and ice information to vessels so as to address issues related to bandwidth, latitude, and black-out areas (RS-7, RS-8, IST-19, IST-20).

> **Recommendation 11:** Actions should be taken to improve the availability of information on sensitive sites and to enhance protections and awareness of those sites. Better understanding of the impact that shipping has on northern communities should be pursued, and enhanced protections be considered for identified cultural and ecologically sensitive areas that could potentially be impacted by increased ship traffic in the Arctic (RS-4, RP-22).

> **Recommendation 12:** Data sharing and partnerships should be undertaken with relevant parties in order to obtain and share real-time, standardized meteorological and oceanic data (RS-2).

6.3 Conclusion

Climate change is having profound impacts across the Canadian Arctic. Increased average temperature, changing precipitation patterns, melting permafrost, and reductions in sea ice extent are creating important opportunities and risks for the marine transportation sector (ACIA, 2004; IPCC, 2014; Howell et al., 2015). The purpose of this report was to: a) examine the changing temporal and spatial patterns of shipping activity across Arctic Canada (1990–2020), and b) identify potential climate change adaptation strategies for the Arctic marine transportation sector.

Since 1990, there have been increases in shipping activity in Arctic Canada, which are more pronounced within some vessel categories and within certain geographic regions. The Northwest Passage has been increasingly and reliably accessible during the summer season, and as a result has seen increased activity over the past decade. Some increased traffic is expected in the near-term future, but rapid increases are not likely considering that ice and other hazards in the region continue to persist. Climate change is acting as an enabler for shipping activity in Arctic Canada as reductions in sea ice extent and thickness have created increased access to the region, but it is not a direct driver of change, given that operators are not traveling to or through the region just because they can. An exception to this is tourism vessels, which in some cases are attracted to visit the region directly because of climate change. Thus, some future climate-related increases in shipping activity are expected, but other factors, such as commodity prices or technology advances, will play a much larger role in dictating future trends.

Climate change is and will continue to present opportunities and risks for shipping in Arctic Canada. The region is becoming increasingly accessible, and so creating important economic opportunities related to resource development, tourism, and trade. However, changing sea ice dynamics will continue to create significant and often unpredictable hazards to ships. Adaptation strategies will play an important role in helping ship operators and the nation take advantage of emerging opportunities and mitigate associated risks.

In order to establish a comprehensive set of recommended adaptation strategies within this study to deal with climate change in the Arctic shipping sector, it was important to involve a network of individuals working directly in the shipping industry (operators, policy-makers, staff at relevant NGOs, local residents) and consider the level of consensus among stakeholders in their ranking of suggested strategies. Such an approach facilitated a higher level of compliance and acceptance from stakeholders than would be the case if they were not directly involved in the development of potential adaptation strategies. The best adaptation strategies are those that have been identified and vetted through direct discussion with relevant stakeholders and experts.

The entire process involved iterative consultation with a variety of stakeholders to ensure that reliable and reasonable recommendations were created. However, one final validation step was taken to account for any biases or other issues that might have emerged during the research process. This included detailed discussions with representatives from three Arctic shipping companies in Canada and with Transport Canada. This important step was employed in an attempt to identify and anticipate any side effects or issues with the suggested strategies. Although we cannot anticipate every possible outcome, this approach enhances reliability and validity of the suggested strategies. Finally, additional analysis on how each of the suggested strategies will be operationalized will need to occur within relevant government and other sectors prior to implementation. It is suggested that not only the final recommendations be considered for implementation, but that all suggested strategies also be considered and analyzed based on political appetite, funds available, and cost-benefit analysis. Individuals working directly in the sector and managing the sector are best positioned to determine the specific details of implementation and what additional steps may be necessary to make some of these recommendations a reality.

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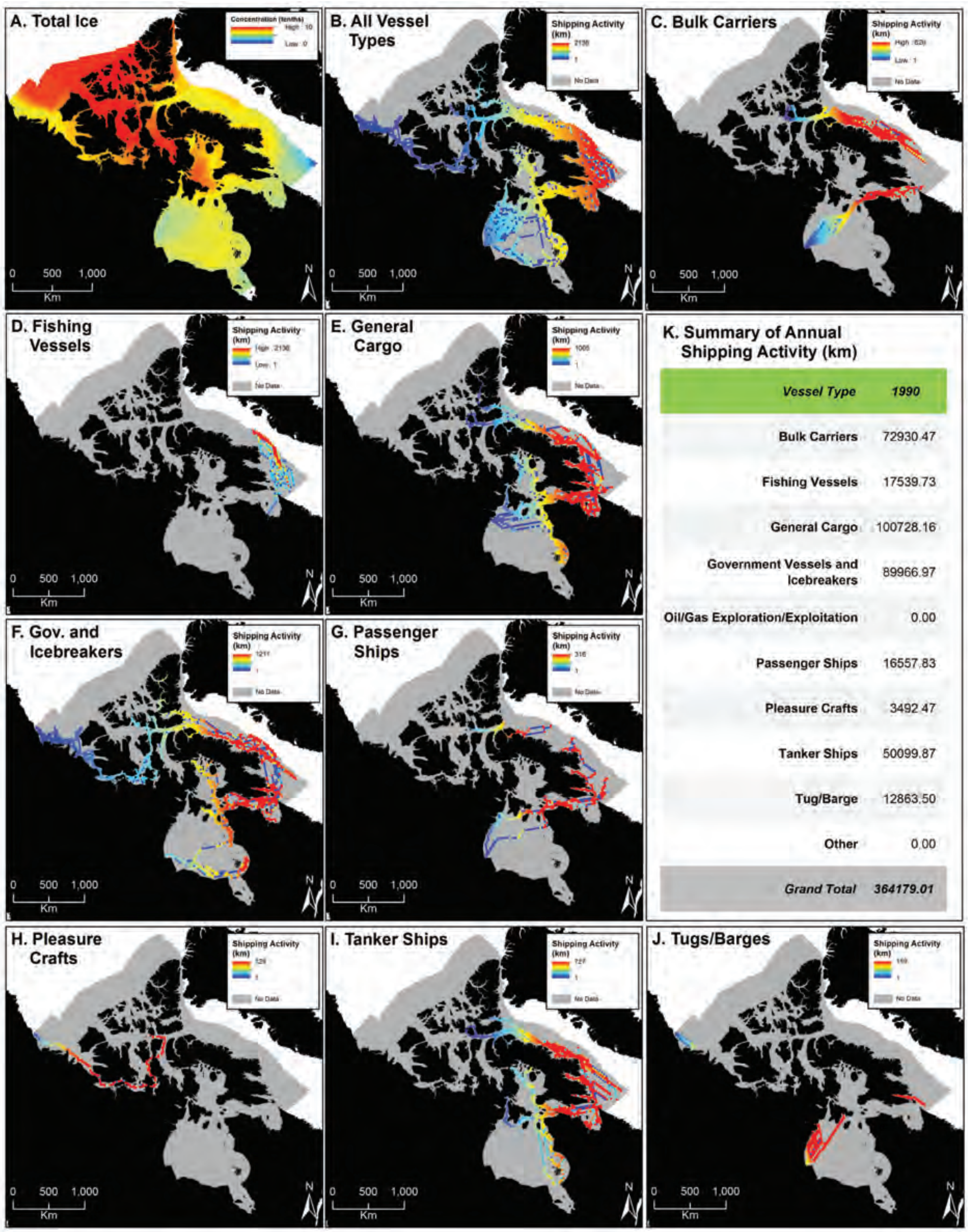
Appendix A. Shipping and Sea Ice Distributions



K. Summary of Annual Shipping Activity (km)

Vessel Type	1990
Bulk Carriers	72930.47
Fishing Vessels	17539.73
General Cargo	100728.16
Government Vessels and Icebreakers	89966.97
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	16557.83
Pleasure Crafts	3492.47
Tanker Ships	50099.87
Tug/Barge	12863.50
Other	0.00
Grand Total	*364179.01*

Figure A1

Shipping and sea ice distribution across the Canadian Arctic in 1990

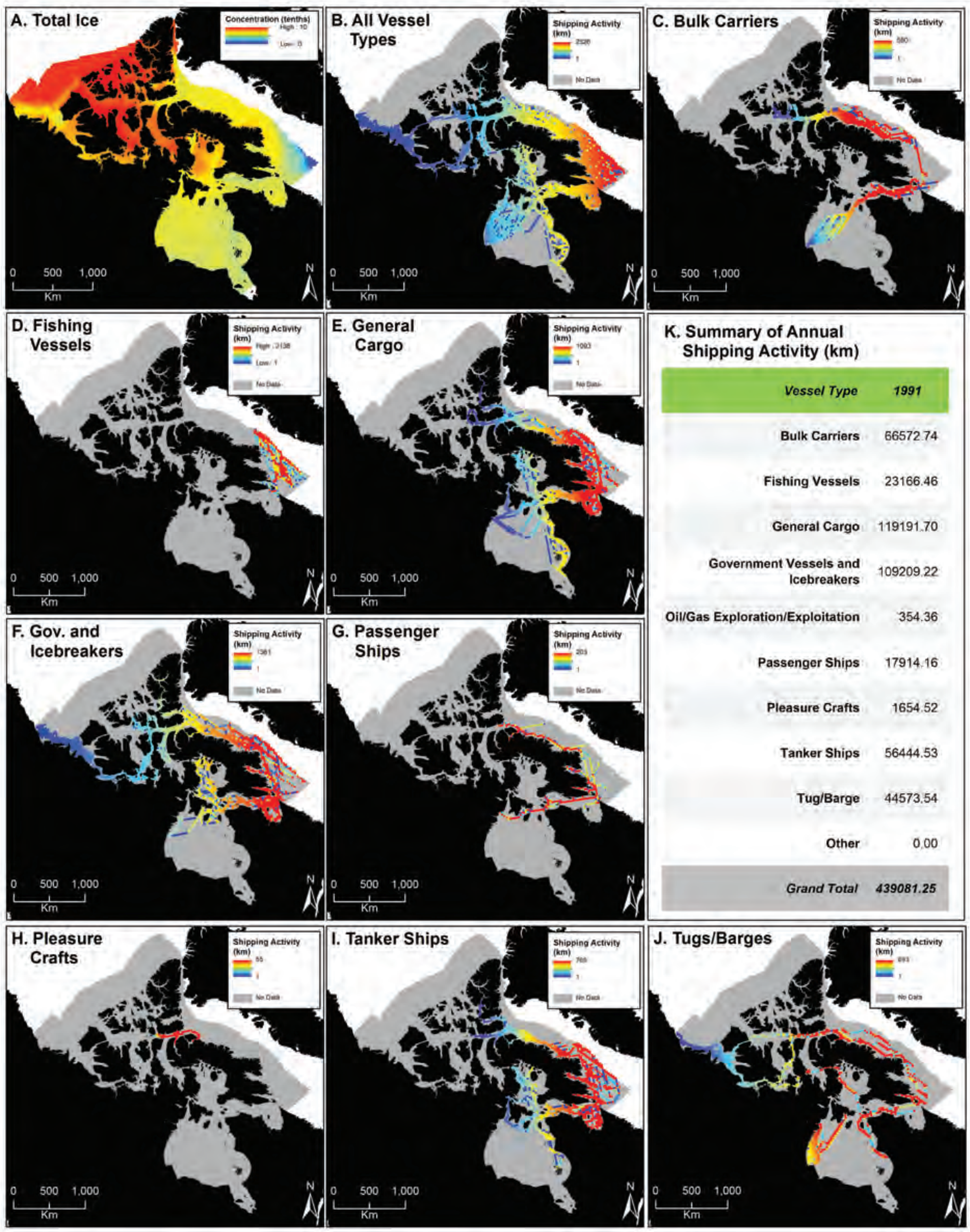
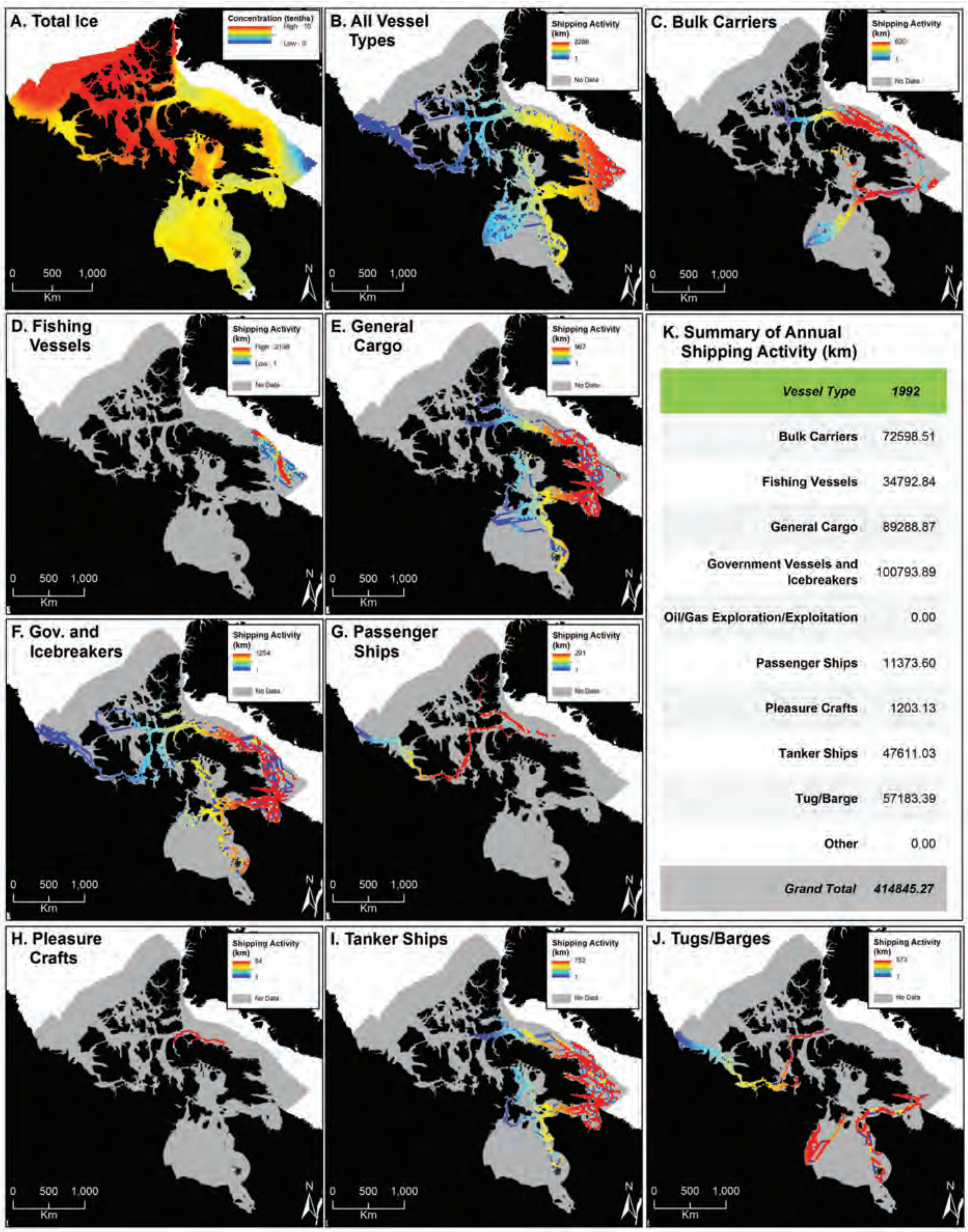


Figure A2

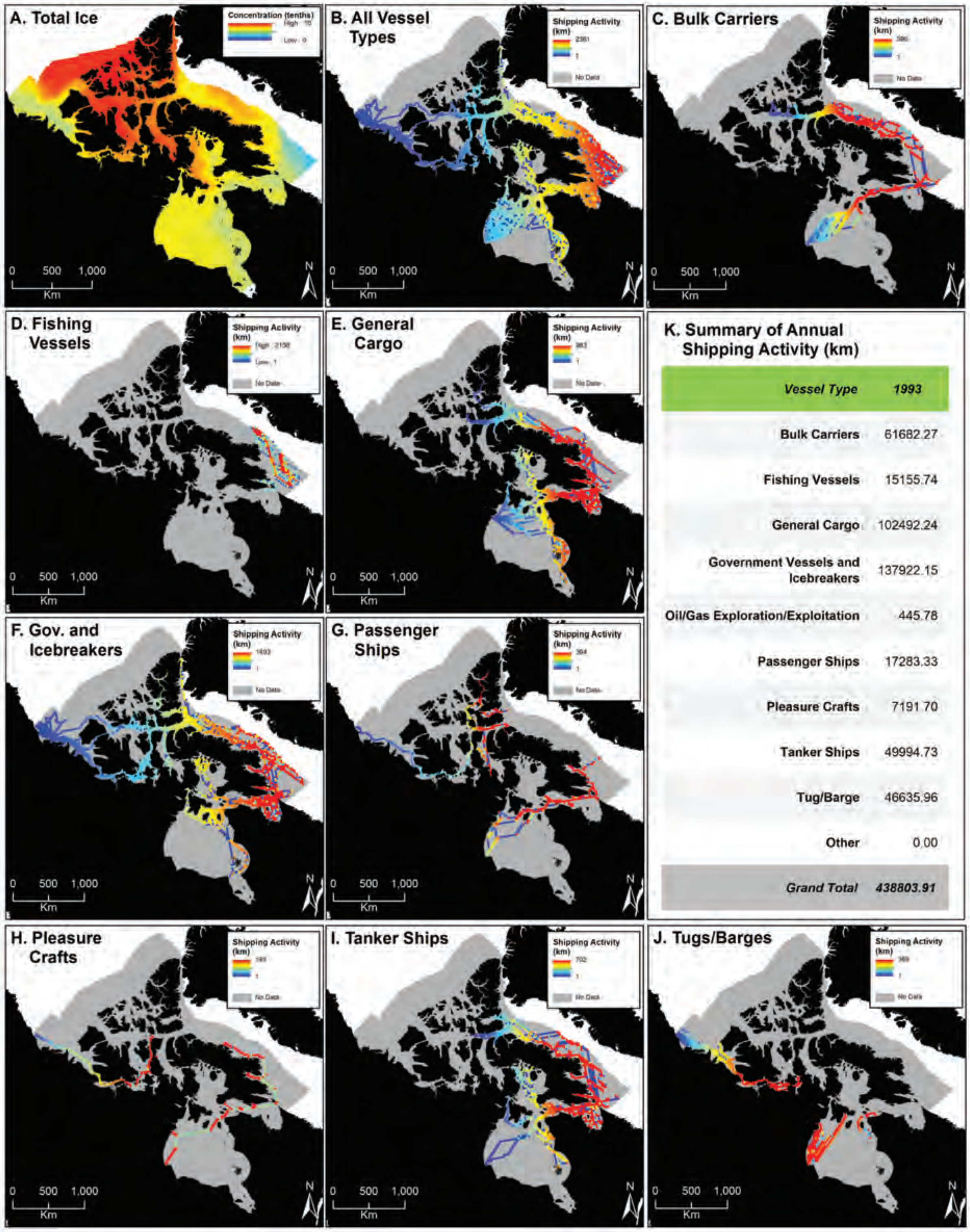
Shipping and sea ice distribution across the Canadian Arctic in 1991



