Northern marine transportation corridors: Creation and analysis of northern marine traffic routes in Canadian waters

René Chénier | Loretta Abado | Olivier Sabourin | Laurent Tardif

Canadian Hydrographic Service, Fisheries and Oceans Canada, Ottawa, Canada

Correspondence
René Chénier, Canadian Hydrographic Service, Fisheries and Oceans Canada, Ottawa, ON K1A 0E, Canada.
Email: rene.chenier@dfo-mpo.gc.ca

Abstract
The concept of the Northern Marine Transportation Corridors (NMTC) initiative was developed under the Government of Canada World-Class Tanker Safety System Initiative (WCTSS). The NMTC is an interdepartmental Arctic initiative within the Department of Fisheries and Oceans Canada (DFO), through the Canadian Coast Guard (CCG) and the Canadian Hydrographic Service (CHS), in collaboration with Transport Canada (TC). The NMTC initiative was developed to strengthen the safety of marine navigation in the Arctic, and to offer an efficient planning guide for present and future Arctic investments. Transportation corridors identified through this initiative will provide the Government of Canada the framework needed to better prioritize and deliver on its programs and services, including: nautical charts and products; aids to navigation; ice-breaking services; and marine safety regulations. The corridors were generated and analyzed with a Geographic Information System (GIS) using two main data sources: the Automated Identification System (AIS) and CHS’s nautical charts and publications. The geographic extent of the NMTC is defined as the Northern Canada Vessel Traffic Service Zone (NORDREG Zone) and the Mackenzie River. With close to 4 million km² of water in the Arctic and 162,000 km of coastline, surveying the Arctic to modern standards represents an enormous challenge to CHS. By adopting a corridor-based approach, CHS and other government programs can prioritize their efforts on 12% of the Canadian Arctic waters. CHS currently has 32% of the NMTC adequately surveyed, with an additional 3% surveyed to modern standards.

1 | INTRODUCTION

In 2014, the Government of Canada announced that they would be strengthening Canada’s already robust tanker safety system by adding measures to reinforce marine oil spill prevention, preparedness and response, as well as

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2017 The Authors. Transactions in GIS published by John Wiley & Sons Ltd.
liability and compensation, through its World-Class Tanker Safety System Initiative (WCTSS). The Canadian Hydrographic Service (CHS), a sector within the Department of Fisheries and Oceans Canada (DFO), was tasked with contributing to this effort. CHS’s mandate includes the collection of data to support the creation of navigational products in Canadian waters to ensure safe, sustainable, and navigable use. In collaboration with the Canadian Coast Guard (CCG) and Transport Canada (TC), an approach to integrate a series of geospatial information in support of the WCTSS Expert Panel for North of 60° was devised, resulting in the Northern Marine Transportation Corridors (NMTC) initiative. The primary goals of the NMTC include the following: strengthening marine navigation safety in the Arctic through the provision of safer navigation routes within the Northern Canada Vessel Traffic Service (NORDREG) Zone; to act as a planning guide for present and future government Arctic investments; reducing the risk of oil and hazardous substances spills; enhanced protection of ecologically and biologically significant areas; encouraging economic development; and to support the Northern community resupply efforts.

This article focuses on the approach, methodology, data, and main drivers used to create the NMTC and highlights the advantages for CHS in having a corridors-based approach for prioritizing its efforts in the Arctic.

In accordance with CHS’s mandate and national agreements (e.g. International Convention on the Safety of Life at Sea-SOLAS), it is expected that the NMTC will be of great benefit for long-term planning and chart prioritization.

SOLAS Chapter V includes a requirement for all ships to carry up-to-date nautical charts and publications for the intended voyage (International Hydrographic Bureau, 2010). For certain classes of vessels, the use of an Electronic Chart Display and Information System (ECDIS) with appropriate navigational charts issued by members of the International Hydrographic Organization (IHO) is required.

Even if CHS charts and products provided coverage for all of the NORDREG Zone, some of the areas on these charts either contain no depth information (unsurveyed areas), or sparse information that was collected with techniques that predate the more advanced and more accurate technologies available to CHS today. The NMTC corridors are the key to offering enhanced services to the Northern communities in Canada and industries North of 60°. Focusing on the corridors will assist the Government of Canada in matters of the safety of mariners, in addition to supporting the Canadian economy in the Arctic and protection of the environment. The NMTC will help fulfill the Tanker Safety Expert Panel statement of finding “opportunities to enhance Canada’s prevention, preparedness and response requirements for the Arctic and hazardous and noxious substances to better protect the public and our environment” (Tanker Safety Expert Panel, 2014).

