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Marine transportation risks and rewards for mines and stakeholders in the Canadian North

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Abstract

The shipment of ore and supplies through sub-Arctic and Arctic waters is a vital activity for Northern mines. Marine transportation is steadily intensifying with the development of exceptional resources and year-round windows of operation for ice-capable ships. All stakeholders are exposed to some level of risk during these operations. Chartered ore carriers assume the uncertainty of navigation through poorly charted waterways with highly variable sea ice and weather conditions, all of which can result in the loss of property and personnel or damage to the environment. Miners assume significant financial and reputational risk in these situations. Underwriters risk considerable payouts for lost cargo and salvage operations. Northern communities and other commercial operators depend on the viability of a unique and sensitive marine-terrestrial ecosystem as well as reliably navigable waterways and ice-ways. Frequently, operational support and emergency response is constrained by scheduling conflicts and the vast Northern geography. Successful operators leverage their access to prized ore with accelerated delivery to international customers and reliable and economical camp re-supply. Communities may benefit from economic activity, infrastructure development and concentrated efforts in icebreaking, traffic routing, and search and rescue operations. In an environment where data is scarce and models uncertain, local knowledge and mariner experience form the backbone of a thoughtful risk management process. Combined with historical records of hazardous conditions, a picture of shipping risk for Northern mines and stakeholders can be established.

This paper first presents a brief summary of mine-related shipping in Northern waters and potential future developments in this industry. Next, marine shipping hazards are introduced with emphasis on vessel safety and environmental protection. Briefly, Northern waters' regulations and insurance considerations are described as risk control and risk financing instruments. Potential community impacts, both positive and negative, are highlighted along with considerations in a changing climate. Finally, risk communication is discussed in the context of the National Research Council's Canadian Arctic Shipping Risk Assessment System (CASRAS).

Introduction

The Canadian North and Arctic regions above the 55th parallel are a vast expanse of taiga, tundra, fjords, narrow channels, and wind-swept sounds. The lands host rich mineral reserves and the waterways have long acted as all-season transportation corridors for traditional land owners. Sea-ice plays an important role in the dynamic geomorphology of the maritime regions for most of the year. Ongoing commercial exploration and development activities in the North have led to an increasing need for the marine shipping industry to identify, evaluate, communicate and mitigate risks to all stakeholders.

In Nunavut alone, gross domestic product (GDP) grew by 32% from 2007 to 2012 as a result of increased activity in the mining, quarrying, and oil and gas sectors (CPCS, 2014). A significant portion of this activity, particularly during construction phases, relies on marine transportation for the movement of supplies, equipment, and fuel. Similar statistics are reflected in the Yukon and Northwest Territories where the extractive industries represented 27% and 29% of GDP in 2012. In a recent initiative to help focus the allocation of scarce and widely-dispersed resources, the Canadian Coast Guard (CCG) and Canadian Hydrographic Service (CHS) have mapped marine traffic as part of the Northern Marine Transportation Corridors initiative (Dawson *et al.*, 2016) (Figure 1).