Vessel Type	*1992*
Bulk Carriers	72598.51
Fishing Vessels	34792.84
General Cargo	89288.87
Government Vessels and Icebreakers	100793.89
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	11373.60
Pleasure Crafts	1203.13
Tanker Ships	47611.03
Tug/Barge	57183.39
Other	0.00
Grand Total	*414845.27*

Figure A3

Shipping and sea ice distribution across the Canadian Arctic in 1992



K. Summary of Annual Shipping Activity (km)

Vessel Type	*1993*
Bulk Carriers	61682.27
Fishing Vessels	15155.74
General Cargo	102492.24
Government Vessels and Icebreakers	137922.15
Oil/Gas Exploration/Exploitation	445.78
Passenger Ships	17283.33
Pleasure Crafts	7191.70
Tanker Ships	49994.73
Tug/Barge	46635.96
Other	0.00
Grand Total	*438803.91*

Figure A4

Shipping and sea ice distribution across the Canadian Arctic in 1993

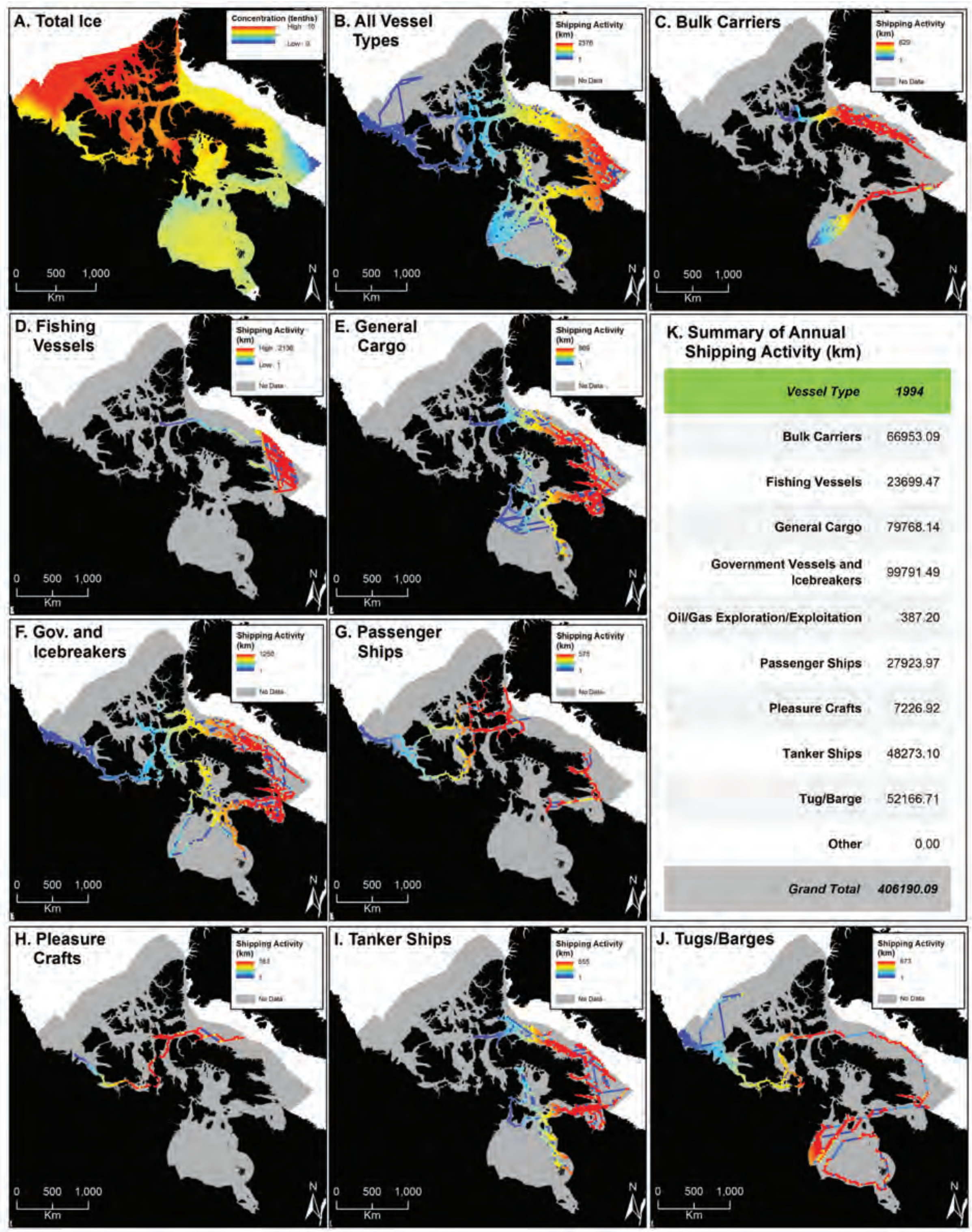
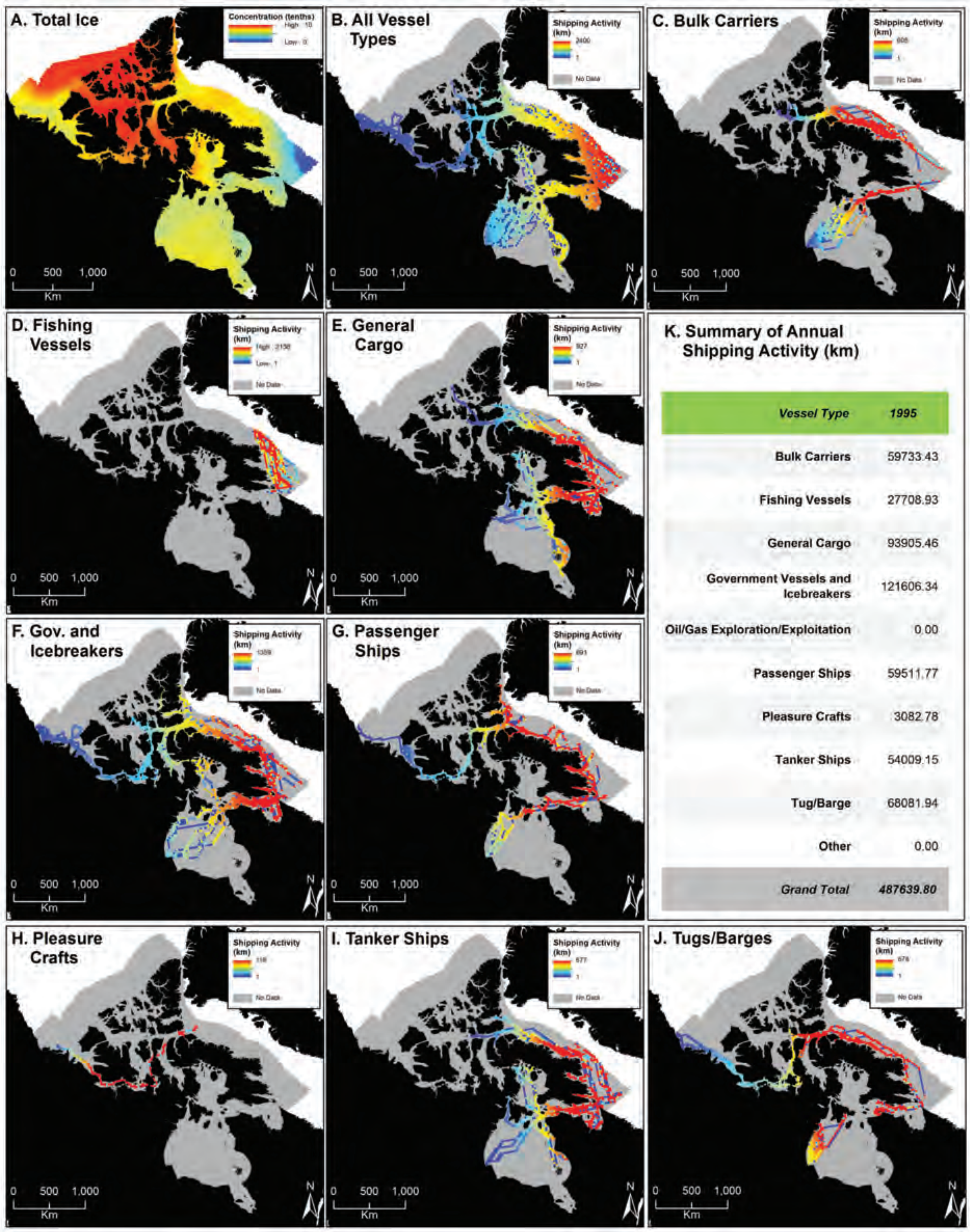


Figure A5

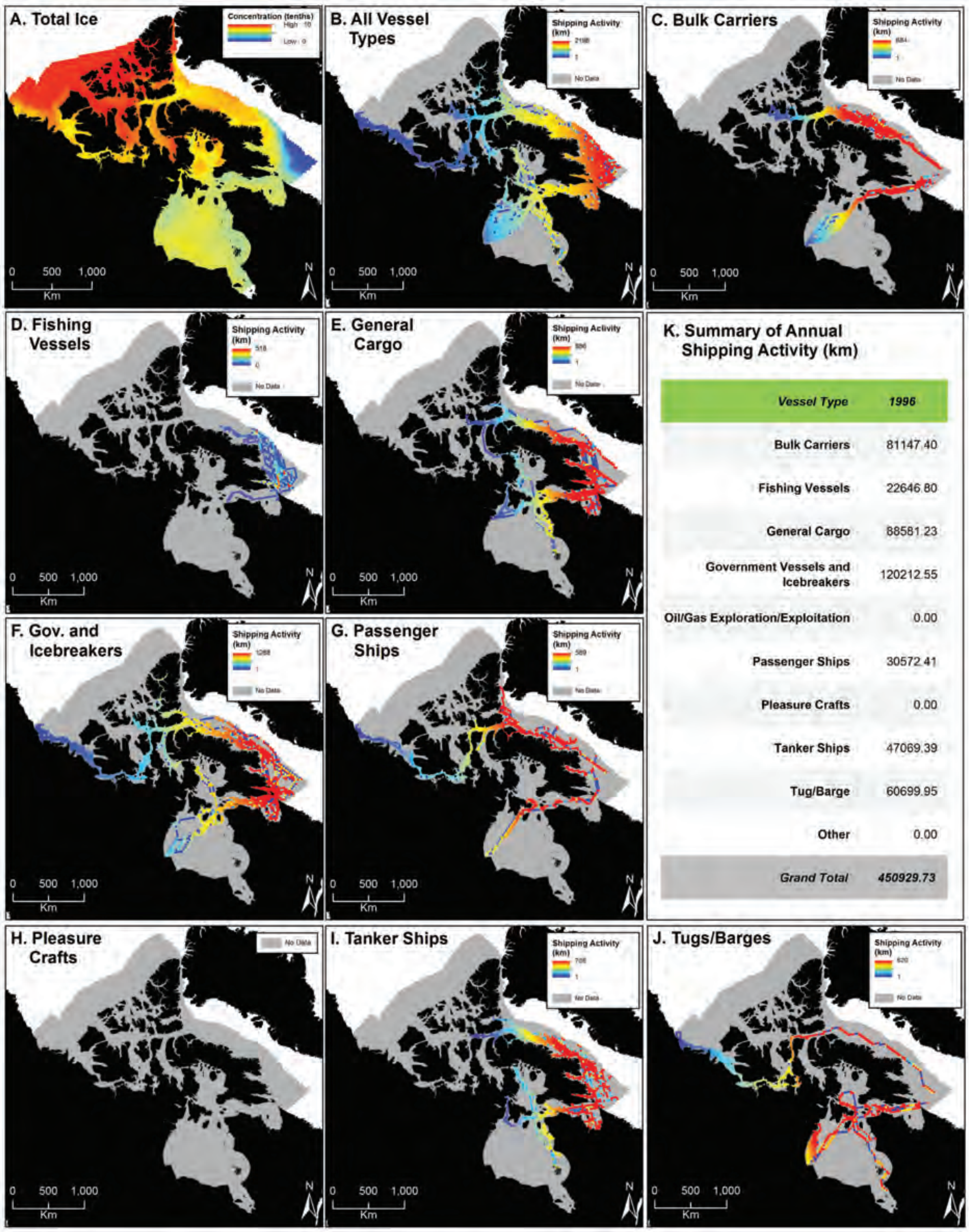
Shipping and sea ice distribution across the Canadian Arctic in 1994



Vessel Type	1995
Bulk Carriers	59733.43
Fishing Vessels	27708.93
General Cargo	93905.46
Government Vessels and Icebreakers	121606.34
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	59511.77
Pleasure Crafts	3082.78
Tanker Ships	54009.15
Tug/Barge	68081.94
Other	0.00
Grand Total	*487639.80*

Figure A6

Shipping and sea ice distribution across the Canadian Arctic in 1995



Vessel Type	1996
Bulk Carriers	81147.40
Fishing Vessels	22646.80
General Cargo	88581.23
Government Vessels and Icebreakers	120212.55
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	30572.41
Pleasure Crafts	0.00
Tanker Ships	47069.39
Tug/Barge	60699.95
Other	0.00
Grand Total	*450929.73*