2 | AREA OF INTEREST

The objective of creating the NMTC is to provide mariners and interested parties with marine transportation routes within the NORDREG Zone. This zone represents Canadian waters North of 60°, extending to Hudson Bay, James Bay, Ungava Bay, Foxe Basin, Hudson Strait, and the Mackenzie River system (from Hay River to Beaufort Sea) (Figure 1). Approximately 47% of the NORDREG Zone is underwater, with 3.7 million km² of underwater features, and more than 162,000 km of coastline including the Mackenzie River system. To pinpoint areas of interest in such a large area, the creation of the NMTC was conducted from a mariner’s point of view, through the use of an information inventory, or data atlas, managed by CHS (Table 1).

3 | METHODOLOGY

With a large range of information available to the initiative, CHS, in collaboration with CCG and TC, were able to better define what would constitute a corridor. A corridor is an area that contains “a measurable amount of diverse marine transportation information and services in support of economic development, community resupply, safety of navigation, and protection of the environment” (Leyzack, Chenier, & Hinds, 2014). The NMTC are categorized in five classes, allowing for better distinction and analysis between traffic types and activities
within these classes. The corridors were divided according to a hierarchical ranking system, as follows (Table 2):
Main Corridor (Primary); Approach Corridor (Secondary); Refuge Corridor (Tertiary); Private Interest Corridor (Quaternary); and Projected Corridor (Quinary).

TABLE 1 GIS data inventory collected by CHS

| Source | Data Inventory |
|--------|----------------|
| Canadian Hydrographic Service (CHS) | - Paper Charts  
- ENCs  
- CATZOC Bathymetry Database  
- Surveyed Pecked Lines  
- Anchorage Areas  
- Canadian Ports and Port Tonnage  
- Places of Refuge  
- AIS Traffic Pings |
| Transport Canada (TC) | - NORDREG Zone  
- Ice Concentration (with CIS, EC)  
- Risk of Grounding Matrix—Hydrographic Priority Zones  
- Canadian Ports and Port Tonnage  
- Places of Refuge  
- AIS Traffic Pings |
| Department of National Defense and the Canadian Armed Forces (DND) | - North Warning System  
- Traditional Knowledge (Biodiversity and Marine Mammal Habitat Zones) |
| Canadian Ice Service (CIS) | - Traditional Knowledge (DFO Ecosystems and Habitat Management)  
- Marine Protected Areas and Areas of Interest  
- Ecologically and Biologically Significant Marine Areas |
| Parks Canada Agency | - Protected Areas (National Parks and National Marine Conservation Areas) |
| Canadian Coast Guard (CCG) | - Navigational Services (Aids to Navigation)  
- NORDREG Zone  
- Ice Concentration (with CIS, EC)  
- Risk of Grounding Matrix—Hydrographic Priority Zones  
- Marine Protected Areas and Areas of Interest  
- Ecologically and Biologically Significant Marine Areas |
| Department of Fisheries and Oceans Canada (DFO) | - Small Craft Harbor Ports  
- Traditional Knowledge (DFO Ecosystems and Habitat Management)  
- Marine Protected Areas and Areas of Interest  
- Ecologically and Biologically Significant Marine Areas |
| Natural Resources Canada (NRCan) | - Populated Places  
- Mines, Minerals, and Metals  
- Projected Mines  
- Oil and Gas Developments  
- Oil and Gas Licenses |
| Hunters and Trappers Organizations in Nunavut (HTO) | - Traditional Knowledge (Biodiversity and Marine Mammal Habitat Zones) |
| Environment Canada (EC) | - Ice Concentration  
- Protected Areas (Wildlife Areas and Migratory Bird Sanctuaries) |
| General Bathymetric Chart of the Ocean (GEBCO) | - Depth Contours\(^a\) |

Note. All input datasets were taken into consideration while creating the NMTC.