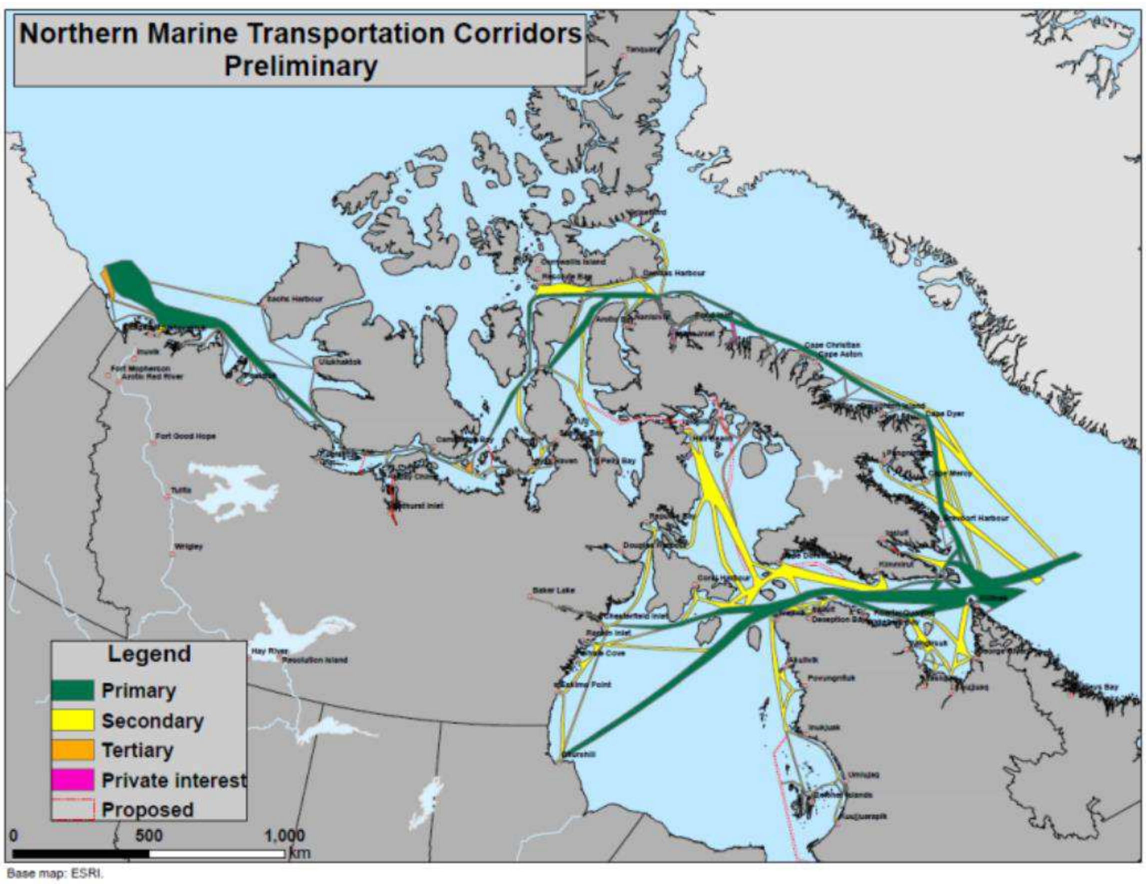

Figure 1 Northern Marine Transportation Corridors (reproduced from Dawson *et al.*, 2016).

The National Research Council of Canada (NRC), in consultation with other government departments and industry partners, is currently developing an information technology tool and risk assessment framework for stakeholders in Northern marine transportation. The NRC Canadian Arctic Shipping Risk Assessment System (CASRAS) comprises a growing database of key meteorological, oceanographic, ecological, regulatory, and community-relevant datasets. These extensive datasets are queried, visualized, and post-processed using modularized risk assessment and reporting tools to facilitate risk communication and mitigation. Similar analytical frameworks have been developed by the shipping industry and academia; however, CASRAS has been purposefully developed as a stand-alone system comprising data specific to the Canadian Arctic, bolstered by the knowledge and experience of commercial and Inuit mariners.

Marine transportation and mining

Existing operations

Several notable operations that occupy the coastal regions north of the 55th parallel are introduced in this section.

Voisey's Bay (Vale)

The Voisey's Bay open-pit mine ships nickel-cobalt-copper and copper concentrate from the northern Labrador Coast to Québec City with plans to ship to a new hydrometallurgical plant in Long Harbour, Newfoundland. The mine produces 6,000 tonnes per day and employs approximately 400 fly-in/fly-out workers including members of the Innu Nation and Nunatsiavut Government (Vale, 2016).

Raglan (Glencore)

The Raglan underground mine ships nickel and copper concentrate from Deception Bay on Québec's northern coast (Nunavik) to Québec City. The concentrate is shipped by icebreaking cargo ship (the *MV Arctic*) with a capacity of 27,000 tonnes. The mine processes over 3,500 tonnes of ore per day and employs 950 full-time workers from southern and Inuit communities (Glencore, 2016a).