Figure A7

Shipping and sea ice distribution across the Canadian Arctic in 1996

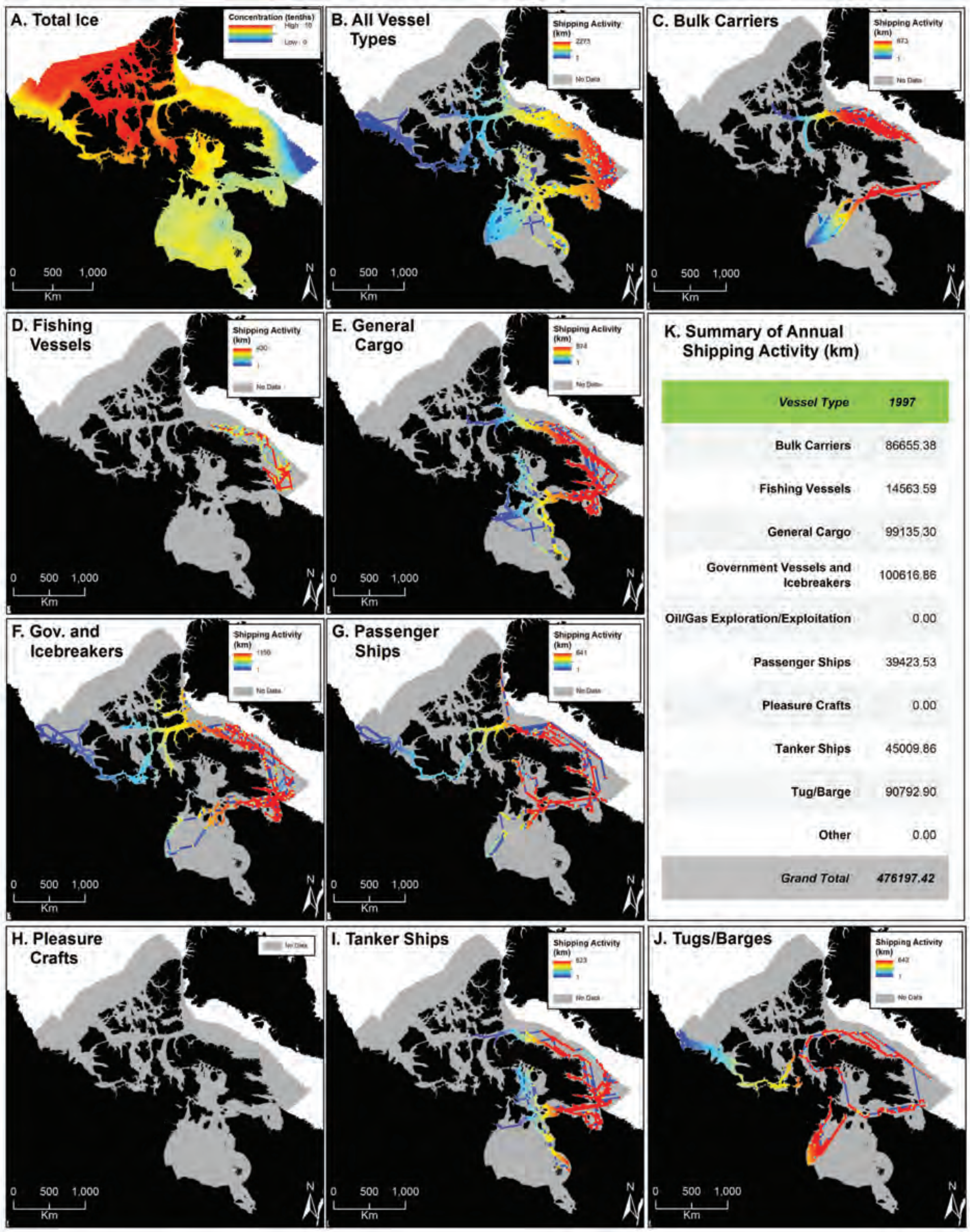
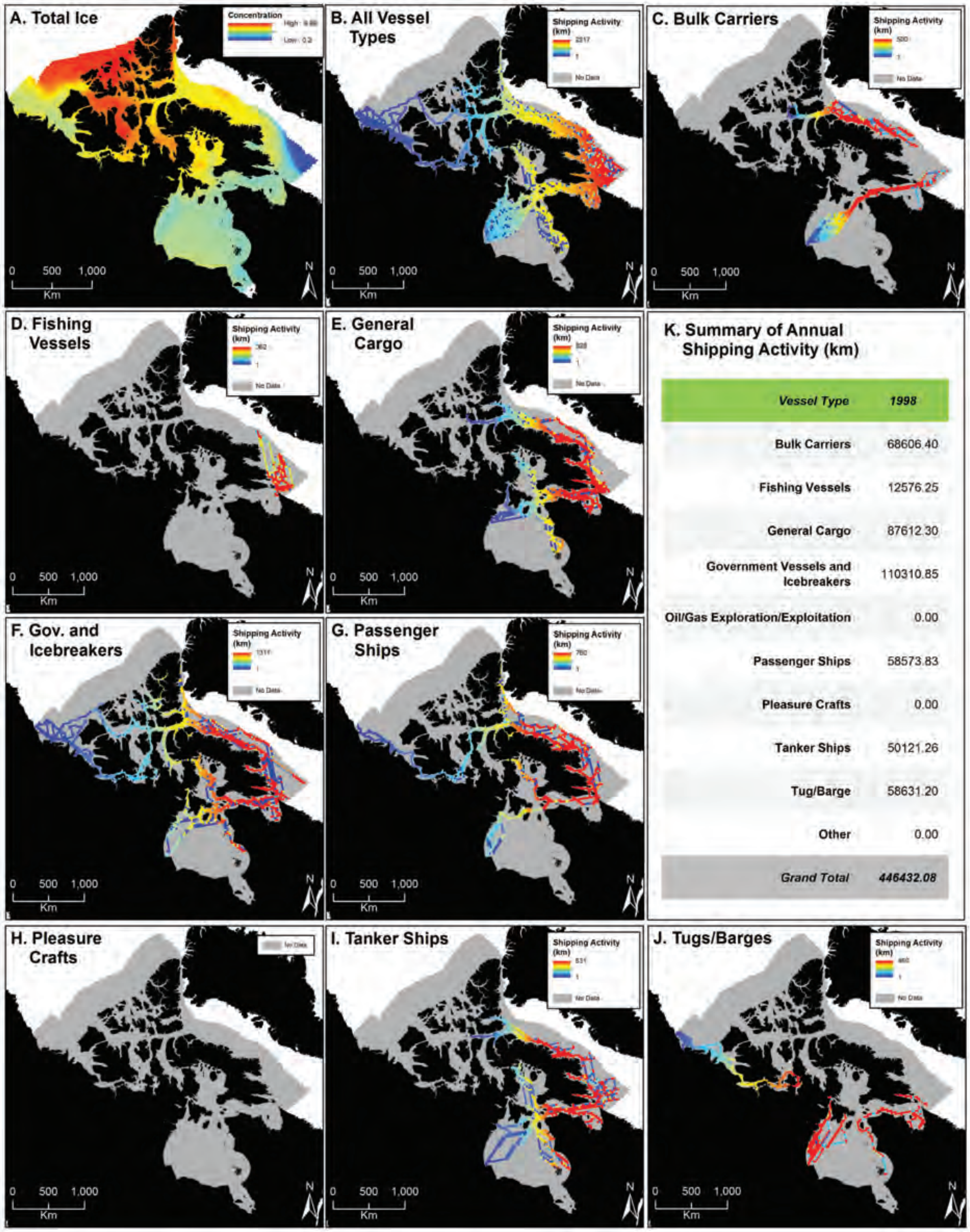


Figure A8

Shipping and sea ice distribution across the Canadian Arctic in 1997



Vessel Type	1998
Bulk Carriers	68606.40
Fishing Vessels	12576.25
General Cargo	87612.30
Government Vessels and Icebreakers	110310.85
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	58573.83
Pleasure Crafts	0.00
Tanker Ships	50121.26
Tug/Barge	58631.20
Other	0.00
Grand Total	*446432.08*

Figure A9

Shipping and sea ice distribution across the Canadian Arctic in 1998

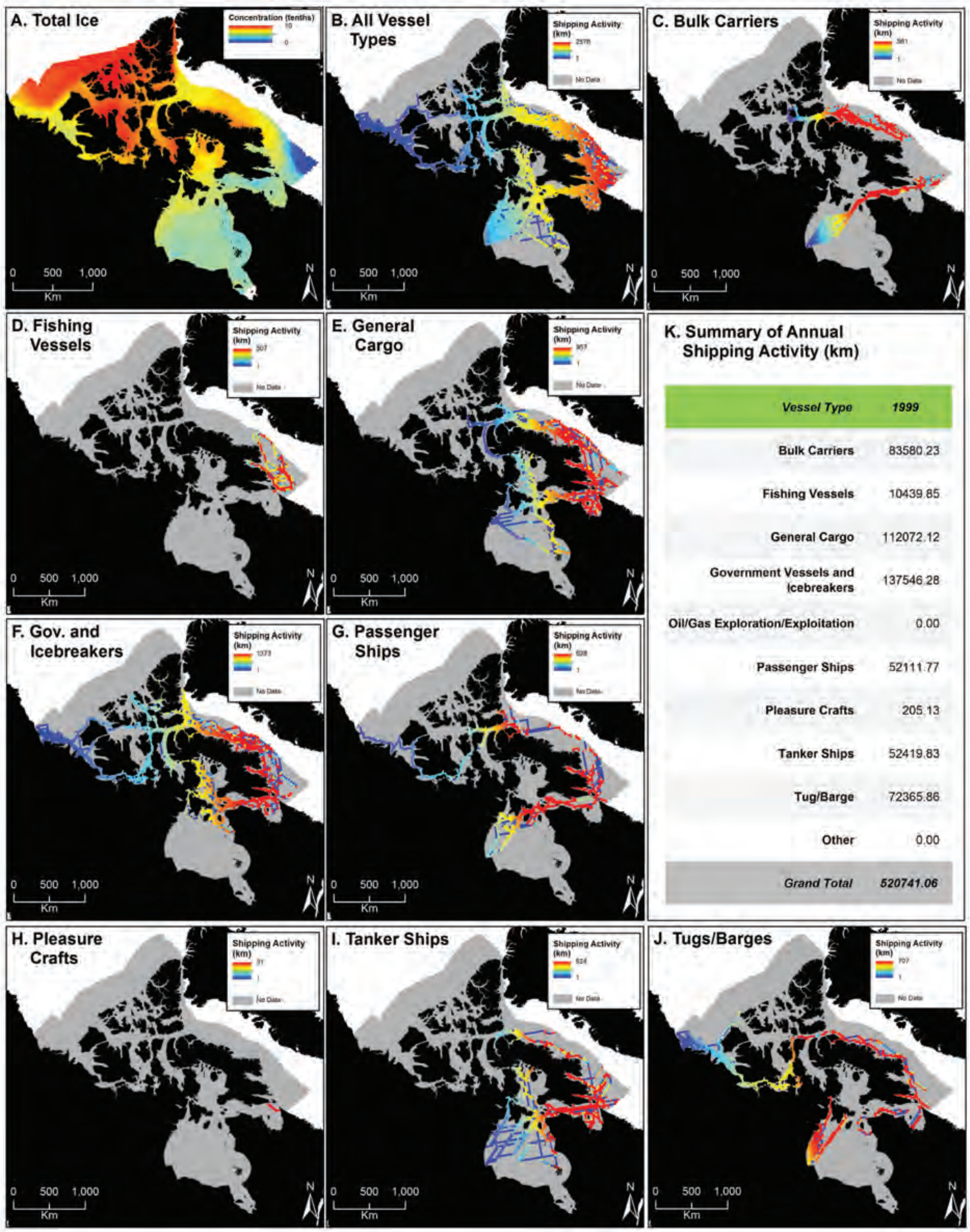
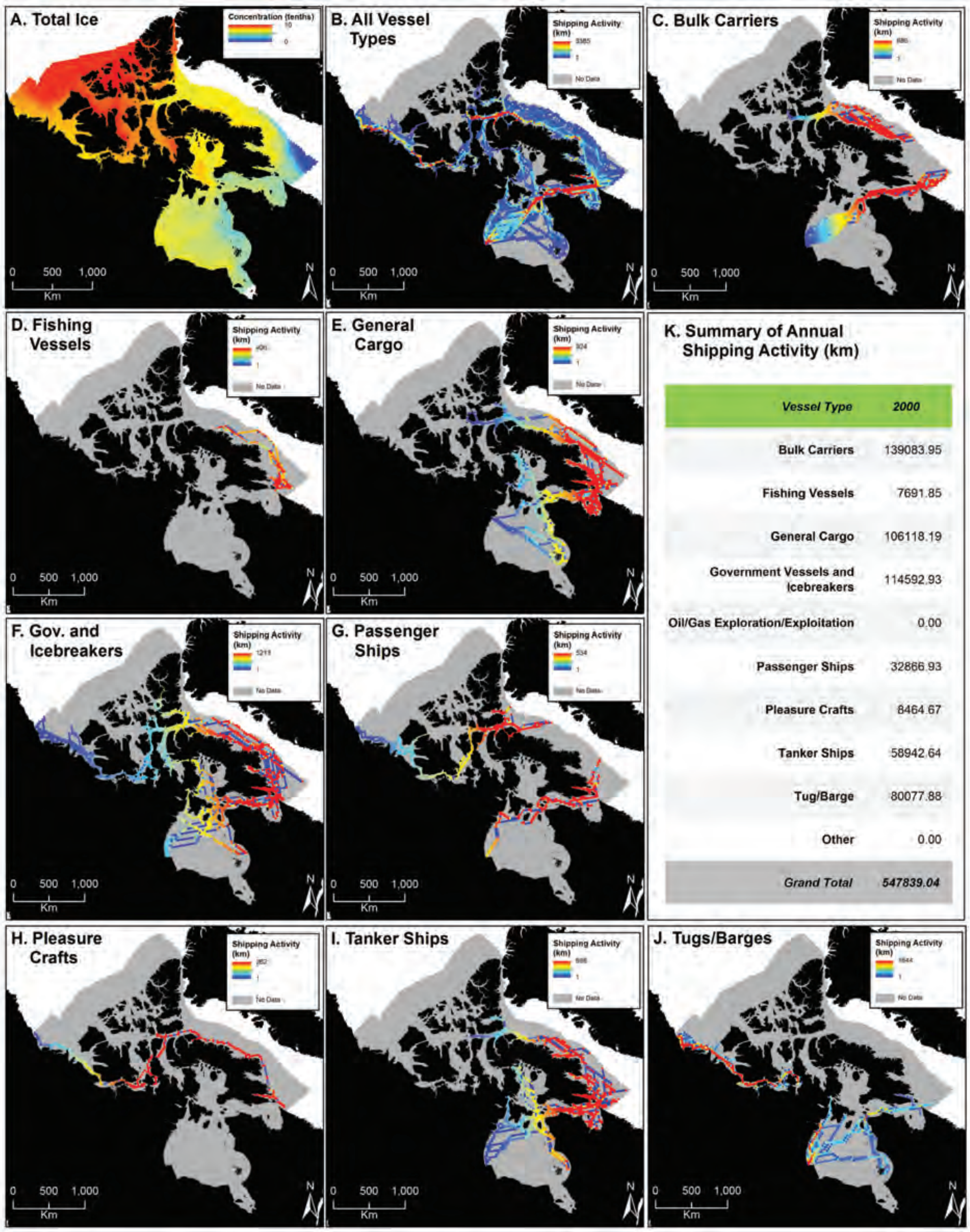


Figure A10

Shipping and sea ice distribution across the Canadian Arctic in 1999



Vessel Type	2000
Bulk Carriers	139083.95
Fishing Vessels	7691.85
General Cargo	106118.19
Government Vessels and Icebreakers	114592.93
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	32866.93
Pleasure Crafts	8464.67
Tanker Ships	58942.64
Tug/Barge	80077.88
Other	0.00
Grand Total	*547839.04*

Figure A11

Shipping and sea ice distribution across the Canadian Arctic in 2000

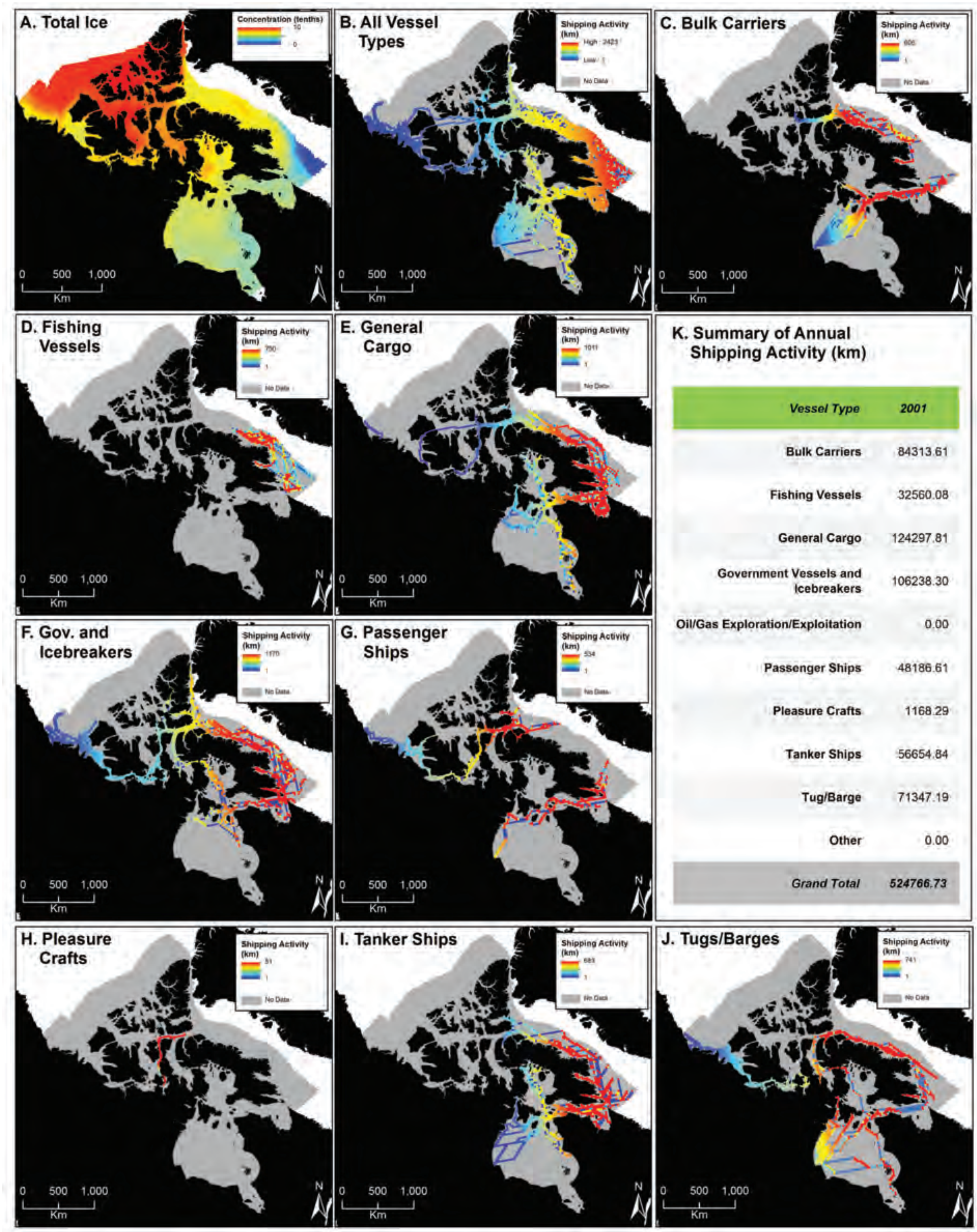
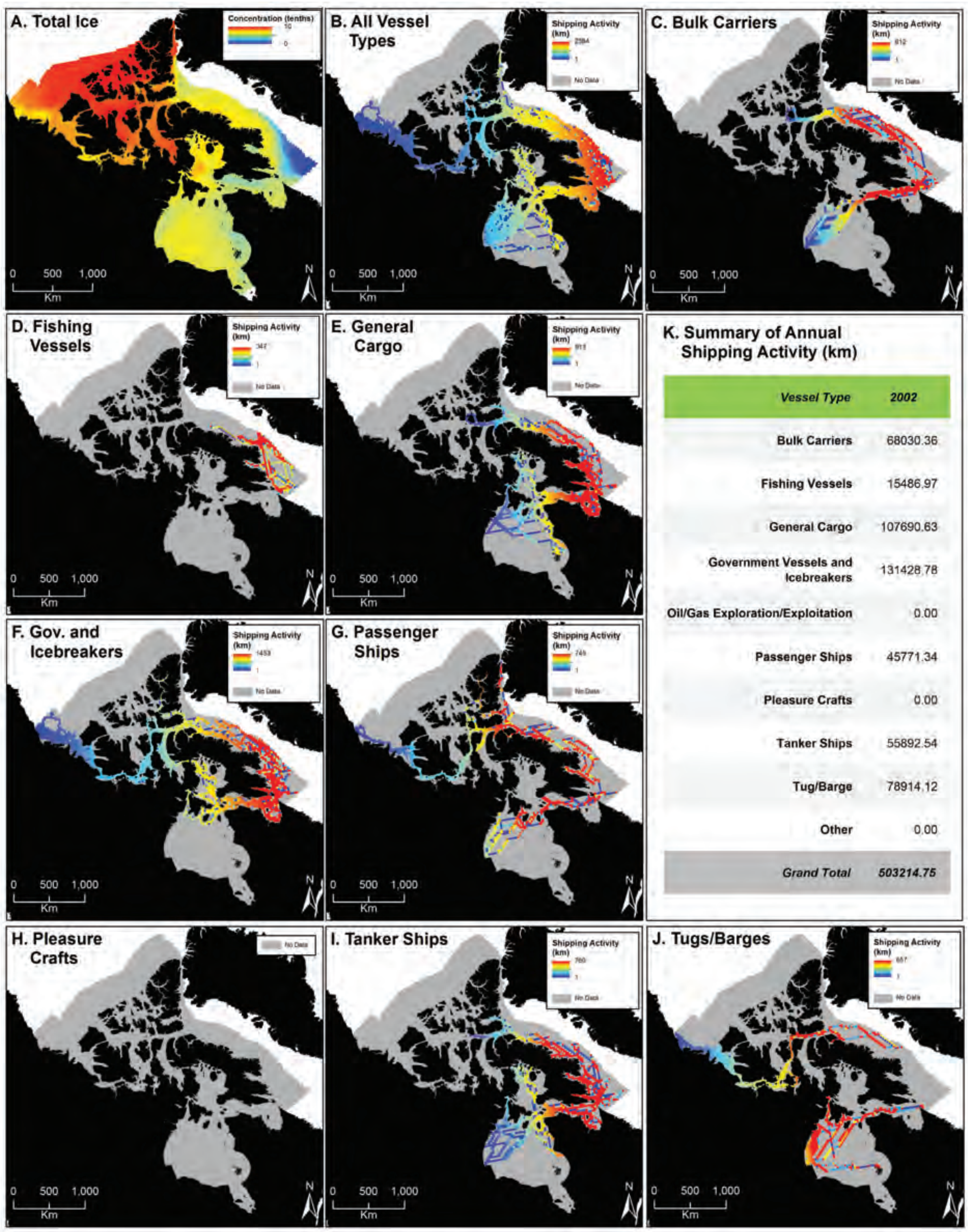