\(^a\)For calculating statistics only.
With the classes of the corridors defined, CHS was able to begin the task of digitizing these corridors with the information inventory collected in the preliminary stages of the initiative (Table 1).

3.1 | Metadata

The input factors are modeled and created in an Esri ArcGIS environment, with the metadata for each layer compliant with ISO 19115: Geographic Information Metadata format. Metadata is used by CHS to ensure data quality as well as to manage datasets created and downloaded by CHS. The metadata, if filled out to ISO 19115 standards, will have information about the source and date, as well as descriptive information, for the resource in question. CHS uses a program called jNAPMetaWriter, which was developed within the DFO and is used internally to ensure best practice with regard to metadata use.

3.2 | Main drivers: AIS data and CHS products

The AIS pings and the CHS paper and digital charts (Electronic Navigational Charts [ENCs] and BSBs) were the primary drivers in the creation of the NMTC. AIS pings are the most efficient way of tracking and positioning vessels in Canadian waters. Each AIS-equipped vessel in Canadian waters broadcasts with a tracking system, which creates a “ping,” or a pinpoint, for its location within the database. Positions are broadcast frequently, approximately every 2–10 s depending on the vessel’s speed, or every 3 min if at anchor (International Telecommunications Union, 2014). Unfortunately, there are no active ground AIS stations to collect data at higher precision in the Canadian Arctic; therefore, the position cannot be acquired at this frequency. Even if there were ground AIS stations in the Arctic, shipboard AIS transceivers are limited to a horizontal range of around 75 km. Therefore, AIS reception in the Canadian Arctic relies solely on satellite AIS (SAT-AIS) (Figure 2). The exactEarth constellation of satellites orbits at approximately 650 km over the Earth’s surface. The satellites’ field of view is nearly 5,000 km in diameter, and they gather AIS transmissions from all vessels within that field of view (Marine Traffic, 2015). Although AIS pings in Arctic waters are not as accurate or frequent, due to the large distances between ships and satellites, and the absence of AIS antenna receivers in the Canadian Arctic, this is still the most efficient measure for tracking vessels (Larsen et al., 2012). The launch of new satellites from the two major AIS constellations, exactEarth and ORBCOMM, as well as the addition of new satellites such as the RADARSAT Constellation Mission (RCM) and the recent launch of M3MSat, will increase the density of the pings, allowing for better monitoring of vessel traffic patterns (Canadian Space Agency, 2015; exactEarth, 2016; Parsons, Youden, & Fowler, 2013; RCM, 2015). While CHS used AIS pings as a main approach for digitizing corridors, the inaccuracies and limitations of AIS pings must be acknowledged. It is stated that “47% of ships displayed incorrect length and 18% of them...
displayed incorrect beam in their AIS information (Harati-Mokhtari, Wall, Brooks, & Wang, 2007). Each ping within the database contains pieces of information that allow for easy understanding of the type of ship identified (e.g., tanker, cargo, passenger, etc.), as well as the Maritime Mobile Service Identity (MMSI), which allows access to additional information to decide if a corridor is needed in the area (Gunnar Aarsaether & Moan, 2009; Ou & Zhu, 2008). The four main traffic vessels used for analysis were tankers, hazardous ships, passenger ships, and cargo ships. CHS compiled AIS traffic pings from 2010 to present. There is an average of 14 million AIS pings collected globally each day with exactEarth satellites. The data is collected, cleaned, processed, and used to create traffic tracks for analysis. Although the traffic tracks are not fully representative of a ship’s path, they provide a generalization which simplifies the identification of shipping patterns (Figures 3a and 4d).

Owing to the limitations of AIS data in the Arctic, it is not accurate enough to define precise passageways on its own (Figure 3a). The analysis of CHS products is the most efficient way to adapt a mariner’s mentality when developing corridors, as a large range of marine navigational information is embedded in these products, such as anchorage areas, alignment lights, and marine protected areas. Any factor which may affect marine navigation within the corridors was considered during the digitization process. Therefore, the use of CHS charts (paper charts and ENCs) and publications was essential in identifying safe routes through high-risk areas. By using aids to navigation, anchorage areas, water depths, and shoals mapped on the charts, CHS was able to refine the corridors to a more realistic view of current traffic patterns (Figure 3b). Data shown within the pecked lines are more complete and accurate than for areas outside the pecked lines (see Figures 3c and d). Mariners will typically take the route that has the highest Zone of Confidence (ZOC) level, in turn reducing the risk to navigation. Refining the corridors with the use of the pecked magenta or pecked gray lines (Leyzack et al., 2014) provides a more logical approach in comparison to placing a corridor in a zone with poor or no survey data.