Meadowbank (Agnico Eagle)

The Meadowbank open-pit mine is situated 300 km west of Hudson Bay and relies on annual sealifts of bulk supplies and heavy equipment originating from the St. Lawrence seaway. The mine processes close to 11,000 tonnes of ore per day and in Q2 2016 produced over 72,000 ounces of gold and 66,000 ounces of silver. The mine employs nearly 700 workers and is linked to the hamlet of Baker Lake by a 110 km all-season road (Agnico Eagle, 2016).

Mary River (Baffinland Iron Mines)

In August 2015, over 50,000 tonnes of iron ore was shipped to Nordenham, Germany using a Montréal-based FedNav bulk carrier. Ore shipments continue from Milne Inlet to the European steel markets. The current shipping season extends from mid-July to mid-October when ice conditions are most favorable; however, current proposals seek extension of the season into the winter from June through March using ice-strengthened vessels. During the Early Revenue Phase, Baffinland plans to ship 3.5 million tonnes of ore per year – or the equivalent of nearly 10,000 tonnes per day – out of the Canadian Arctic (Baffinland, 2016). At a full production rate of 18 million tonnes per year, the mine would require 180 one-way ship transits for ore delivery, 3 general cargo ship visits, and 3 to 6 fuel re-supply trips carrying over 200 million litres of fuel (CPCS, 2014). As of December 2015, the Inuit hiring rate was 18% according to a Canadian Broadcasting Corporation (CBC) interview with the Qikiqtani Inuit Association (CBC, 2015).

Future operations

Hopes Advance Bay (Oceanic Iron Ore)

The Hopes Advance Bay project could deliver 27,000 to 55,000 million tonnes per day equivalent iron ore from a 330 metre wharf in Ungava Bay, northern Québec to international markets (CPCS, 2014). This production rate could result in 80 to 200 one-way ship transits per year depending on the vessels used. The nearest community, Aupaluk, so named for its iron-bearing red soil, has drawn mining interest since the late 1950s (NTA, 2016). The pre-feasibility study was completed in 2012.

Meliadine (Agnico Eagle)

Following the Meadowbank project, Agnico Eagles's Meliadine gold project in the Nunavut Low Arctic west of Hudson Bay could require 4 to 6 dry cargo ship deliveries per year and over 120 million litres of diesel fuel delivered annually from the St. Lawrence seaway (CPCS, 2014). In 2015, the Nunavut Impact Review Board issued a Project Certificate and Agnico Eagle has committed to work towards a 50% Inuit employment rate.

Izok Corridor (MMG)

MMG's Izok Corridor project comprises the Izok Lake and High Lake zinc-copper-lead deposits in the Kitikmeot region of Nunavut. A deep water port would be operated on the Coronation Gulf with an estimated 80 one-way concentrate shipments to Asian and European markets during the 'open-water' season (mid-July through October). The average on-site work force is estimated to be some 670 people and MMG estimates an 18% increase in territorial GDP during operations (compared to a 2012 baseline). MMG is currently evaluating alternative engineering opportunities to improve project economics before review by the Nunavut Impact Review Board (MMG, 2016).

Back River (Sabina Gold and Silver)

In 2013, Sabina Gold and Silver completed the pre-feasibility study for the Back River gold project located 520 km northeast of Yellowknife, Northwest Territories and 75 km southwest of Bathurst Inlet, Nunavut. A port could be constructed in the south of Bathurst Inlet to accommodate 5 to 10 general cargo ships and tankers during construction phases and 3 to 5 ships during regular operations (CPCS, 2014).

Hackett River (Glencore)

The Hackett River zinc-silver project is situated just 45 km west of the Back River deposits in Nunavut's Kitikmeot region. Hackett River represents one of the largest undeveloped volcanogenic massive sulfide deposits in Canada. At a production rate of 500,000 tonnes of zinc concentrate per year (nearly 1,400 tpd), up to 20 one-way ship transits per year could be required out of Bathurst Inlet (CPCS, 2014).
Formerly owned by Sabina Gold and Silver, the company retains a 22.5% and 12.5% royalty on silver production up to and after the first 190 million ounces produced, respectively (Sabina Gold and Silver, 2016).