Figure A12

Shipping and sea ice distribution across the Canadian Arctic in 2001

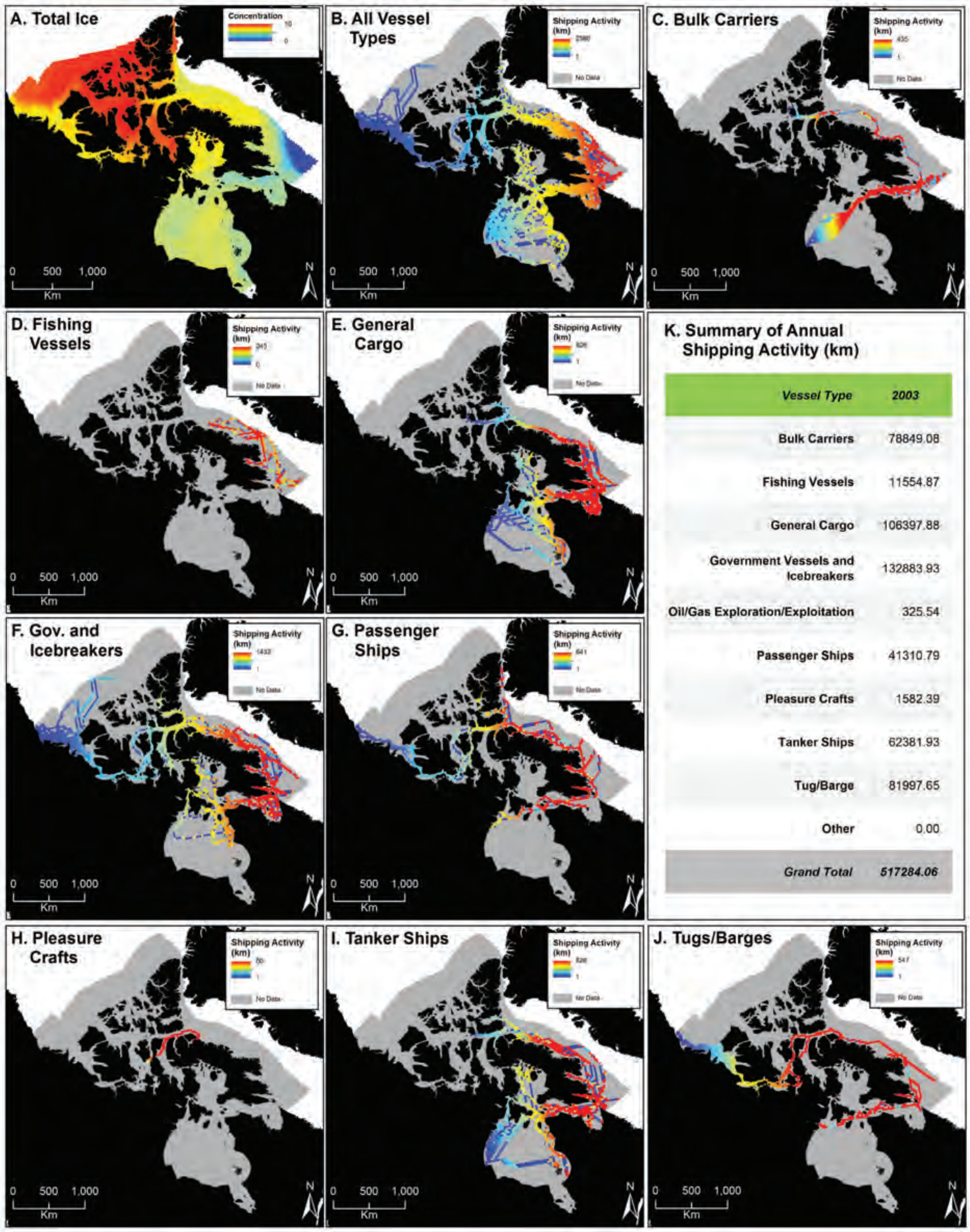


K. Summary of Annual Shipping Activity (km)

Vessel Type	*2002*
Bulk Carriers	68030.36
Fishing Vessels	15486.97
General Cargo	107690.63
Government Vessels and Icebreakers	131428.78
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	45771.34
Pleasure Crafts	0.00
Tanker Ships	55892.54
Tug/Barge	78914.12
Other	0.00
Grand Total	*503214.75*

Figure A13

Shipping and sea ice distribution across the Canadian Arctic in 2002

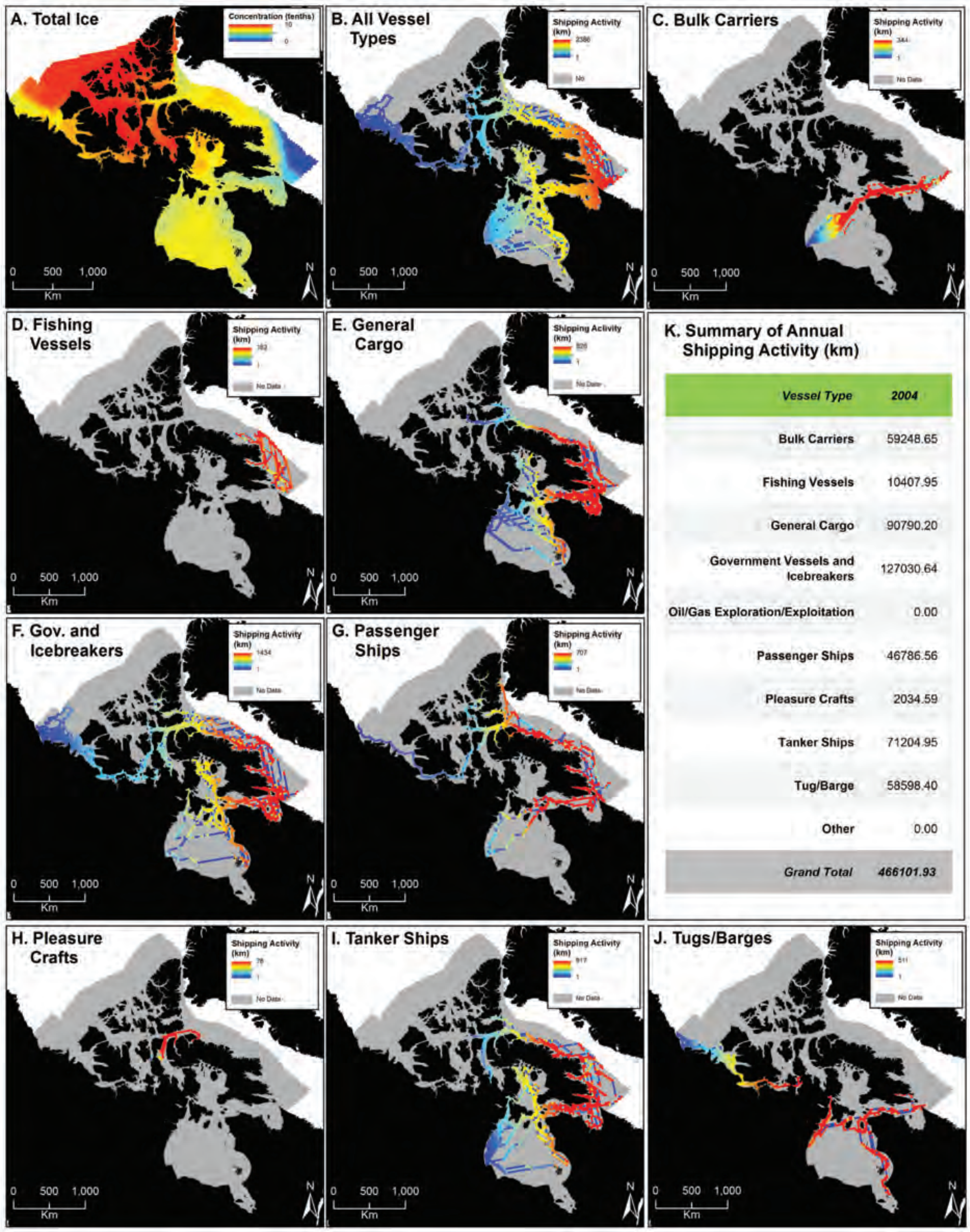


K. Summary of Annual Shipping Activity (km)

Vessel Type	2003
Bulk Carriers	78849.08
Fishing Vessels	11554.87
General Cargo	106397.88
Government Vessels and Icebreakers	132883.93
Oil/Gas Exploration/Exploitation	325.54
Passenger Ships	41310.79
Pleasure Crafts	1582.39
Tanker Ships	62381.93
Tug/Barge	81997.65
Other	0.00
Grand Total	*517284.06*

Figure A14

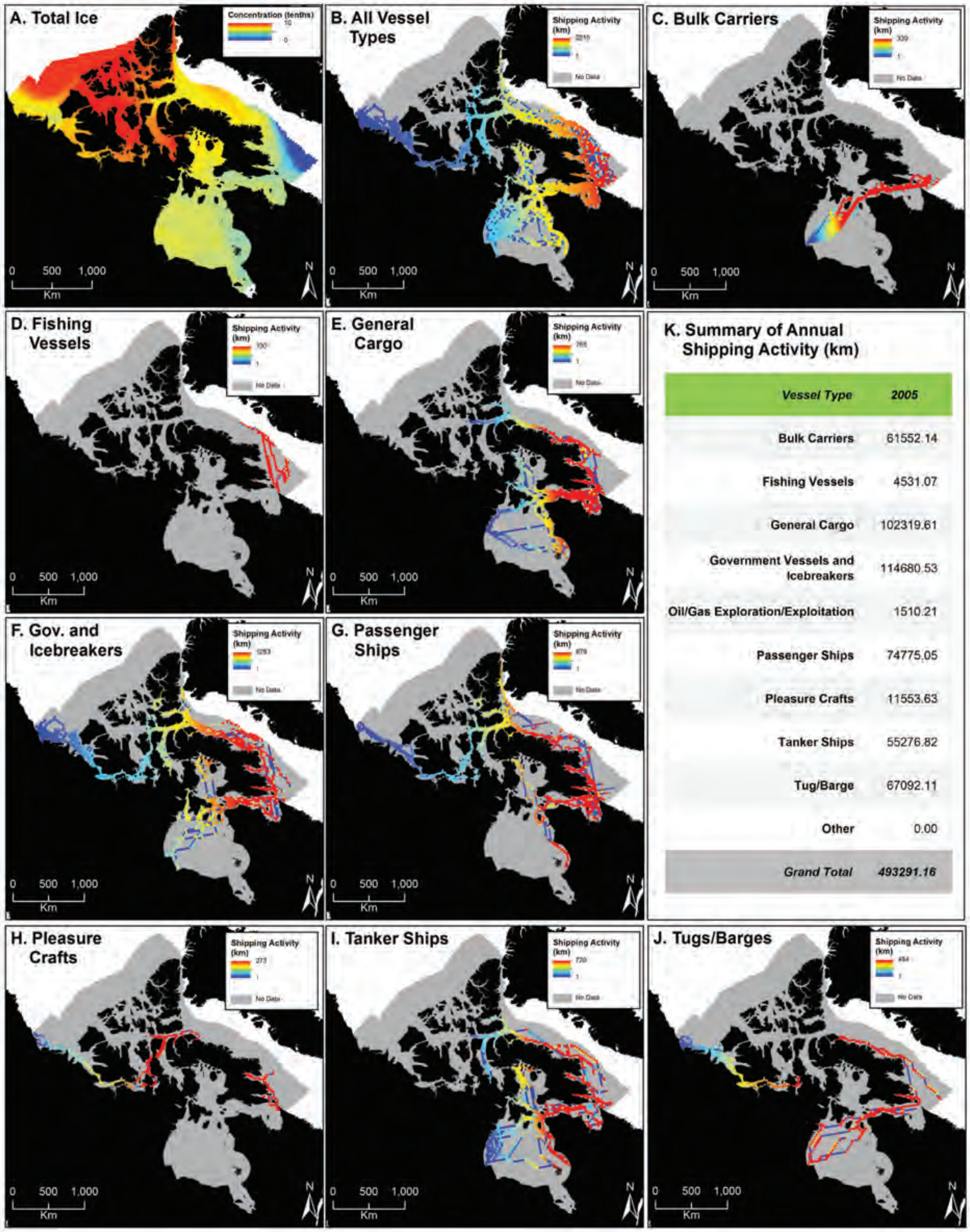
Shipping and sea ice distribution across the Canadian Arctic in 2003



Vessel Type	2004
Bulk Carriers	59248.65
Fishing Vessels	10407.95
General Cargo	90790.20
Government Vessels and Icebreakers	127030.64
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	46786.56
Pleasure Crafts	2034.59
Tanker Ships	71204.95
Tug/Barge	58598.40
Other	0.00
Grand Total	*466101.93*

Figure A15

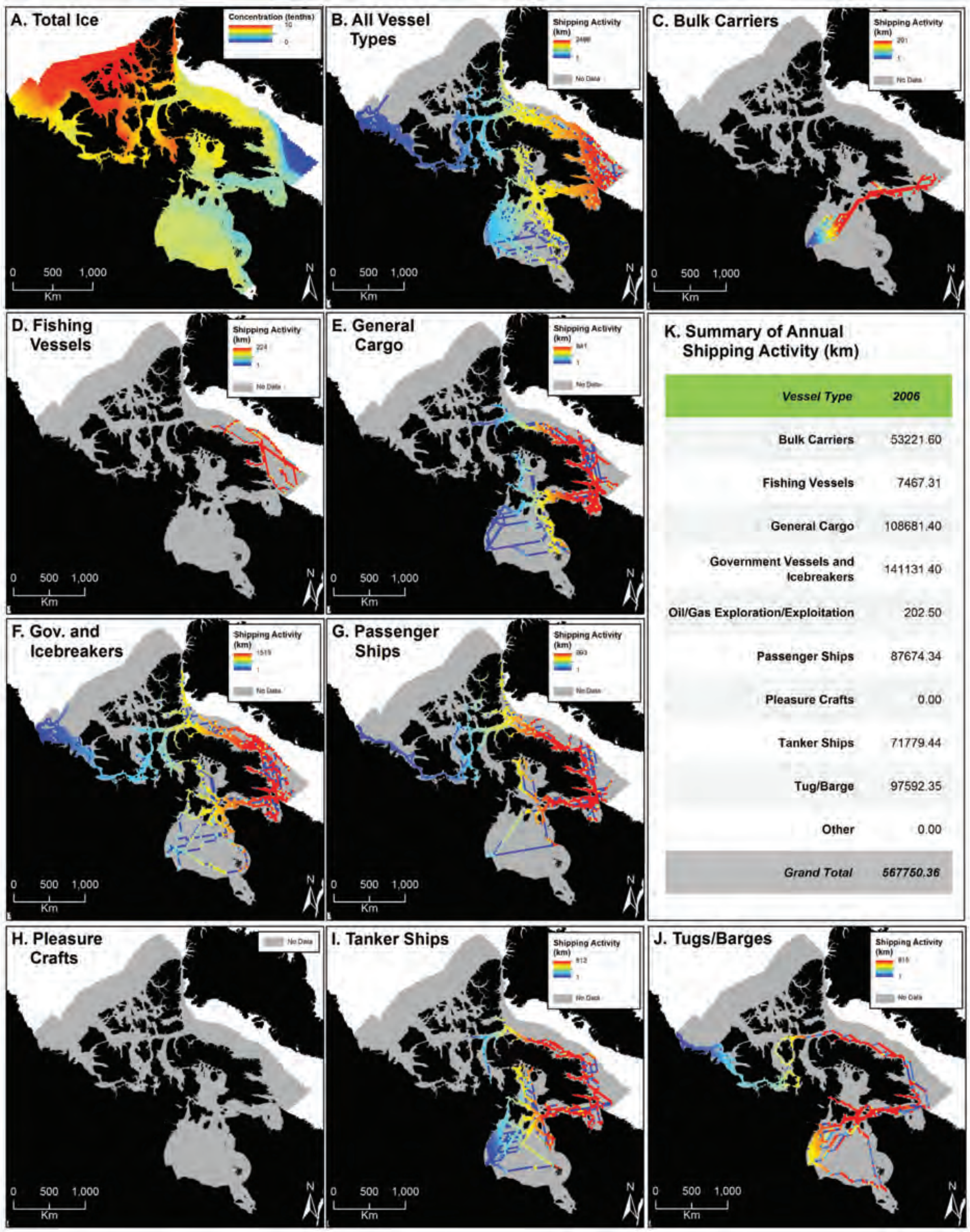
Shipping and sea ice distribution across the Canadian Arctic in 2004