3.3 Category of zone of confidence (CATZOC)

Another prominent factor used in the NMTC was the Category of Zone of Confidence (CATZOC), which is the standard for assessing surveying done in water (Anonymous, n.d.). CATZOC was developed “to provide a simple and logical means of classifying all bathymetric data and displaying to the mariners the confidence that a national charting authority places it in” (Johnson, 2004) (see Figure 4a). For CHS’s criteria, CATZOC A1 and CATZOC A2 are required for critical depths of 0–50 m. CATZOC A1 and CATZOC A2 are the highest quality of surveys, using multibeam echo sounders. CATZOC C has the lowest confidence approach of surveying data, and is only acceptable in deep waters (International Hydrographic Bureau, 2008). As navigating through unsurveyed areas presents multiple risks, analyzing CATZOC coverage and AIS pings was imperative. As stated, critical depths of 0–50 m require CATZOC A standards, hence the reliance on accurate depth data is important. There
are some cases where ships are traveling through routes that are not optimal, because there is a cap on survey/CATZOC data.

3.4 | Remote sensing

The use of satellite imagery, such as Google Earth Pro and acquired Landsat imagery, was vital while digitizing the approach corridors to ports and communities in the North. To ensure the safest passage for mariners to travel to their destinations, satellite imagery, especially in critical depth areas, was used for the creation of the NMTC. Under a Government Related Initiatives Program (GRIP) with the Canadian Space Agency, CHS is looking at remote sensing data to optimize shipping routes (Chenier, Faucher, Ahola, Jiao, & Tardif, 2016). Optimizing these routes will not only be more efficient for the shipping industry, but also reduce the response time for search and rescue and oil spill management missions. Ships are currently following the magenta pecked lines (Figures 3c and d), which are what CHS deems to be
the safest routes—but not necessarily optimized routes—and this is where remote sensing can be used to investigate alternative routes.

3.5 Environmental drivers

Environmental information was considered while digitizing the NMTC. Protected areas defined by Environment Canada, Parks Canada, and the DFO were used in order to minimize the impact of shipping in the Arctic environment (see Figure 5).

Layers such as cultural and traditional knowledge were not used directly to digitize the corridors, but are integrated as layers in the GIS tool to ensure that this valuable information is used in engagements and consultations with the Northern communities. Traditional knowledge and cultural knowledge from the Northern communities provide valuable insights into the little-known marine biology and human activity within the Canadian Arctic. To better understand the impacts of shipping routes on human activities, ecosystems, and maritime mammals in the Canadian Arctic, the corridors in conjunction with traditional and cultural knowledge are vital. Ecologically and Biologically Significant
Areas (EBSAs) contain important information on species in Canadian waters, but have a limitation as the dataset is split into large geographic zones. The dataset does not have an environmental sensitivity index, and does not contain temporal information in relation to where species are present year round. These pieces of information attached to the EBSAs and traditional knowledge zones would be of value to apply regulations or to prioritize services in the corridors.

The use of traditional knowledge, as well as EBSAs, can aid in creating safer marine traffic routes. The organizations can further plan and identify where there is a need for a deeper analysis of highly ecologically or biologically significant areas. "The identification of EBSAs is not a strategy for protecting habitats or communities, rather it is a tool for calling attention to areas that have particularly high ecological or biological significant" (Hartwig, 2009). Traditional knowledge was gathered and refined using three workshops to identify EBSA zones with Northern Canadian communities. Traditional knowledge, though it has its limitations, can be used, with an ongoing engagement and collaboration with the communities, to refine the geographic areas, and leads to better decision making for the areas of importance (Cobb, 2011; DFO, 2011). Hartwig (2009) noted that the integration of traditional knowledge alongside scientific knowledge shows the benefits that each can provide when identifying zones of high ecological and biological importance. The NMTC can offer these communities the knowledge of where vessels are traveling in the Arctic waterways, providing more refined zones of ecologically and biologically significant areas.