Marine hazards

In a 2016 report, the Council of Canadian Academies (CCA) found that the likelihood of a marine shipping accident is increased in the North due to a lack of navigation aids and charting, inadequate infrastructure, and unfavourable ocean and weather conditions (CCA, 2016). Much of the risk associated with these top three factors emerges from the uncertainty of vessel position relative to known and unknown physical hazards and the uncertainty in forecasting potentially hazardous environmental conditions. The International Maritime Organization Polar Code (IMO, 2016), set to come into force in 2017, also identifies low temperatures, ice, and human factors as shipping hazards in polar regions. These elements are briefly introduced in the following section.

Lack of infrastructure and remoteness

The North poses several challenges to marine transportation and a lack of adequate infrastructure is commonly cited as the primary hazard. Several related deficiencies are as follows:

- Lack of aids to navigation (e.g. buoys, radar beacons, and fixed light aids)
- Lack of reliable ship-to-shore and ship-to-ship communication and positioning systems
- Lack of accurate paper and digital charts and bathymetry for navigation

- Lack of harbor infrastructure for loading and off-loading of cargo
- Availability of ice-breaking support

Most, if not all, of the infrastructure challenges in the North are a function of remoteness and the vast geography of the Northern regions.

Presence of sea ice and low temperatures

Sea ice and sustained low temperatures present several challenges to mariners in Northern waters. Sea ice, in its many forms, poses navigational challenges especially when combined with poor visibility, tides and currents, variable winds, or snow and rain during operations. Ice that has survived at least one summer's melt (old ice) and consolidated ice ridges pose significant threats to shipping. Contact with hazardous ice may result in damage to propulsion systems, the hull, or a phenomenon known as besetting where vessels are locked in place due to high confining pressures in a concentrated ice pack. The Canadian Ice Service (CIS), a division of the Meteorological Service of Canada, and the Canadian Coast Guard (CCG) provide regular updates on ice conditions during the shipping season. In addition, the National Research Council of Canada has developed tools for forecasting hazardous ice conditions and the movement of ice on a scale relevant to shipping operations.

In the marine industry, low air temperature conditions exist when the statistical mean daily low temperature during operations in a specific location is below -10°C (ABS, 2016). Low temperatures pose threats to machinery and navigation and communication systems onboard vessels. When low temperatures are combined with high winds and waves, vessels can succumb to icing spray that may result in loss of essential systems or even vessel instability. Low temperatures also increase the risk of exposure-related injuries to crew at sea, especially in emergency situations.

Metocean conditions uncertainty

In marine terms, meteorological and oceanographic conditions are collectively referred to as *metocean* conditions. Metocean conditions comprise all aspects of physical oceanography (including tides, currents, waves, and swell) along with familiar weather states (including storms, fog, and precipitation). These environmental agents create synergistic effects and are known to develop rapidly and unfavorably in Northern waters.

For example, Northern Québec's Ungava Bay experiences tidal ranges on par with those of the Bay of Fundy, among the highest in the world. If low tide coincides with unfavourable winds, ships can be forced onto shallow shoals resulting in grounding. In the metocean system, there are also examples of negative feedback, such as the dampening of wave action resulting from sea ice coverage and reduced wind shear. Overall, the uncertainty in modelling and forecasting of complex metocean conditions in the North decreases the level of comfort when operating in these regions.

Sensitivity of marine habitat

Shipping and ice-breaking activities have the potential to disrupt sensitive marine habitats, particularly those associated directly with dynamic sea-ice and land-fast ice. The effects of underwater noise, air emissions, hydrocarbon and waste pollution, and the introduction of invasive species could have significant impacts on Arctic ecosystems and traditional hunting and fishing activities. Such impacts can directly affect the supply of indigenous country food and may result in reputational, legal, and financial implications for operators and their customers.