Vessel Type	2005
Bulk Carriers	61552.14
Fishing Vessels	4531.07
General Cargo	102319.61
Government Vessels and Icebreakers	114680.53
Oil/Gas Exploration/Exploitation	1510.21
Passenger Ships	74775.05
Pleasure Crafts	11553.63
Tanker Ships	55276.82
Tug/Barge	67092.11
Other	0.00
Grand Total	*493291.16*

Figure A16

Shipping and sea ice distribution across the Canadian Arctic in 2005

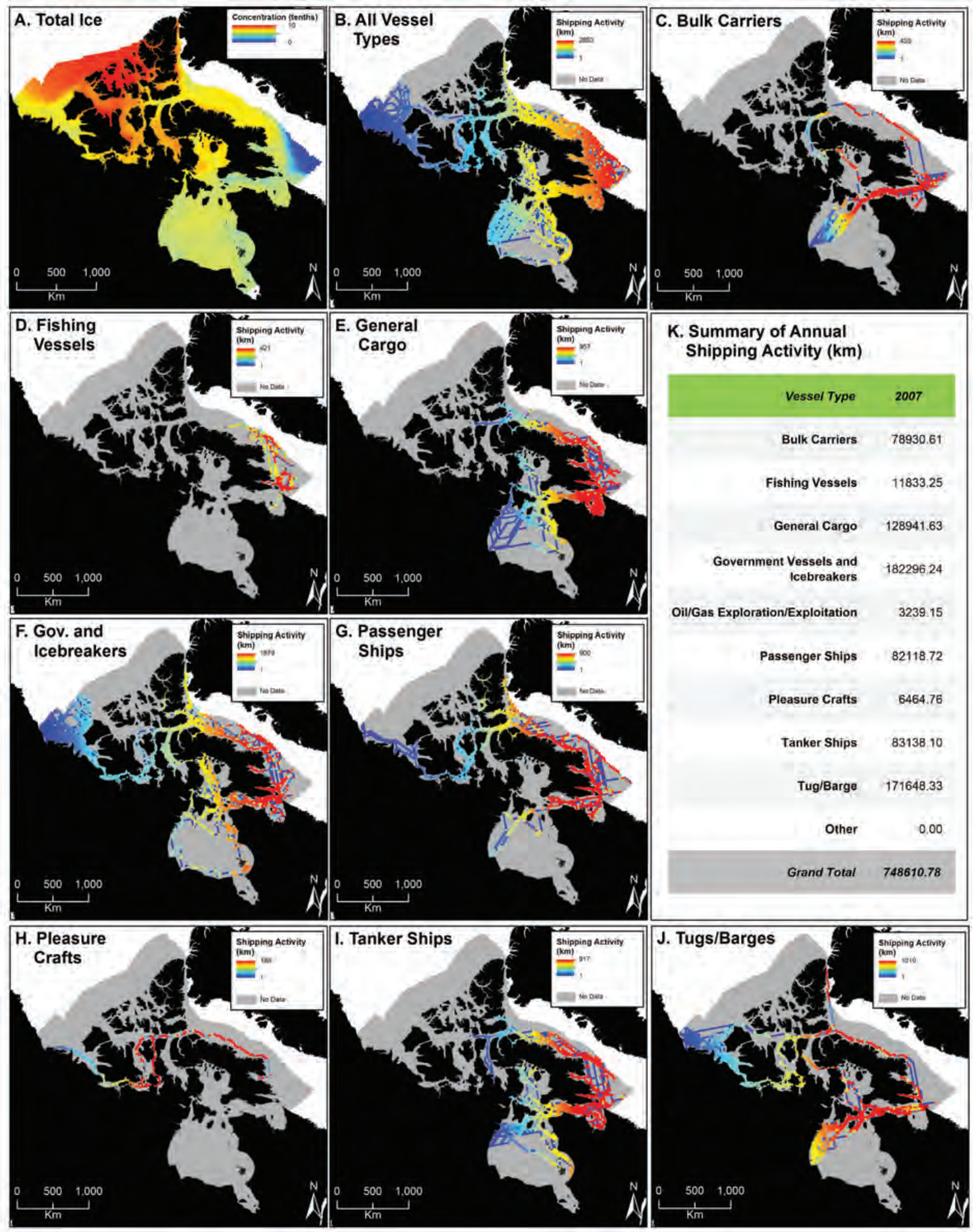


K. Summary of Annual Shipping Activity (km)

Vessel Type	*2006*
Bulk Carriers	53221.60
Fishing Vessels	7467.31
General Cargo	108681.40
Government Vessels and Icebreakers	141131.40
Oil/Gas Exploration/Exploitation	202.50
Passenger Ships	87674.34
Pleasure Crafts	0.00
Tanker Ships	71779.44
Tug/Barge	97592.35
Other	0.00
Grand Total	*567750.36*

Figure A17

Shipping and sea ice distribution across the Canadian Arctic in 2006

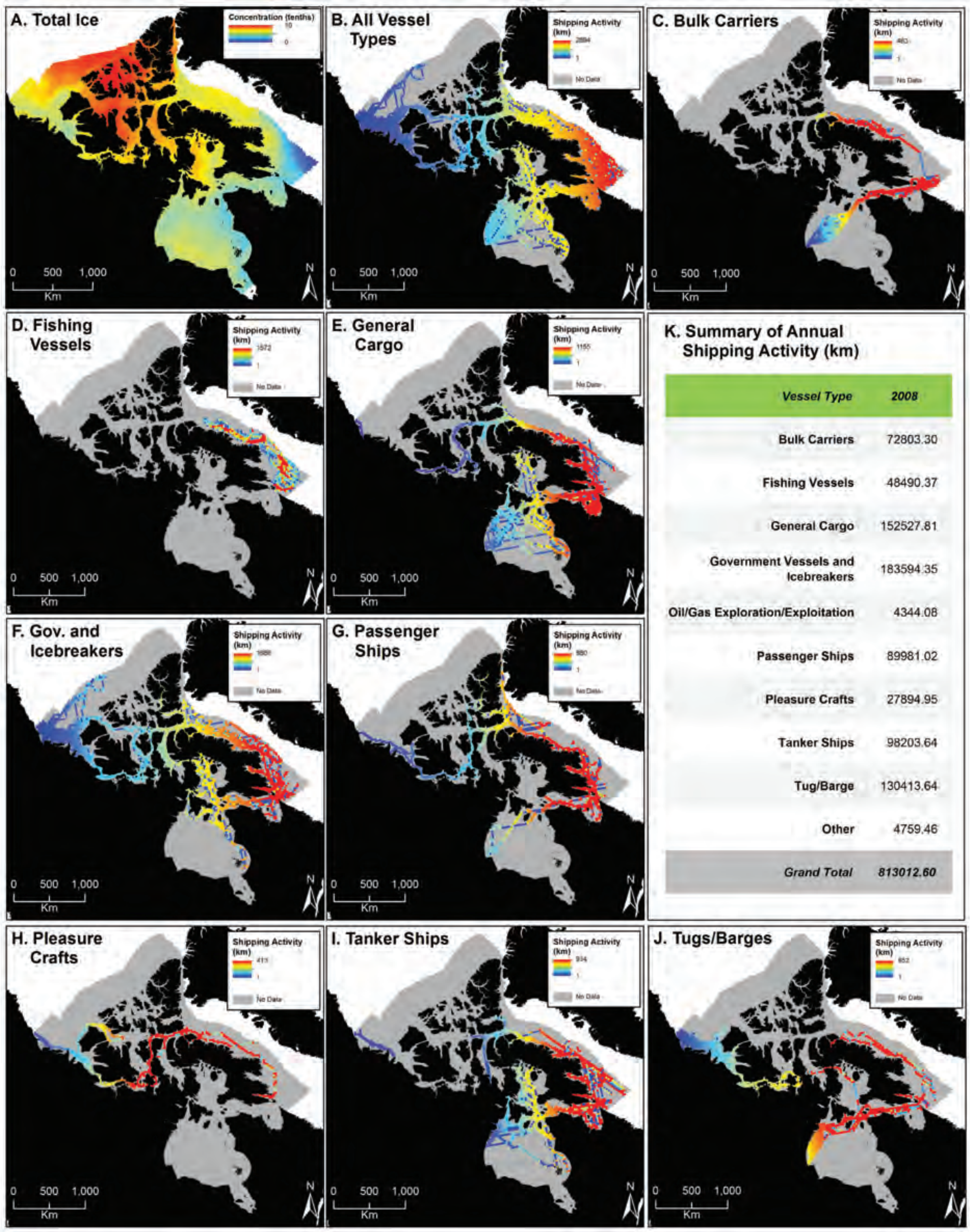


K. Summary of Annual Shipping Activity (km)

Vessel Type	2007
Bulk Carriers	78930.61
Fishing Vessels	11833.25
General Cargo	128941.63
Government Vessels and Icebreakers	182296.24
Oil/Gas Exploration/Exploitation	3239.15
Passenger Ships	82118.72
Pleasure Crafts	6464.76
Tanker Ships	83138.10
Tug/Barge	171648.33
Other	0.00
Grand Total	*748610.78*

Figure A18

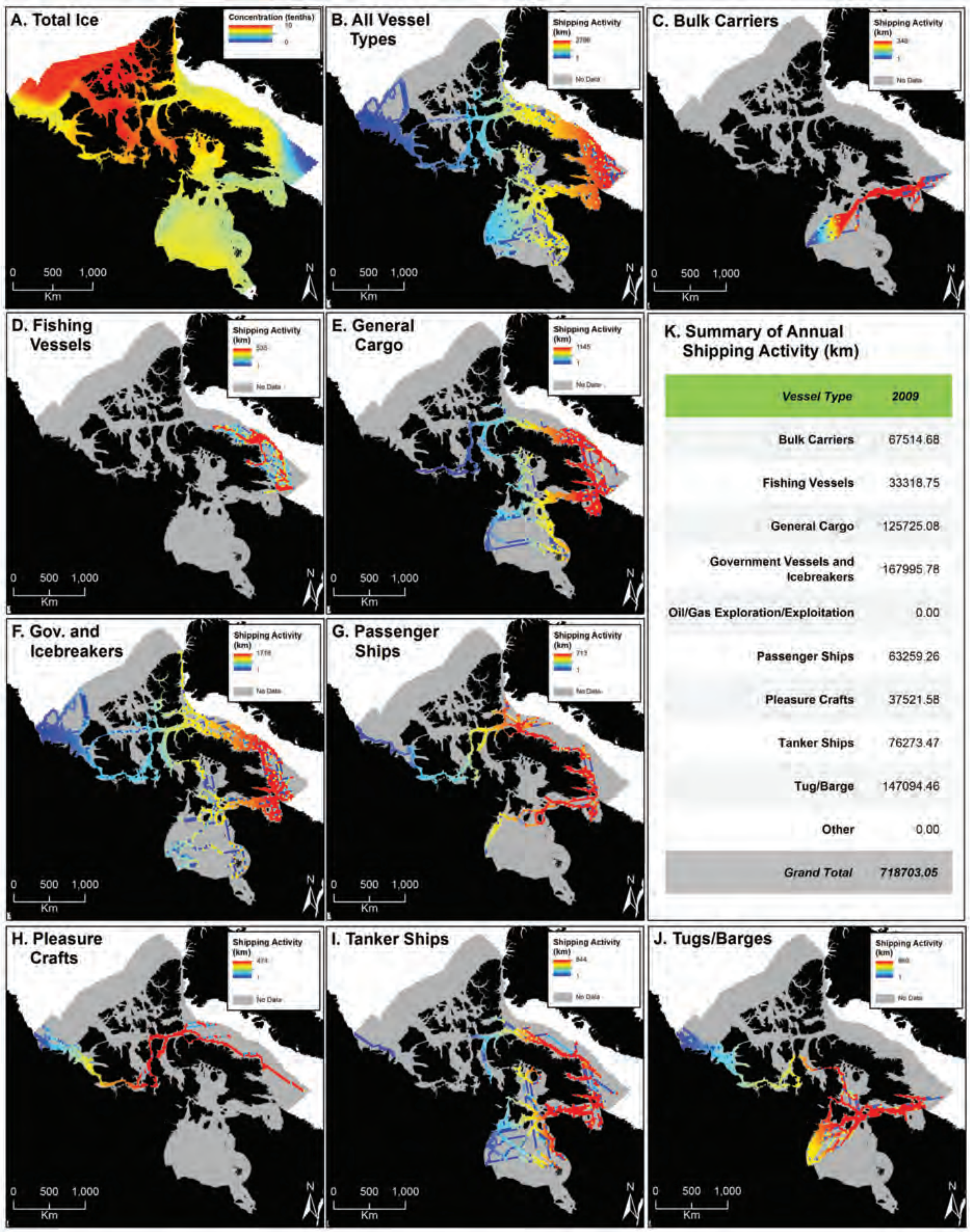
Shipping and sea ice distribution across the Canadian Arctic in 2007



Vessel Type	2008
Bulk Carriers	72803.30
Fishing Vessels	48490.37
General Cargo	152527.81
Government Vessels and Icebreakers	183594.35
Oil/Gas Exploration/Exploitation	4344.08
Passenger Ships	89981.02
Pleasure Crafts	27894.95
Tanker Ships	98203.64
Tug/Barge	130413.64
Other	4759.46
Grand Total	*813012.60*

Figure A19

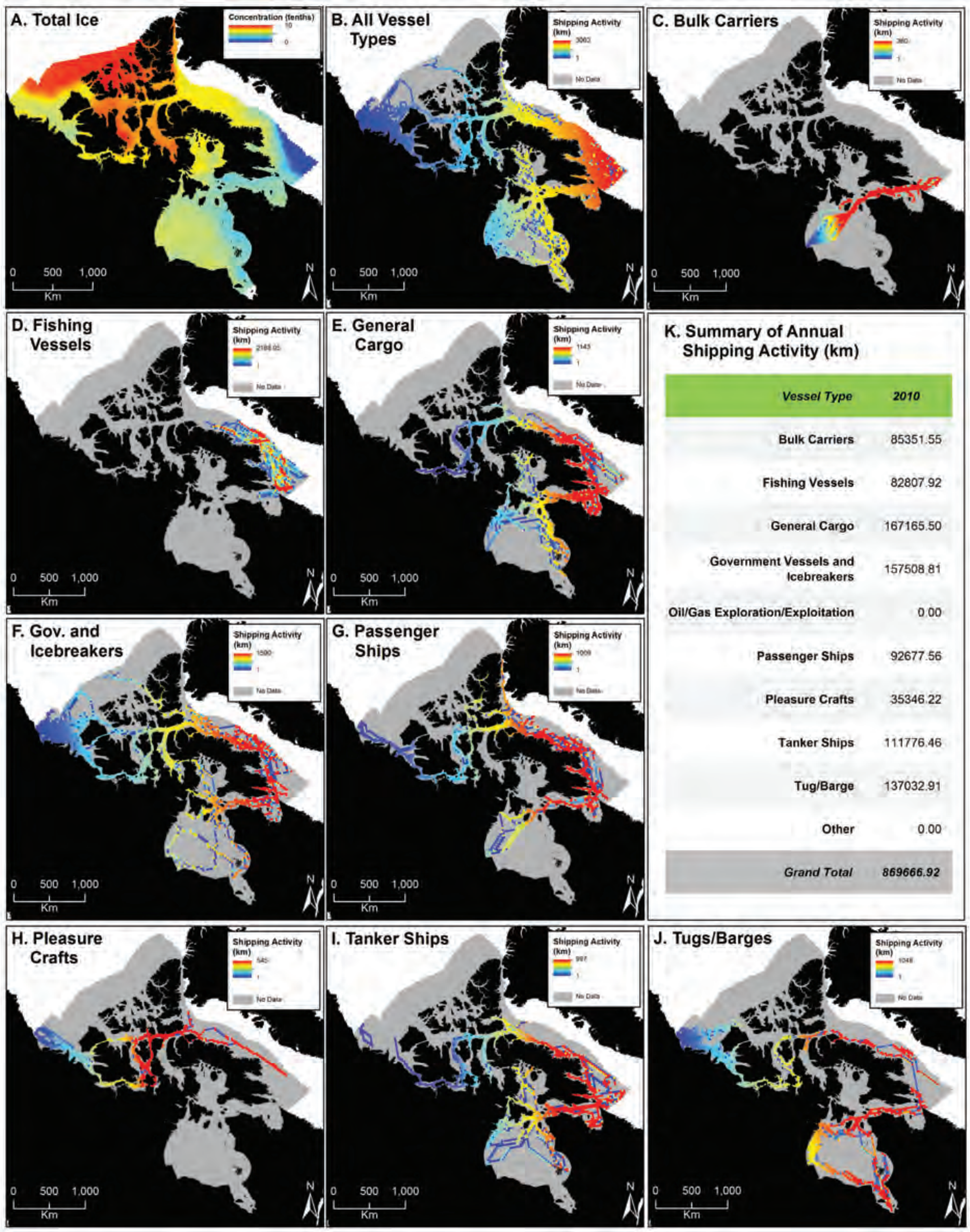
Shipping and sea ice distribution across the Canadian Arctic in 2008