### 3.6 Ice data

The Arctic has a limited amount of activity year round, restricted by sea ice conditions, although there is a positive trend in terms of the number of voyages in the NORDREG Zone in Canada’s North (Table 3). Owing to receding ice (Tivy et al., 2011), improvements in vessel construction, technology, growing communities, and industrial demand “have resulted in resupply vessels operating in the North a little longer each year, often starting in June and ending in November” (Tanker Safety Expert Panel, 2014). As a result of the unpredictability of ice concentration in the Canadian Arctic and in ice concentration models, there is no real measure of when there will be less ice to travel through in the Arctic waters (Partial Opening of the Northwest Passage, 2015). Ice conditions typically restrict ship activity, therefore limiting access to

---

**FIGURE 5** Protected areas around Baffin Island in the Canadian Arctic were taken into consideration while digitizing the NMTC. This is an example of three major protected areas in the Canadian Arctic, and the corridors avoiding these areas.
corridors while ice is present (Higginbotham, Charron, & Manicom, 2012). CHS follows the AIS pings, but also takes into consideration the average ice concentration from 1981 to 2010, to enhance knowledge and analyze where the corridors should be digitized on a yearly basis. By using ice concentration data, CHS is also able to digitize accordingly, resulting in corridors being wider in zones where ice is prominent, allowing mariners a wider corridor for navigation.

3.7 | Other drivers

One point of interest is areas that have little or no bathymetric information from CHS (provided either by CHS paper charts or ENCs). For areas lacking bathymetry information, General Bathymetric Charts of the Oceans (GEBCO) information was used (Figure 4b). The North Warning System (National Defence) and Populated Places (Natural Resources Canada) datasets were used to show areas that corridors should cater to for community resupply, places of refuge, and cultural or socioeconomic reasons (Figure 4c). Oil and gas licenses for proposed projects in Canada’s North were created by Indigenous and Northern Affairs Canada (INAC). This data was used to create the final class of the NMTC, projected corridors. These are areas which may contain higher traffic volume in the future, due to increased oil and gas development. The NMTC, as well as anchorage areas, are also significant in emergency situations, as they are used as a route to places of refuge in times of crisis.

4 | RESULTS AND DISCUSSION

4.1 | Traffic trends

With the use of a GIS (Esri ArcGIS Suite), corridors were created to better represent the traffic flow and patterns within the Canadian Arctic (Figure 1). Based on traffic volume from the AIS data, the main corridors can be grouped into two passages: the Northwest Passage (NWP) and the Arctic Bridge. The NWP (Figure 1, depicted as 1) has three main routes: Prince Regent Inlet (Figure 1, depicted as 1a), Peel Sound (Figure 1, depicted as 1b), and Prince of Wales Strait (Figure 1, depicted as 1c); although the majority of the NWP traffic is transiting through Prince Regent Inlet. The Canadian portion of the Arctic Bridge (Figure 1, depicted as 2) is the main corridor passing through Hudson Strait and going to Churchill, Manitoba (Figure 1, depicted as 2a), with an extension leading to Baker Lake and Rankin Inlet (Figure 1, depicted as 2b). It can be noted that approximately 80% of vessels traveling in the NORDREG Zone are traveling within the NMTC, and 90% are traveling within a 5 nautical mile radius of the corridors (based on 2012–2014 AIS traffic pings). There is a common trend of increasing traffic within the NORDREG Zone, as shown in Figure 2. The voyage count tripled from 1990 to 2014, with approximately 100 voyages in 1990 and 300 in 2014. The voyage count was steady from 1990 to 2006; from 2006 to 2014 there is a large increase in voyage count.

4.2 | Application of NMTC in strategic planning

In March 2016, the NMTC initiative was reinforced by the joint statement signed by Prime Minister Justin Trudeau and U.S. President Barack Obama, which committed to ensuring that shipping corridors will be developed as low-
impact corridors, meaning that they have as little impact as possible on the environment. It has also planned to protect at least 17% of land areas and 10% of marine areas by 2020 (Fitzpatrick, 2016). From the Canadian Budget 2017 (Government of Canada, 2017), under the Oceans Protection Plan, the Canadian government announced an important investment of $1.5 billion that will be used to improve marine safety, support responsible shipping, protect Canada’s marine environment, and create stronger partnerships with indigenous and coastal communities. TC, CCG, and CHS have been heavily involved in community engagement, with sessions in Iqaluit, Yellowknife, Montreal, Ottawa, and St. John’s. Ensuring safe navigation in polar waters and the protection of the environment aligns with Canada’s involvement in the International Code for Ships Operating in Polar Waters and the UN’s Convention on the Law of the Sea.