In a report released by the World Wildlife Fund and financially supported by Montréal-based shipping company FedNav, the author concludes:

> *…it appears that many operators are already carrying out their environmental stewardship duties and responsibilities. While there are numerous national and international regulations in place dealing with various aspects of Arctic shipping there are chasms in these regulations. Some operators appear to have recognized the gaps in these regulations aimed at protecting the Arctic and have gone above and beyond that required of them by regulators. While this may be the case with some operators there needs to be a means in place to ensure that all individuals and companies operating in the Arctic act as environmental stewards. A mandatory Polar Code would help to ensure such responsibility (WWF, 2012).*

The Human Factor

The role of human decision making remains an overwhelmingly dominant factor governing risk in marine operations, as in most other industrial activities. The Canadian Council of Academies reports that at least 75% of international marine incidents and accidents are attributed to human error (CCA, 2016) while an ABS review of data from Canada, US, UK, and Australia estimates that human error played a role in 80% to 85% of marine casualty cases (Baker and Seah, 2004). Baker and Seah (2004) suggest that 50% of those human-related accidents were initiated by a human action while in 30% of cases the human did not adequately intervene to mitigate the outcome. Fatigue from long periods on watch is often a contributing factor in human error related casualties. The IMO recommends addressing the human element by integrating Human Reliability Analysis (HRA) in marine safety assessments (IMO, 2002).

Risks and opportunities

The risks of vessel damage and marine pollution are among the primary concerns for operators and stakeholders in the North. The 2016 CCA report suggests that the top three perceived socio-economic impacts of a shipping accident in the North are as follows: reduced food security; human health effects due to consumption of contaminated food; and disruption of cultural fabric (CCA, 2016). The cost-benefit picture is complicated with the knowledge that both industry and Northern communities, particularly in the Arctic, are heavily dependent on essential goods received by ship. For example, Northern communities and mine sites in 2011 received deliveries of 359,230 tonnes and 351,606 tonnes of general cargo by ship, respectively (CPCS, 2014). Such deliveries would not be possible by land and would be uneconomical by air.

The myriad hazards and increased uncertainty in the North are apparent from analysis of historic data; though those data are subject to the systemic effects of under-reporting and incomplete or erroneous records. Reported accident and incident rates for cargo ships, barges, and tugs in the North are considerably higher (1incident per 100 vessel movements) than for similar vessels along the British Columbia coast (0.1 incidents per 100 vessel movements) for example (CCA, 2016). From 2004 to 2015, the top three reported incident types in the North were total machinery failure, serious human injury or death, and damage to the ship rendering it unfit for service. Kubat and Timco (2003) analysed vessel damage reports from 1978 to 2003 in the Canadian Arctic and showed that the more severe events and 73% of all damage events occurred in regions where old sea ice was present. The CCA reports that of all commercial marine incidents in Canadian waters, fewer than 2% involved a known release of pollutants (CCA, 2016).

Despite higher incident rates reported in the North, increased shipping activity may result from increased mining activity if supported by the markets and regulators. To mitigate risks to operators and to the environment, such activity should be supported by improved charting and navigational aids, additional marine infrastructure, improved understanding and forecasting of severe sea ice and metocean conditions, and continued study of ecosystem impacts caused by shipping. The benefits of such advancements could be realized for commercial operators as well as for local sustenance hunting and fishing, search and rescue operations, research, regulatory enforcement, and national defence. The role of regulation and insurance also plays a role in risk control and risk financing and will be introduced in the following section.

Regulation and insurance

Several key pieces of legislation govern shipping activities in the Canadian North and serve as risk control strategies. Most notably, the Arctic Shipping Pollution Prevention Regulations (ASPPR) and the overarching Arctic Waters Pollution Prevention Act (AWPPA) seek to protect the marine environment from intentional (operational) and unintentional (accidental) acts of polluting. The AWPPA stipulates a zero-discharge condition, such that vessels may not release any quantity of oil, food waste, or human waste to the marine environment. In addition, the ASPPR defines the limits of liability for infractions involving the discharge of domestic and industrial waste in regions north of 60°N. In addition to these regulations, the Canadian Coast Guard enforces the Northern Canada Vessel Traffic Services Zone Regulations (NORDREG) that stipulate reporting requirements for vessels meeting established tonnage or dangerous cargo criteria.

Transport Canada currently restricts vessel traffic in the Northern waterways using the Zone/Date System. Regulated zones become accessible to lighter vessels as the ice conditions improve throughout the shipping season. Outside these regulated Zone/Date windows of operation, Transport Canada's Arctic Ice Regime Shipping System (AIRSS, 2003) dictates which vessels can transit based on observed ice conditions and a vessel-specific algorithm.