Vessel Type	2009
Bulk Carriers	67514.68
Fishing Vessels	33318.75
General Cargo	125725.08
Government Vessels and Icebreakers	167995.78
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	63259.26
Pleasure Crafts	37521.58
Tanker Ships	76273.47
Tug/Barge	147094.46
Other	0.00
Grand Total	*718703.05*

Figure A20

Shipping and sea ice distribution across the Canadian Arctic in 2009

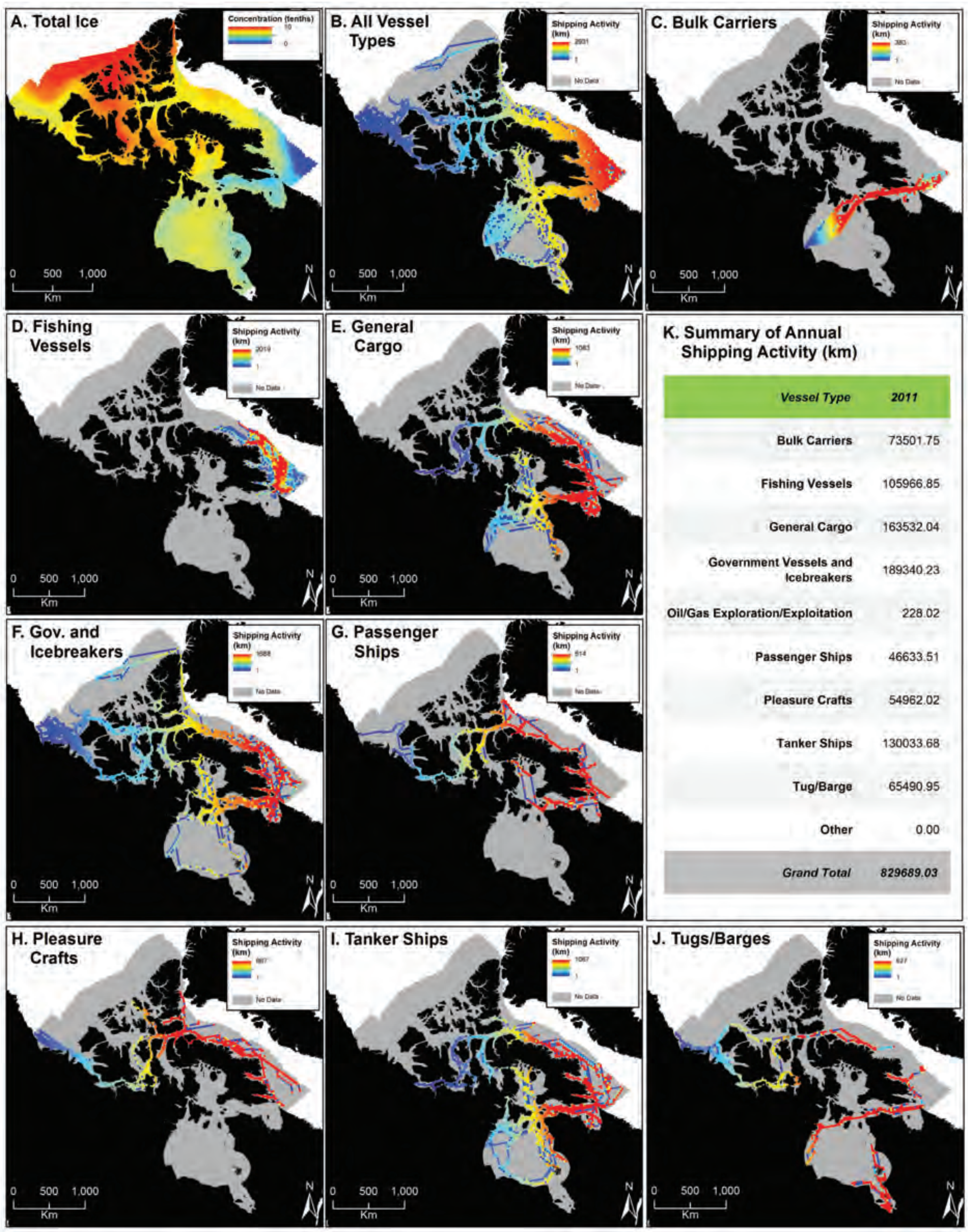


K. Summary of Annual Shipping Activity (km)

Vessel Type	2010
Bulk Carriers	85351.55
Fishing Vessels	82807.92
General Cargo	167165.50
Government Vessels and Icebreakers	157508.81
Oil/Gas Exploration/Exploitation	0.00
Passenger Ships	92677.56
Pleasure Crafts	35346.22
Tanker Ships	111776.46
Tug/Barge	137032.91
Other	0.00
Grand Total	*869666.92*

Figure A21

Shipping and sea ice distribution across the Canadian Arctic in 2010

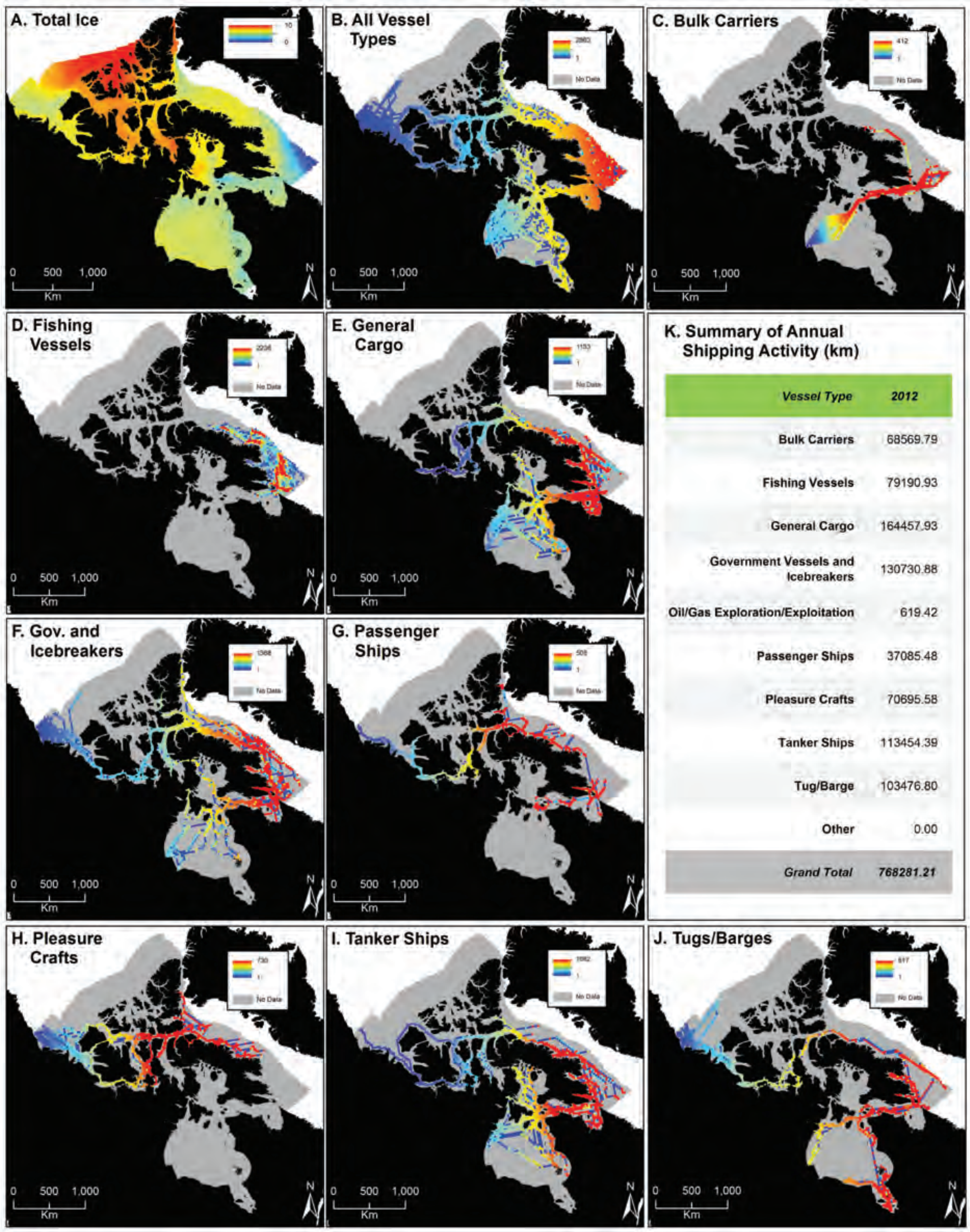


K. Summary of Annual Shipping Activity (km)

Vessel Type	*2011*
Bulk Carriers	73501.75
Fishing Vessels	105966.85
General Cargo	163532.04
Government Vessels and Icebreakers	189340.23
Oil/Gas Exploration/Exploitation	228.02
Passenger Ships	46633.51
Pleasure Crafts	54962.02
Tanker Ships	130033.68
Tug/Barge	65490.95
Other	0.00
Grand Total	*829689.03*

Figure A22

Shipping and sea ice distribution across the Canadian Arctic in 2011

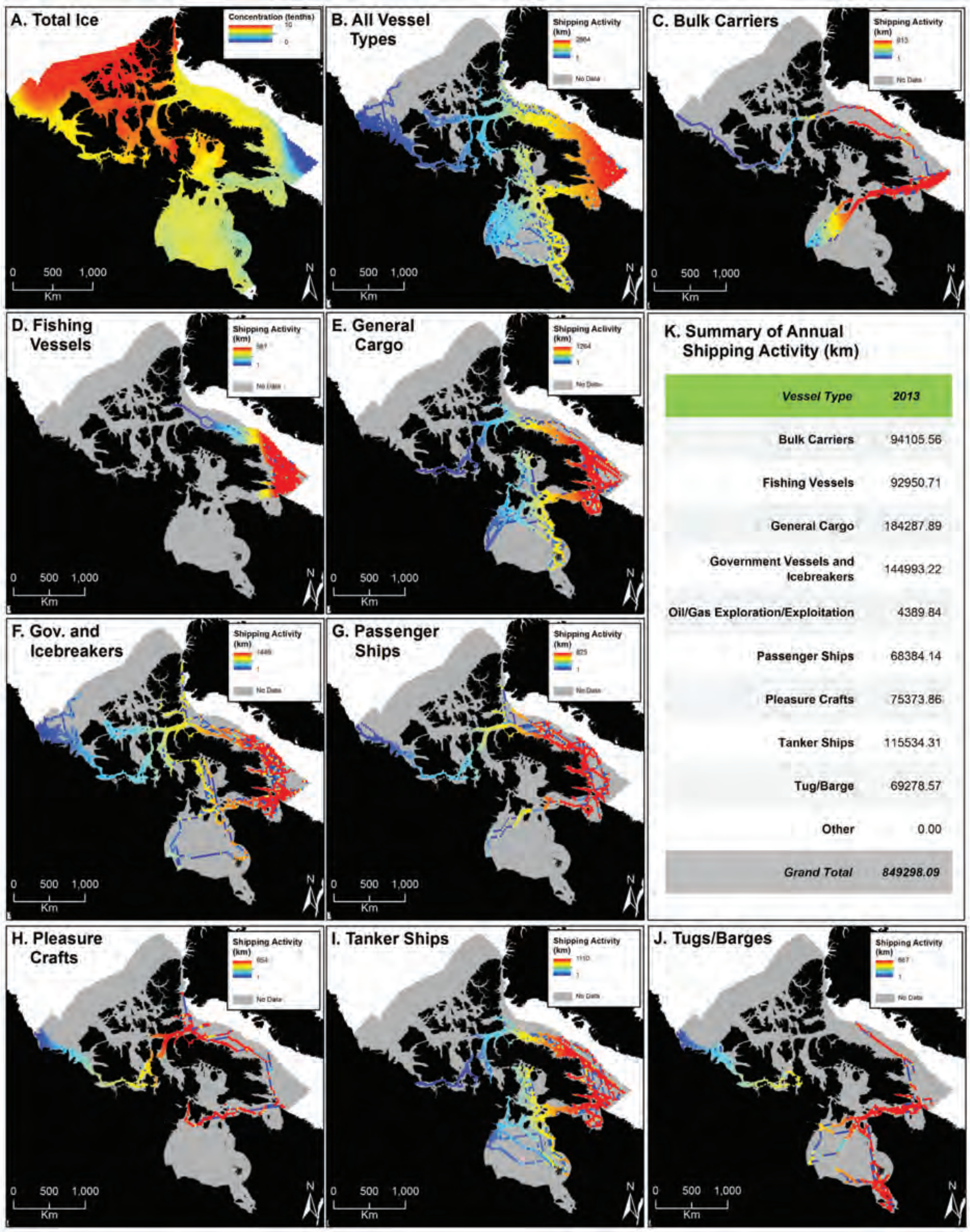


K. Summary of Annual Shipping Activity (km)

Vessel Type	*2012*
Bulk Carriers	68569.79
Fishing Vessels	79190.93
General Cargo	164457.93
Government Vessels and Icebreakers	130730.88
Oil/Gas Exploration/Exploitation	619.42
Passenger Ships	37085.48
Pleasure Crafts	70695.58
Tanker Ships	113454.39
Tug/Barge	103476.80
Other	0.00
Grand Total	*768281.21*

Figure A23

Shipping and sea ice distribution across the Canadian Arctic in 2012



Vessel Type	2013
Bulk Carriers	94105.56
Fishing Vessels	92950.71
General Cargo	184287.89
Government Vessels and Icebreakers	144993.22
Oil/Gas Exploration/Exploitation	4389.84
Passenger Ships	68384.14
Pleasure Crafts	75373.86
Tanker Ships	115534.31
Tug/Barge	69278.57
Other	0.00
Grand Total	*849298.09*

Figure A24

Shipping and sea ice distribution across the Canadian Arctic in 2013

Appendix B. Sea Ice Figures

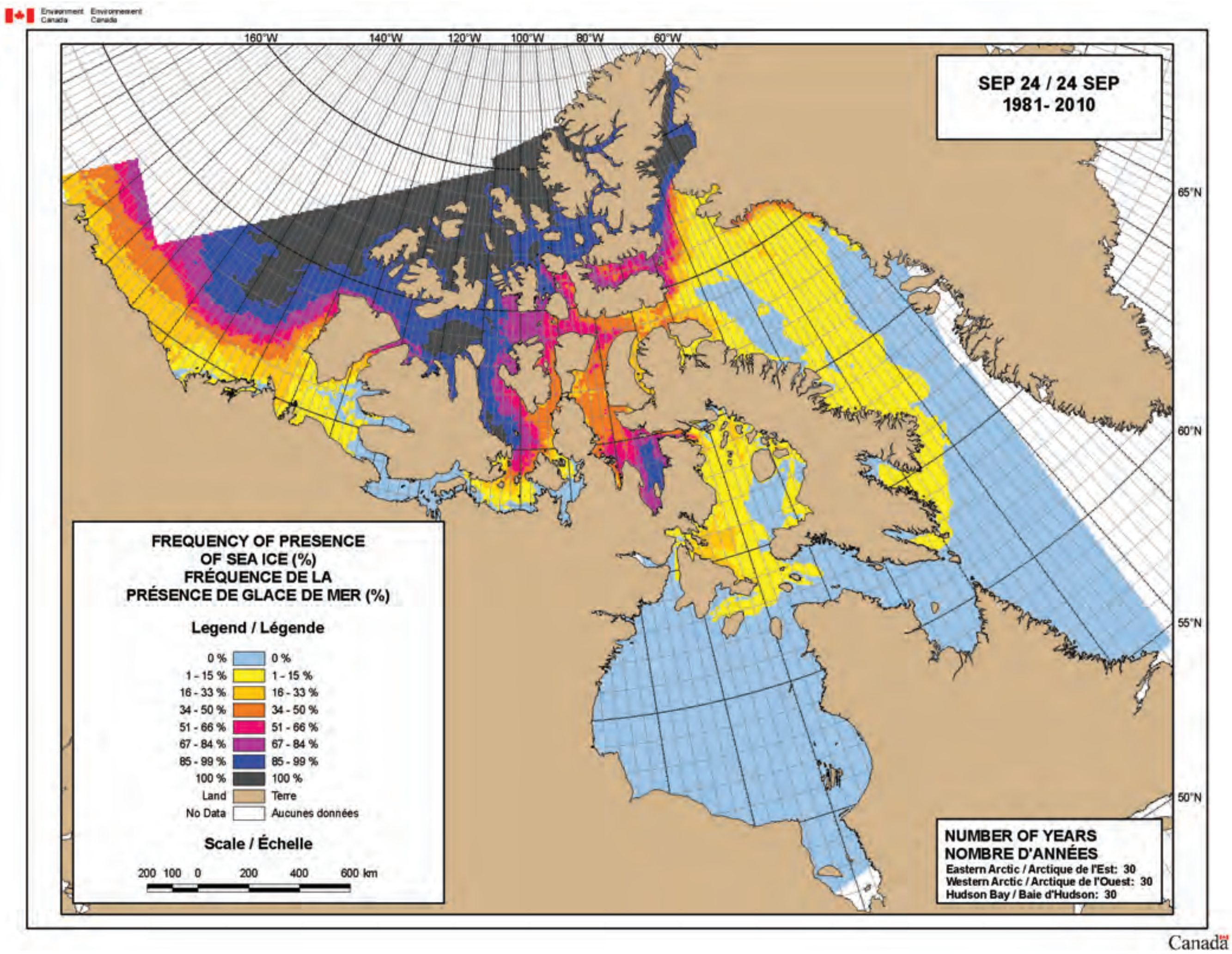
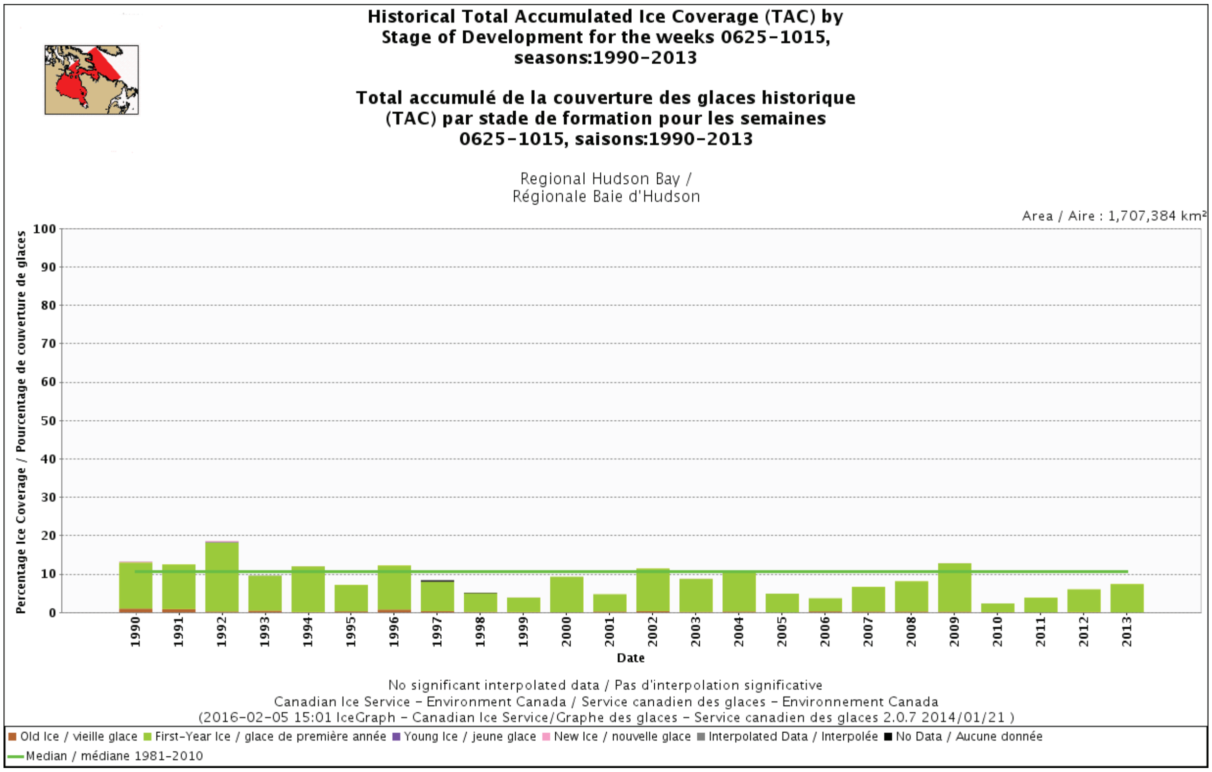