With these new investments and governmental priorities, the NMTC initiative will be an important framework for future projects in the Canadian Arctic. The corridors have currently been shared with different Canadian government agencies, private industries, and universities for different studies. As an example, the Geography Department of the University of Ottawa has been using the corridors for gathering more cultural information in the Canadian Arctic. The National Wildlife Research Centre, a branch of Environment Canada, will be using the corridors to enhance their Coastal Oil Spill Risk Assessment, and the data created can in turn help with the corridors initiative. As an example, if an area is defined to be more prone to an oil spill, then TC, CCG, and CHS can give priority to those areas and ensure that the proper mitigating measures are put in place to avoid as far as possible the risk of oil spills in those areas or to minimize the overlap of traffic in those areas.

Currently, the corridors cover approximately 451,000 km² out of the 3,749,596 km² of water surface in the NORDREG Zone, which represents 12% of the Canadian Arctic waters (Table 3). The corridors are not intended to be the only areas where ships can travel, but rather to support the Canadian government with optimizing and prioritizing the delivery of its programs in these navigationally significant areas. The NMTC illustrates where traffic is currently going, with the exception of the projected corridors, which only represent 0.4% of the corridors (Table 3). No corridors were drawn in the Mackenzie River since it is a very dynamic, narrow channel, due to sediment deposition and erosion. In this area CHS is using remote sensing data, mainly RADARSAT-2 and Landsat (Chenier & Hemmingway, 2014) to chart changes.

Only 10% of the Arctic waters are currently surveyed adequately, with a mere 1% surveyed to modern standards. Subsequently, surveying the full Arctic with modern surveys is not possible as of now. By adopting a corridor-based approach to prioritize areas to be surveyed and charted, CHS can prioritize its efforts on 12% of the Canadian Arctic waters. Currently, 32% of the NMTC are surveyed adequately, with an additional 3% of them surveyed to modern standards (see Table 1 for more information) (Chenier, Abado, Sabourin, & Tardif, 2016). The remaining 65% of the NMTC that requires surveying still remains an important challenge for CHS, as it represent an area of 293,000 km². Given the ice conditions, remoteness, and short window of surveying opportunities in the Arctic, long-term planning will be required to fully survey the NTMC area. The Federal Government announced in Budget 2015 (July 31, 2015) that $22 million is going towards mapping the Arctic seafloor: the money is to be spent over 5 years, and will be used to “improve the safety of marine transportation in the Arctic” (Anonymous, 2015). Of the $22 million investment, $12 million is going towards buying and installing multibeam sonar systems for the Canadian Coast Guard Icebreakers, to allow for modern surveying of the seafloor in specific regions. This new investment will help the Government of Canada to acquire the data needed to support safe navigation in the Arctic. For CHS, the corridors are used in the development and implementation of the CHS Priority Planning Tool (CPPT), which aids in prioritizing surveying and charting needs on a national scale (Chenier, Abado, et al., 2016).

The WCTSS has had a focus on the regime South of 60° N within Phase I. With the NMTC, the safety system in place can expand to the North as high-traffic routes have been distinguished. The WCTSS focuses on prevention, preparedness, and response, as well as liability and compensation (Fadaie, 2015). The expansion of the WCTSS is to reach North of 60°, which would be an asset as traffic patterns are increasing every year (Judson, 2010). As of September 2014, the Tanker Safety Expert Panel has commenced Phase II: Regime for the Arctic (North of 60°) and Hazardous and Noxious Substances (Gascon, 2014). There are many other uses of the NMTC within government agencies, such as the Canadian Coast Guard for planning and prioritizing response times (Breton, 2015).
4.3 Limitations and challenges

As the uses of the NMTC are vast, the corridors will be updated dynamically as new information is available for use, such as AIS data from exactEarth and ice concentration data provided by the Canadian Ice Service (CIS). The DFO has published a web map on its intranet in order to allow access to the input layers and the final product to other branches of the department, providing additional tools for decision making.