International conventions such as IMO's Safety of Life at Sea (SOLAS) originated after the Titanic disaster of 1912. SOLAS governs vessel construction standards, fire protection and life boat requirements, and regulation concerning the transportation of dangerous goods among many other elements. As of January 1, 2017, SOLAS will make mandatory the International Code for Ships Operating in Polar Waters (the "Polar Code") which details additional risk-based planning, training, communication, and safety requirements for vessels in polar waters and low temperatures. IMO also administers the International Convention for the Prevention of Pollution from Ships (MARPOL) which includes regulations governing accidental pollution prevention and mitigation of operational releases of oil, noxious liquids, packaged goods, sewage, and garbage.

Risk financing and insurance in the marine industry is an enormous subject in itself and will only be briefly introduced. A typical insurance policy will include coverage for cargo and hull and machinery (M&H) damage that may result in actual losses or constructive losses from collisions with ice, other vessels, natural formations, or marine infrastructure. A constructive loss is one where the vessel cannot be economically salvaged or repaired. Notably, constructive losses in the Arctic are more likely due to the remoteness and expense of salvage operations. In addition to the traditional insurance market, Protection and Indemnity (P&I) Clubs are mutual insurance pools formed by ship owners in order to finance non-standard losses like environmental damage resulting from pollution.

Much experience and casualty data has been obtained along the Russian Arctic coast and the Northern Sea Route; however, the Canadian Arctic is notably more susceptible to severe ice conditions and hazards related to high strength old ice. For insurers, this difference likely limits a direct translation of frequency and severity data between regions.

Risk communication

Regulation and guidance

Several sources of risk management guidance may be found that address practices in the marine transportation industry. The first is the IMO Guidelines for Formal Safety Assessment (FSA) (IMO, 2002), which outlines the formalized steps of a FSA including: identification of hazards; risk analysis; risk control; cost benefit assessment; and recommendations for decision making. While the guidelines are extensive and detailed, methods and considerations for risk communication to users and stakeholders are not specifically addressed in this document.

Another reference to the risk management process can be found in the Polar Code (IMO, 2016). The risk-based code describes operational assessments as a means to establish operational limits and procedures for specific ships operating in specific environments. Furthermore, the Polar Code calls for risk-based voyage planning before departure and for the development of a Polar Water Operational Manual (PWOM) which addresses ship-specific limitations and capabilities. Guidance on the presentation of a PWOM is provided in an appendix to the code and suggests that assumptions used in conducting the analyses should be included directly in the Manual. Beyond this suggestion, no formal risk communication strategies or tools are presented.

To address the need for a transparent hazard identification and risk communication framework, the NRC has developed a system and complimentary tools for the compilation of environmental and operational data, identification of historically hazardous conditions, statistical assessment of those conditions, and visualization and reporting in a customizable, modularized format. The system and applications are described in the following section.

Canadian Arctic Shipping Risk Assessment System (CASRAS)

CASRAS is an integrated risk assessment system for marine transportation in the Canadian North. The PC-based system provides a comprehensive platform for the storage, search and visualization of all key environmental data with specific application to shipping, icebreaking and navigation in Northern waters and Arctic marine corridors. CASRAS processes large datasets including georeferenced static and time-varying rasters, points, polygons, time-series, text, and digital media as part of a centralized workflow. The system is a platform for a range of historical datasets and operational products including:

- Marine weather
- Marine hydrography and physical oceanography
- Sea-ice conditions, ice hazards and physical properties
- Community information and Marine Protected Areas
- Mariner knowledge including notes, charts, and digital media

The CASRAS datasets were selected and prioritized for inclusion in the system based on consultation with experienced mariners and Northern community stakeholders. Datasets are sourced from the public domain, other government departments, and in-house databases developed by the NRC. Central to the system's philosophy is that all datasets are retained in their original format such that no manipulation of the data occurs prior to analysis. Some applications of the data analysis tools include: assessment of tidal conditions; assessment of daily low temperatures for vessel and crew safety (Figure 2); and assessment of hazardous ice conditions and navigability for a specific vessel type (Figure 3).