Figure B1

Average presence of sea ice across the Canadian Arctic, 1981–2010



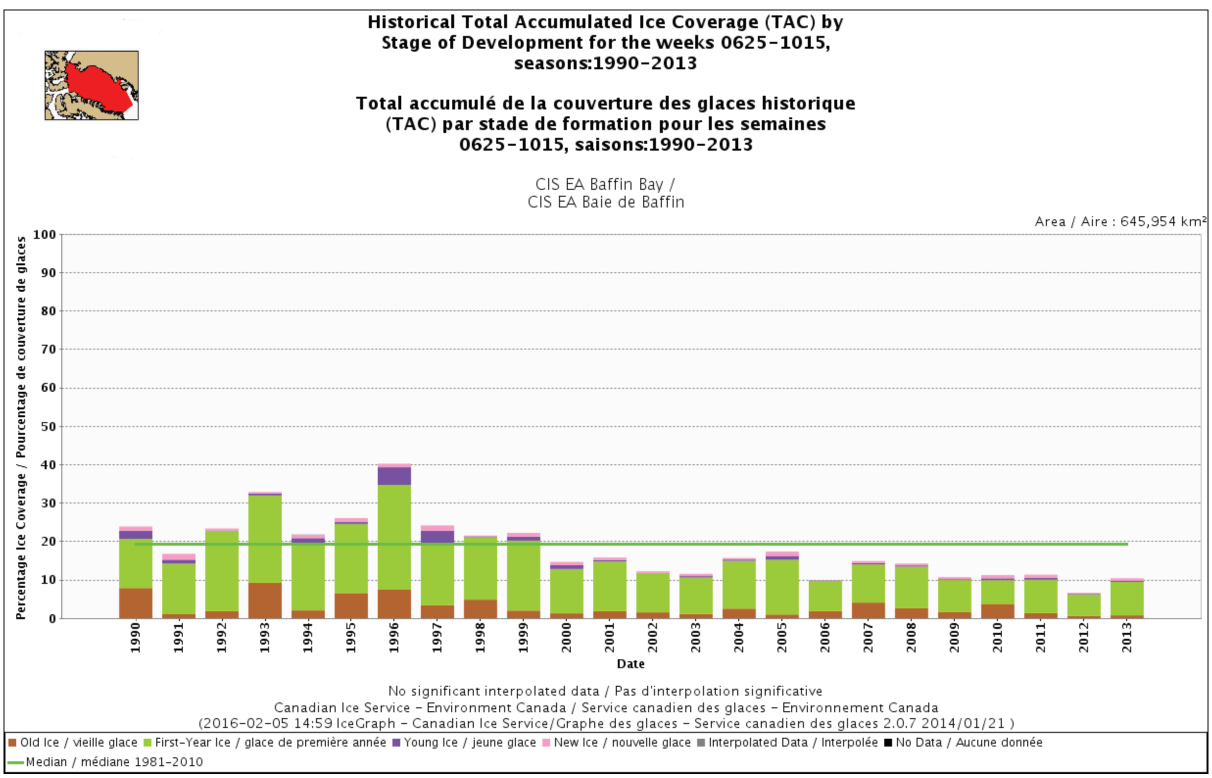
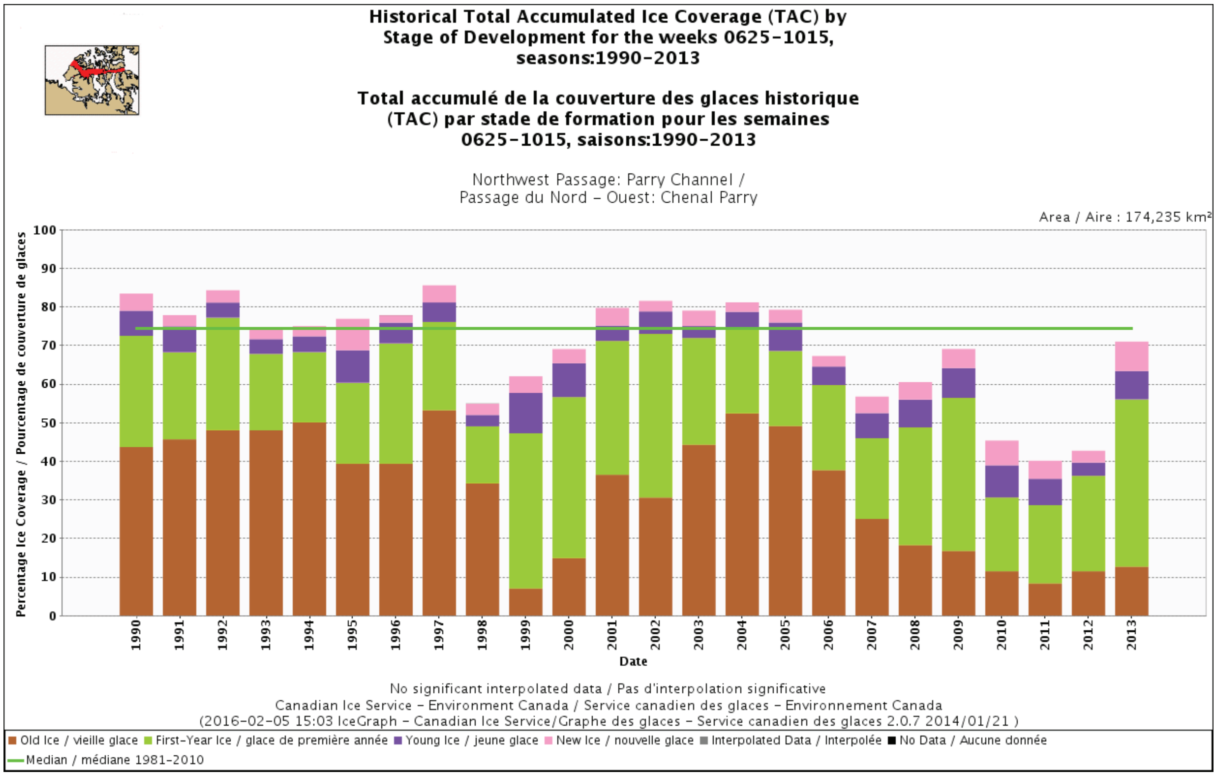


Figure B2

Total accumulated ice coverage, 1990–2013, for: (a) Hudson Bay, (b) Baffin Bay



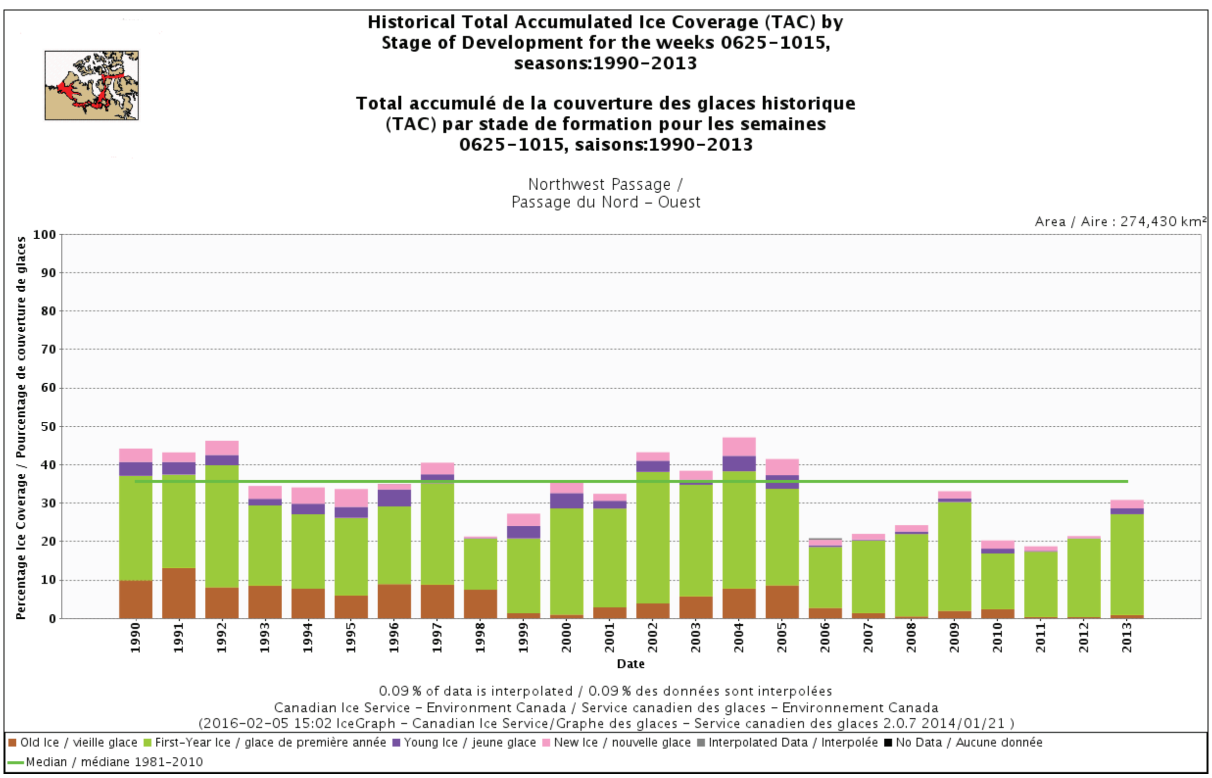


Figure B3

Total accumulated ice coverage, 1990–2013, for: (a) Northern Northwest Passage (N-NWP) route, (b) Southern Northwest Passage (S-NWP) route

Appendix C. Adaptation Strategies Implementation Timelines (range and median)

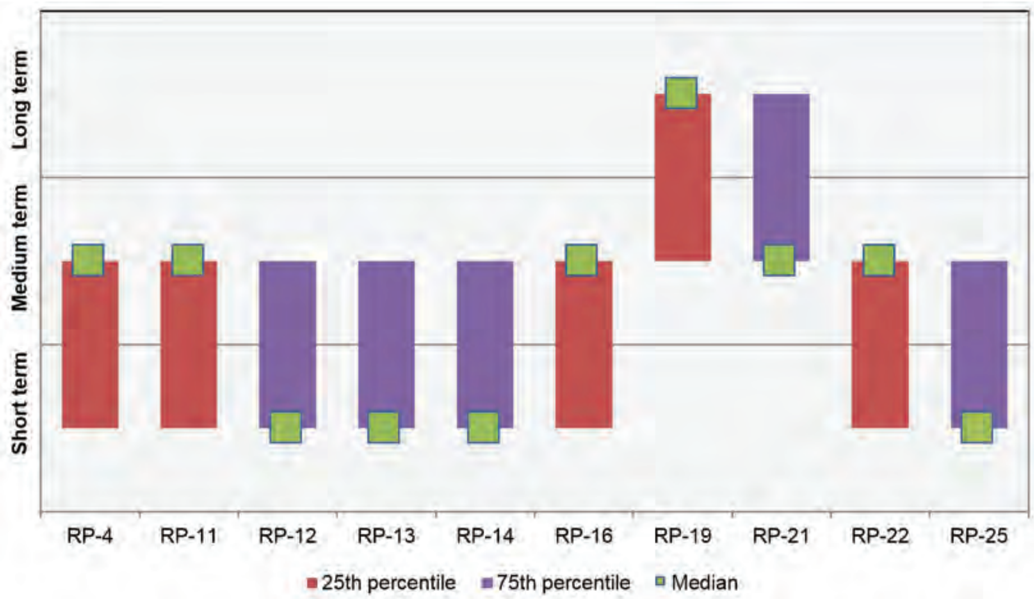


Figure C1

Recommended timeframe for implementation for regulation and policy strategies (interquartile range and median)

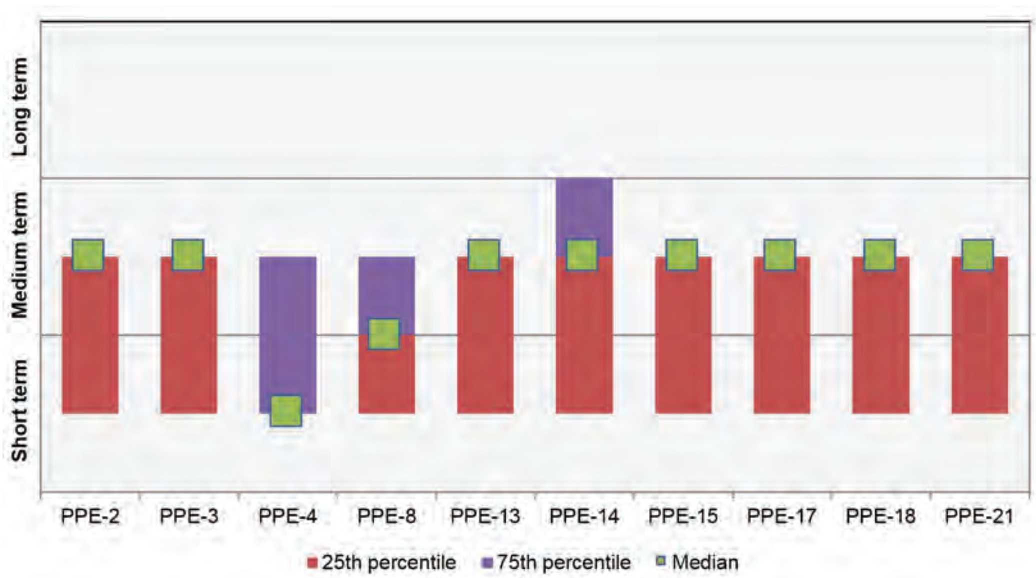


Figure C2

Recommended timeframe for implementation for planning, preparedness, and enforcement strategies (interquartile range and median)