There is a gap in the environmental data layers within the CHS corridors data atlas. The environmental data CHS is currently using is comprised of large zones with little or no information about the temporal value of species in the area, as well as the risk level. Without this information, CHS—who are not experts in environmental data—must wait for more detailed information to become available. The corridors will evolve with time, as engagement and consultations with the Northern communities take place. The corridors will also evolve based on numerous factors, including commercial activities, demographic changes, climate changes, as well as new environmental and cultural information.

5 CONCLUSIONS

The objective of creating the NMTC initiative was to provide mariners and interested parties with safe marine transportation routes within the Arctic. The NMTC will help services in support of economic development, such as community resupply, mineral and oil and gas development, research, tourism, international (transit) passage, safety of navigation, and protection of the Arctic environment. The corridors aid with the WCTSS Expert Panel in identifying areas to better prepare for oil spills and releases of hazardous and noxious substances. CHS will continue to improve the mapping of these corridors by analyzing annual AIS data. Additionally, under a GRIP with the Canadian Space Agency, CHS is evaluating the use of remote sensing data to support surveying and charting. Satellite derived bathymetry along with coastline and tidal delineation are applications that can be used to refine the corridors.

Although shipping in the Canadian Arctic is still relatively low compared to South of 60°, it has increased by more than 75% over the past 10 years. Based on the 2016 Census (Statistics Canada, 2017), there has been a 6% population increase in the last 5 years in Northern Canada. A direct implication of this population growth in the Canadian Arctic will be an increase in community resupply. One key finding from the Arctic Climate Impact Assessment (ACIA) report was that “reduced sea ice is very likely to increase marine transportation and access to resources” in the Arctic (Arctic Council, 2009; Brigham, 2006; Judson, 2010). However, Pizzolato et al. (2014) suggested that, contrary to popular belief, there is not a strong correlation between sea ice loss and increased ship activity in the Arctic. Their findings showed that the number of vessels voyaging in the NORDREG Zone was more or less stable between 1990 and 2006. A significant increase in ship traffic occurred in 2007 as well as in 2010 (Table 3). During that same period (1990–2012), ice cover in the Arctic has steadily declined. They suggested that other socioeconomic and logistical factors could play a role in the increase in maritime shipping in the Arctic.

It is assumed that there will be a longer season, which will evidently increase the number of transits in the Arctic, especially in relation to the tourism industry and mining activities. Climate studies predict that the Arctic could even be ice-free as early as 2030 (Pizzolato et al., 2014; Wang & Overland, 2012). Regardless of the main causes that are increasing the volume of transits in Arctic waters, the more ships transiting the Arctic, the higher the probability of incidents. This enhances the need for the NMTC and the services and programs to support the safe use of Canadian waterways and the protection of the environment.

The NMTC is one of the main aspects in a GIS prioritizing tool, the CPPT, which CHS is currently developing and which will be used to prioritize areas to survey and chart (Chenier, Abado, et al., 2016). The CHS corridors atlas will not only be an asset for CHS, but also CCG, Transport Canada, as well as environmental assessments and EBSAs within Canadian waters. Overall, the NMTC will be highly useful in the future of prioritizing and planning for many government agencies, mariners, interested parties, and CHS.
ACKNOWLEDGMENTS

The authors would like to thank and acknowledge all parties involved in the Northern Marine Transportation Corridors initiative: Canadian Hydrographic Service (CHS), Transport Canada (TC), Natural Resources Canada (NRCan), Canadian Coast Guard (CCG), Environment Canada (EC), Canadian Ice Service (CIS), Department of Fisheries and Oceans Canada (DFO), Hunters and Trappers Organization in Nunavut, Aboriginal Affairs and Northern Development Canada (AADNC). A special thank you to all individuals involved: Sean Hinds, Alexa Guertin, Andrew Leyzack, Deanna Sokoloski, Chris Hemmingway, Andrew Seko, Nadine Cribb, and Amelie Byam.