CASRAS produces customizable reports on hazardous conditions along user-defined shipping routes or selected regions. These reports contain visualizations of historical analyses in relation to user-defined thresholds for safe operation. In accordance with the Arctic Ice Regime Shipping System (AIRSS), CASRAS computes Go/No-Go and operation-limiting indices for any vessel class along the user-defined shipping route. To address the International Maritime Organization's Polar Code, CASRAS provides information on Polar Service Temperature (PST) requirements and Lowest Mean Daily Low Temperature (LMDLT) data for the selected route and time of the year. CASRAS also computes Polar Operational Limit Assessment Risk Indexing System (POLARIS) values that define operational limits and escorting and vessel speed requirements. This information is useful for industry stakeholders contemplating expanding to new regions, for selecting the vessel types required, for determining the historical windows of safe shipping along each route, and for investigating "choke-points" – where vessels have historically had difficulty passing due to severe ice conditions, poor charting, extreme tides, or other factors.

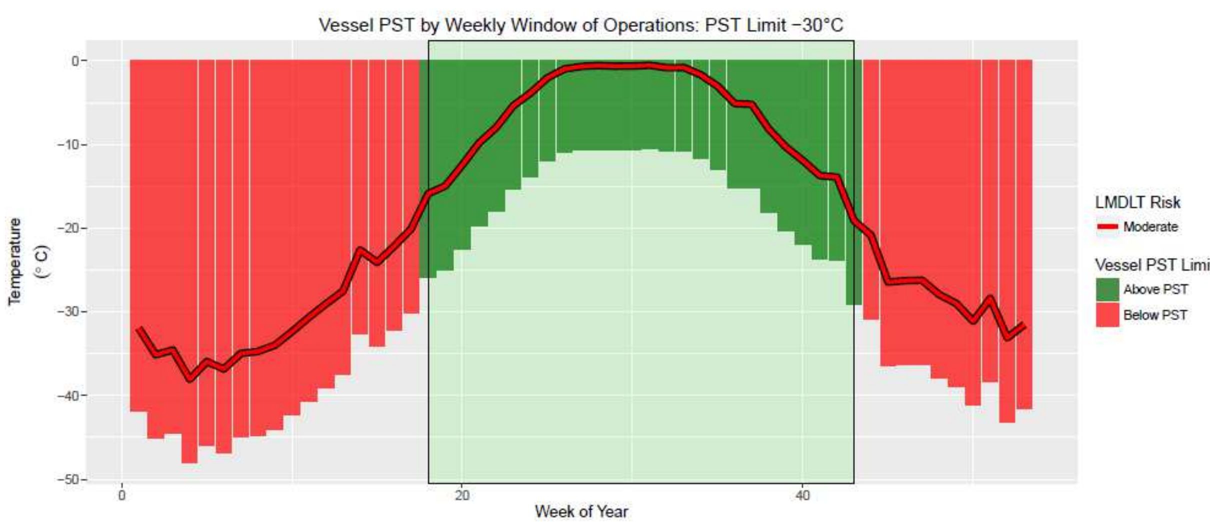

Figure 2 Example of CASRAS output for assessment of low temperatures operations

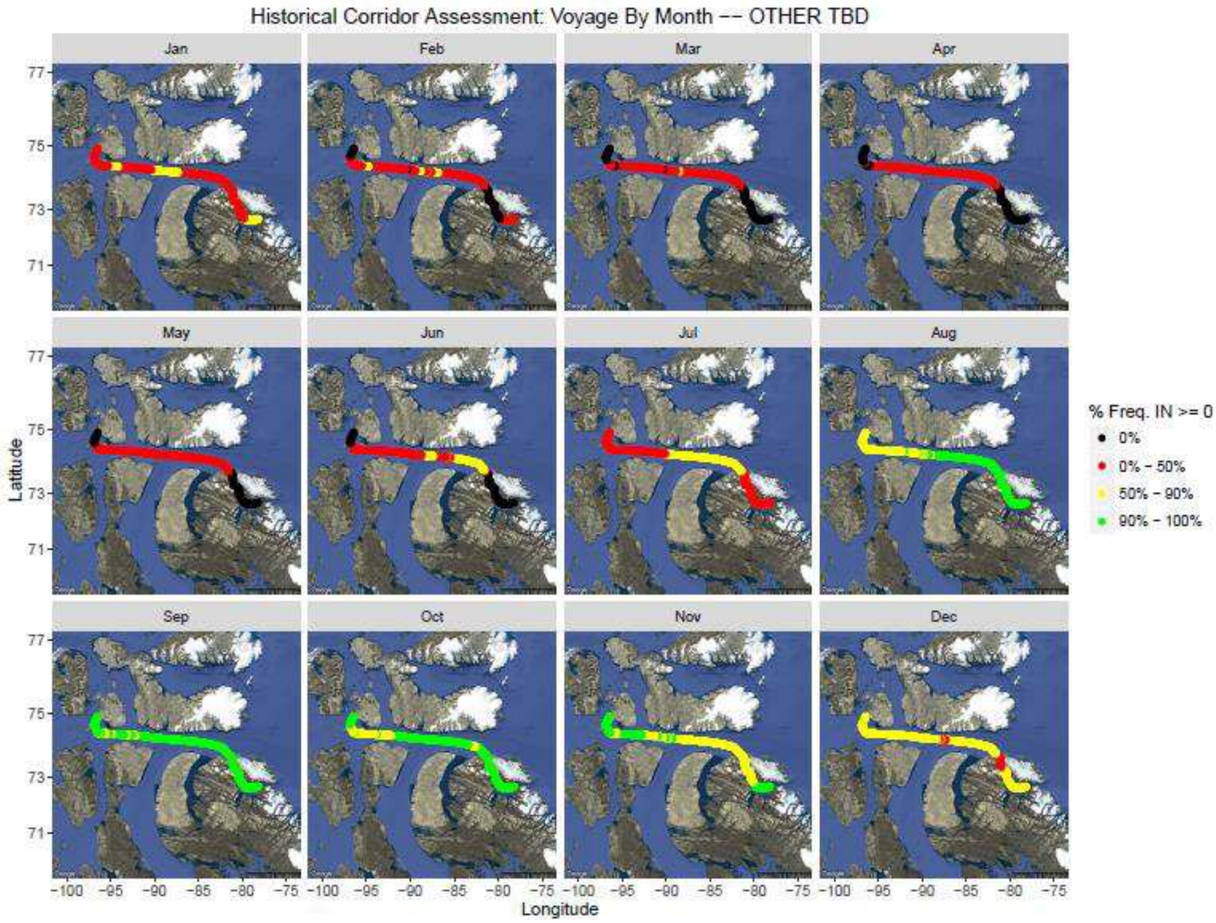

Figure 3 Month-by-month assessment of sea ice navigability for a selected route

CASRAS has been purposefully designed to accommodate data requirements of industrial and community stakeholders and continues to evolve as new data are added and new processing tools developed. The modular framework of the system allows for inclusion of "Risk Modules" designed or requested by end users to maximize utility of the system.

Climate change and uncertainty

The effects of climate change and the resultant changes in sea ice characteristics remain considerable uncertainties for Northern communities and industry. The effects of sea ice reduction and an extended open-water season present the possibility for both positive and negative outcomes for mines and communities supported by shipping. Some concerns include the effect of the high strength old ice break-up and migration south into shipping routes and the impact of more severe and frequent storms on ice and metocean conditions.

Changes in climate and sea ice characteristics must be considered when evaluating risks based on historical data alone.

Conclusion

Marine transportation provides essential services to Northern communities and mining operations alike. Hazardous conditions in the North are exacerbated by the region's remoteness, a general lack of infrastructure, and the sensitivity and value of marine habitats. Canadian and international regulators are addressing marine risk in an Arctic context but much work remains. Climate change and the resultant effects on sea ice and metocean conditions will to some extent govern the success of future operations, but so too will government and community stewardship of Northern waters and resources.

The NRC's CASRAS platform and risk communication tool is presented as an evolving technology to help all stakeholders engage in informed and transparent decision-making and risk management.

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