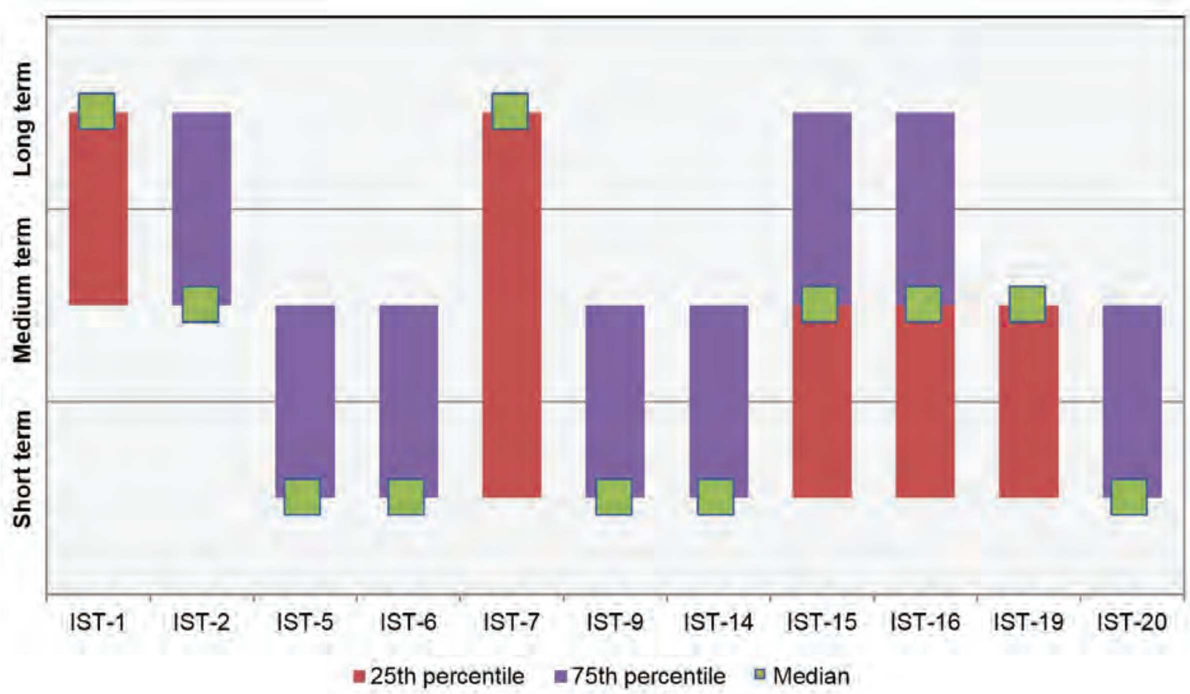


Figure C3

Recommended timeframe for implementation for infrastructure, services, and training (interquartile range and median)

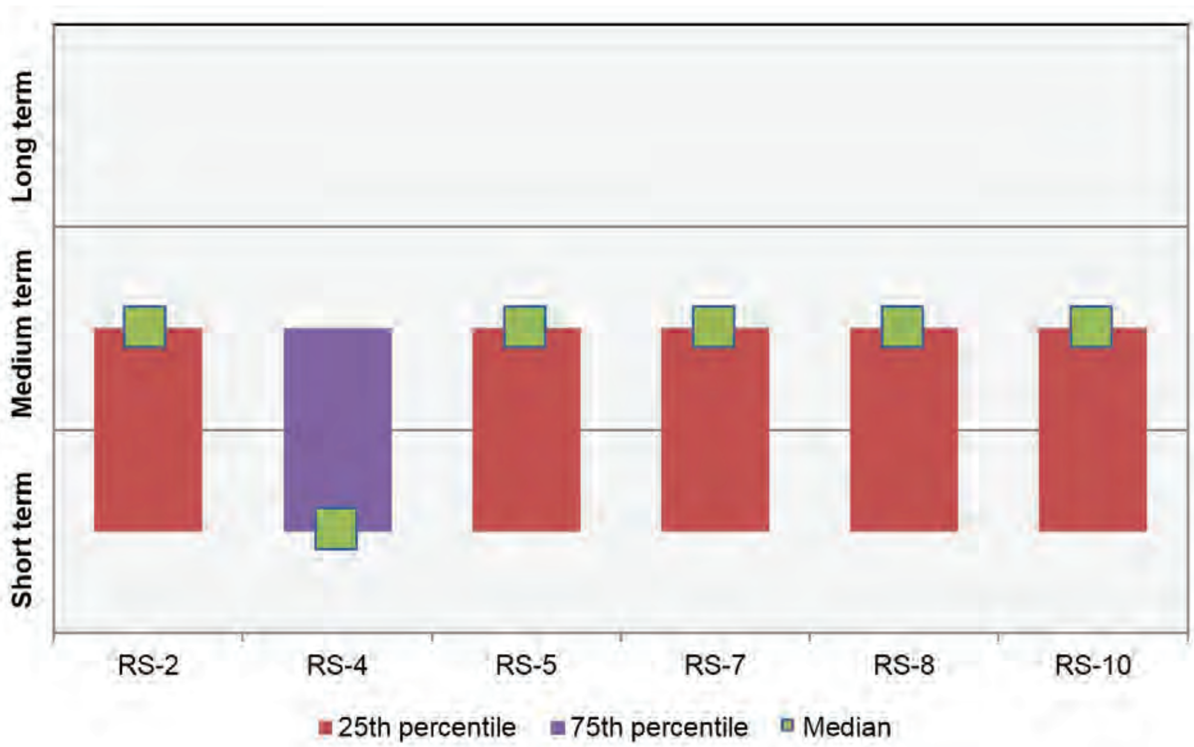


Figure C4

Recommended timeframe for implementation for research strategies (interquartile range and median)

Appendix D. Complete List of Ranked Adaptation Strategies

Table D1

Adaptation Strategies Ranked in Order (Equal Weight to Desirability and Feasibility)

Strategy code	Recommended adaptation strategy	Point of agreement	Consensus	Feasibility	Timescale	Rank
RP-25	Establish site guidelines for access to and use of sensitive tourism sites (i.e., protected areas, cultural heritage areas)	first-order priority	high	probably feasible	short term	1
RP-13	Require all vessels to report to Canadian Coast Guard (i.e., NORDREG) regardless of size	first-order priority	high	probably feasible	short term	1
RS-4	Improve understanding of Arctic indigenous marine use and the impact that increased shipping will have on local communities	first-order priority	high	probably feasible	short term	1
PPE-17	Establish partnerships and protocols with commercial ship operators to support equipment transport in case of a major spill	first-order priority	high	probably feasible	short to medium term	1
RS-10	Conduct a needs assessment for each community to determine minimum infrastructure needs for increased shipping activity (i.e., mooring bollards, dock cranes, discharge ramps, dock lighting, fences, breakwaters, marshalling areas, floating docks, community docks)	first-order priority	high	probably feasible	short to medium term	1
RP-4	Standardize the risk assessment criteria for obtaining insurance for ships operating in Arctic waters	first-order priority	high	probably feasible	short to medium term	1
PPE-8	Allow local RCMP to act as customs and immigration officers for Passenger Ships and Pleasure Craft (i.e., check passports)	first-order priority	high	probably feasible	short to medium term	1
IST-16	Install multi-beams on all Canadian Coast Guard (CCG) vessels to relay bathymetric information to the Canadian Hydrographic Service (CHS)	first-order priority	high	probably feasible	short to medium term	1
RS-2	Facilitate data sharing partnerships between government, academics, and other stakeholders to obtain and share real-time, standardized, meteorological, and oceanic data	first-order priority	high	probably feasible	medium term	1

PPE-2	Adapt the Northern Marine Transportation Corridors in consideration of sensitive ecological sites	first-order priority	high	probably feasible	medium term	1
PPE-3	Adapt the Northern Marine Transportation Corridors in consideration of sensitive cultural sites	first-order priority	high	probably feasible	medium term	1
RP-12	Develop an expedited decision-making and approvals process within Transport Canada's remit on go/non-go areas when the zone date and Arctic Ice Regime Shipping System (AIRSS) systems conflict or are not clear	first-order priority	medium	probably feasible	short term	2
RP-14	Maintain current reporting requirements to NORDREG and implement a voluntary tracking program for Pleasure Craft (i.e., sailboats, motor yachts) and local vessels	first-order priority	medium	probably feasible	short term	2
IST-9	Include future climate change and sea ice scenarios in the prioritization of icebreaking services during the shipping season	first-order priority	medium	probably feasible	short term	2
PPE-21	Build contingency plans into the Arctic pollution prevention certificate	first-order priority	medium	probably feasible	medium term	2
PPE-4	Establish an official intergovernmental Marine Transportation Strategy with an implementation plan	first-order priority	high	neutral	short term	3
IST-5	Keep the Northern Canadian Coast Guard offices open longer to reflect lengthening of shipping season	first-order priority	high	neutral	short term	3
IST-6	Provide additional icebreaking services in the shoulder seasons to reflect the lengthening shipping season	first-order priority	high	neutral	short term	3
IST-14	Establish additional capacity and resources for bathymetric charting	first-order priority	high	neutral	short term	3
IST-20	Establish a reliable method for relaying weather and ice information to vessels in order to address issues related to bandwidth, latitude, and black-out areas	first-order priority	high	neutral	short term	3
RP-22	Enhance the protection of identified ecologically sensitive areas that are now more accessible	first-order priority	high	neutral	short to medium term	3
PPE-14	Ensure spill response kits are placed along identified Northern Marine Transportation Corridors	first-order priority	high	neutral	short to medium term	3

RP-11	Extend the authority of Transport Canada so that it may restrict vessels from operating in unsafe or uncharted waters	first-order priority	high	neutral	short to medium term	3
PPE-13	Expand the Canadian Ranger program for search and rescue (SAR)	first-order priority	high	neutral	short to medium term	3
PPE-15	Develop a spill response and disaster risk management plan for each community and ensure that all communities have accessible spill response kits and proper training for their use	first-order priority	high	neutral	short to medium term	3
IST-19	Improve seasonal ice thickness and extent forecasting (e.g., provide real-time ice charts, improve forecasting of shear, pressured ice, and ridging zones)	first-order priority	high	neutral	short to medium term	3
RS-5	Develop a decision-support system to help navigators make sound decisions (e.g., when to proceed, when to take evasive action based on weather and ice data)	first-order priority	high	neutral	short to medium term	3
PPE-18	Create specific disaster management plans for the cruise tourism industry	first-order priority	high	neutral	medium term	3
RS-7	Dedicate specific resources to improve Arctic wind forecasts	first-order priority	high	neutral	medium term	3
RS-8	Increase weather and ocean current instrumentation and analysis (current meters, meteorological stations), especially near communities and on the Northern Marine Transportation Corridors	first-order priority	high	neutral	medium term	3
RP-21	Provide dedicated resources to enhance monitoring and enforcement for non-compliance with environmental regulations and shipping regulations (i.e., sewage, grey water, ballast discharge)	first-order priority	high	neutral	medium to long term	3
IST-2	Develop a system of small ports and safe harbours	first-order priority	high	neutral	medium to long term	3
RP-19	Include the Arctic as an emission control area to reduce harmful emissions (SOx, NOx, VOCs)	first-order priority	high	neutral	long term	3
RP-16	Require all vessels, regardless of size, to carry Automatic Identification System (AIS) transponders	first-order priority	medium	neutral	short to medium term	4
IST-15	Develop public-private partnerships for charting new areas	first-order priority	medium	neutral	short to medium term	4

IST-1	Develop at least one multi-purpose, deep-water port facility in the Arctic (dedicated area for repair, fuelling, supplies, search and rescue)	first-order priority	high	probably not feasible	long term	5
IST-7	Expand and upgrade the Canadian Coast Guard Arctic marine fleet	first-order priority	high	probably not feasible	long term	5
IST-21	Establish a formal mechanism for ice chart users to report back to the Canadian Ice Service (CIS) on ice conditions during a voyage and provide real-time positioning data (e.g., Twitter or other mechanism)	first- to second-order priority	high	probably feasible	short term	6
RP-10	Require an ice pilot or ice navigator for all vessels over 300 gross tonnes, including Government Vessels	first- to second-order priority	high	probably feasible	short to medium term	6
RS-9	Hire local Arctic weather observers for Environment Canada to record observational weather data	first- to second-order priority	high	probably feasible	short to medium term	6
PPE-19	Provide a free program to local vessels to borrow Emergency Position-Indicating Radio Beacon (EPIRB) equipment	first- to second-order priority	medium	probably feasible	short term	7
RS-6	Continue to fund the Network of Experts for Transportation in Arctic Waters (NEXTAW) (i.e., government working group)	first- to second-order priority	medium	probably feasible	short term	7
RP-23	Implement voluntary speed reductions in ecologically sensitive areas that are now becoming increasingly accessible	first- to second-order priority	medium	probably feasible	short to medium term	7
IST-25	Appoint a local marine transportation coordinator in each community (i.e., to provide a single point of contact for tourism, re-supply, fishing, or other vessels)	first- to second-order priority	medium	probably feasible	short to medium term	7
RS-11	Conduct a climate change assessment during the proposal stage of all new maritime infrastructure	first- to second-order priority	medium	probably feasible	short to medium term	7
RS-3	Develop a searchable database of all completed and ongoing Arctic Marine Transportation research	first- to second-order priority	medium	probably feasible	medium term	7
RP-15	Require that all smaller vessels be fitted with corner reflectors so they can be tracked by satellite radar	first- to second-order priority	low	probably feasible	short term	8

PPE-1	As part of the Northern Marine Transportation Corridors establish dedicated "tourism" corridors with east and west entry points	first- to second-order priority	low	probably feasible	medium term	8
IST-23	Provide training opportunities for industry to understand the Polar Operational Limit Assessment Risk Indexing System (POLARIS)	first- to second-order priority	low	probably feasible	medium term	8
PPE-9	Allow trained local residents to act as customs and immigration officers for Passenger Ships and Pleasure Craft (i.e., check passports)	first- to second-order priority	none	probably feasible	medium to long term	9
PPE-11	Incorporate climate change projections into the National Research Council's (NRC) Canadian Arctic Shipping Risk Assessment System (CASRAS)	first- to second-order priority	high	neutral	short to medium term	10
IST-24	Develop comprehensive information resources for tourism operators and adventurers that outlines regulations, standards, and expectations	first- to second-order priority	high	neutral	medium term	10
RS-1	Prioritize focused research on changing ice conditions and their implications for Arctic marine traffic	first- to second-order priority	high	neutral	medium term	10
IST-4	Re-institute the designated infrastructure fund for harbours to address effects of climate change	first- to second-order priority	high	neutral	medium to long term	10
RP-2	Establish a mandatory bond and/or insurance system to recover costs for search and rescue incidents and salvage	first- to second-order priority	high	neutral	medium term	10
RP-17	Require all vessels, regardless of size, to be equipped with Global Maritime Distress and Safety System (GMDSS) equipment when operating in Arctic waters	first- to second-order priority	medium	neutral	short to medium term	11
RP-18	Require that all personnel on a vessel carry an Emergency Position-Indicating Radio Beacon (EPIRB)	first- to second-order priority	medium	neutral	short to medium term	11
PPE-10	Establish a Transport Canada enforcement, verification, and audit team in the Arctic for the duration of the shipping season	first- to second-order priority	medium	neutral	short to medium term	11
IST-22	Establish/enhance northern education/training programs for: marine navigation, small business operation, search and rescue, oil spill response and recovery, emergency response, and tourism and hospitality	first- to second-order priority	medium	neutral	medium term	11

PPE-12	Implement "flexible" or "mobile" boundaries to Marine Protected Areas (MPAs) to account for changing climate and related biodiversity	first- to second-order priority	medium	neutral	medium term	11
IST-10	Establish mobile search and rescue (SAR) platforms on board re-supply vessels through partnerships between the Canadian Coast Guard (CCG) and industry	first- to second-order priority	medium	neutral	medium to long term	11
PPE-5	Establish an Arctic Port Authority	first- to second-order priority	medium	neutral	medium to long term	11
PPE-6	Establish a mechanism whereby Canada can implement port state control in the Arctic, without actually having an official Arctic port	first- to second-order priority	medium	neutral	medium to long term	11
PPE-16	Establish an Arctic coast oil response corporation (similar to what is on the east and west coasts)	first- to second-order priority	medium	neutral	medium to long term	11
IST-11	Establish small search and rescue (SAR) bases in all communities adjacent to key shipping routes (NMTC) (run and operated by local community members)	first- to second-order priority	medium	neutral	medium to long term	11
RP-3	Establish a user pay system to recover costs for search and rescue incidents and salvage	first- to second-order priority	low	neutral	medium to long term	12
IST-13	Require a minimum of one Tug stationed in the Arctic	first- to second-order priority	low	neutral	medium to long term	12
IST-17	Partner industry to install government supplied multi-beams to relay bathymetric information to the Canadian Hydrographic Service (CHS)	first- to second-order priority	low	neutral	medium to long term	12
RP-6	Charge a fee for icebreaking service requests	first- to second-order priority	none	neutral	medium to long term	13
RP-9	Require double hulled ships in the Arctic at all times	first- to second-order priority	low	probably not feasible	medium to long term	14
PPE-7	Restructure the Canadian Coast Guard to be under Transport Canada (as opposed to DFO) in order to enhance CCG's regulatory and enforcement authority	first- to second-order priority	none	probably not feasible	medium to long term	15

IST-18	Establish a system for commercial and private vessels to relay bathymetric information to CHS (e.g., establish a crowd-sourcing program)	second-order priority	medium	neutral	short to medium term	16
IST-12	Establish a minimum of three search and rescue (SAR) bases in the Canadian Arctic where military search and rescue (SAR) crews would be positioned	second-order priority	high	probably not feasible	medium to long term	17
RP-20	Ban the use of heavy fuel oils (HFOs) in Arctic Canada	second-order priority	high	probably not feasible	long term	17
RP-1	Update the zone/date system to reflect changes in ice conditions and improvements in accessibility	second- to third-order priority	low	probably feasible	short to medium term	18
IST-3	Establish mobile refuelling stations for ships UNDER a certain tonnage, such as Pleasure Craft and small commercial vessels	second- to third-order priority	low	neutral	medium to long term	19
IST-8	Maintain investment in the offshore patrol vessels	second- to third-order priority	low	neutral	medium to long term	19
RP-7	Charge a fee to all vessels for transiting the Northwest Passage	second- to third-order priority	none	neutral	medium to long term	20
RP-24	Establish and enforce strict noise level standards for vessels operating in the Canadian Arctic	second- to third-order priority	medium	probably not feasible	medium to long term	21
PPE-20	Provide subsidies to help Canadian vessels transition away from heavy fuel oils (HFOs)	second- to third-order priority	low	probably not feasible	medium to long term	22
RP-8	Implement a pay per use structure for Canadian Ice Service (CIS) ice charts	third-order to no priority	low	neutral	medium term	23
RP-5	Establish an insurance system for ships that is operated through the federal government (similar to car insurance in some provinces)	third-order to no priority	none	neutral	medium to long term	24