ORCID

René Chénier http://orcid.org/0000-0002-1895-8503

REFERENCES

Anonymous. (n.d.). Category of zone of confidence in data. Retrieved from http://www.caris.com/s-57/attribut/catzoc.htm
Anonymous. (2015). Harper Government takes action to enhance marine safety in the Arctic. Retrieved from http://news.gc.ca/web/article-en.do?id=1012079
Arctic Council. (2009). Arctic marine shipping assessment 2009 report. Tromsø, Norway: Author.
Breton, D. (2015). Canadian Coast Guard services in the Arctic. Retrieved from http://www.dal.ca/content/dam/dalhousie/pdf/cfps/npss/Arctic%20Presentations/CCG%20Presentation%20-%20Daniel%20Breton.pdf
Brigham, L. W. (2006). Arctic marine shipping assessment: The Arctic Council’s response to changing marine access. Retrieved from http://www.sname.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=fab9496d-005d-4a24-b0a3-b40f9855b3a8
Canadian Space Agency. (2015). RADARSAT constellation. Retrieved from http://www.ascscsa.gc.ca/eng/satellites/radarsat/.
Chenier, R., Abado, L., Sabourin, O., & Tardif, L. (2016). CHS Priority Planning Tool (CPPT): GIS approach for defining CHS surveying and charting priorities. In Proceedings of the Canadian Hydrographic Conference. Halifax, NS, Canada.
Chenier, R., Faucher, M.-A., Ahola, R., Jiao, X., & Tardif, L. (2016). Remote sensing approach for updating CHS charts. In Proceedings of the Canadian Hydrographic Conference. Halifax, NS, Canada.
Chenier, R., & Hemmingway, C. (2014). Updating CHS charts with remote sensing data radar and optical approach. In Proceedings of the Canadian Hydrographic Conference. St. John’s, NL, Canada.
Cobb, D. G. (2011). Identification of ecologically and biologically significant areas (EBSAs) in the Canadian Arctic. Ottawa, Canada: DFO Canadian Science Advisory Secretariat Research Document No. 2011/070.
DFO. (2011). Identification of ecologically and biologically significant areas (EBSAs) in the Canadian Arctic (Report No. 2011/047). Ottawa, Canada: DFO Canadian Science Advisory Secretariat Science Advisory.
exactEarth. (2016). exactEarth’s first generation constellation expands with successful launch of M3MSat. Retrieved from http://investors.exactearth.com/2016-06-22-exactEarths-First-Generation Constellation-Expands-with-Successful-Launch-of-M3MSat
Fadaie, K. (2015). CHS role in the implementation of a world class tanker safety system. Presentation to US–Canada Hydrographic Commission. Retrieved from https://www.imo.int/RMC Docs/ASCH/ASCH-2014-014-04/014-044-15.pdf
Fitzpatrick, M. (2016). Canada, U.S. agree to cut methane emissions. Retrieved from http://www.cbc.ca/news/politics/canada-us-trudeau-state-visit-methane-emissions-1.3484699
Gascon, J. (2014). World class tanker safety system & Arctic initiatives. Retrieved from https://static1.squarespace.com/static/5499bdee4b0385fffd1d4f/t/54c7d883e4b089e4969a0e6f/1422383235594/3-Julie-Gascon-Presentation.pdf
Government of Canada. (2017). Building a strong middle class #Budget2017. Retrieved from http://www.budget.gc.ca/2017/docs/plan/budget-2017-en.pdf
Gunnar Aarsaether, K., & Moan, T. (2009). Estimating navigation patterns from AIS. Journal of Navigation, 62(4), 587–607.
Harati-Mokhtari, A., Wall, A., Brooks, P., & Wang, J. (2007). Automatic Identification System (AIS): A human factors approach. Journal of Navigation, 60(3), 375–390.
Hartwig, L. (2009). Mapping traditional knowledge related to the identification of ecologically and biologically significant areas in the Beaufort Sea. Winnipeg, Canada: Fisheries and Oceans Canada, Oceans Programs Division, Freshwater Institute, Central and Arctic Region.
How to cite this article: Chénier R, Abado L, Sabourin O, Tardif L. Northern marine transportation corridors: Creation and analysis of northern marine traffic routes in Canadian waters. Transactions in GIS. 2017;21:1085–1097. https://doi.org/10.1111/tgis.12295