Analysis of Marine Traffic along Canada's Coasts

Phase 2 – Part 2: A spatio-temporal simulation model for forecasting marine traffic in the Canadian Arctic in 2020

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DRDC CORA CR 2013-214
December 2013

Defence R&D Canada

Centre for Operational Research & Analysis

CJOC ORA Team

Canadian Joint Operations Command

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National Defence | Défense nationale

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Defence R&D Canada – Centre for Operational Research and Analysis

Contractor Report

DRDC CORA CR 2013-214
December 2013

Scientific Authority

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Analysis of Marine Traffic

Phase 2 – Part 2: A spatio-temporal simulation model for forecasting marine traffic in the Canadian Arctic in 2020

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Abstract

This document describes the results of the study conducted as Phase 2 – Part 2 of the Analysis of Marine Traffic (AMT) Project, conducted under contract W7714-093795. The purpose of this Part is to develop a spatio-temporal model that can be used to represent current maritime traffic in the Canadian Arctic and sub-arctic, and also simulate future traffic projections. The simulation model comprises a network of feasible routes connecting possible areas where vessels may go, such as communities, mines, offshore developments, and fishing grounds. A route is deemed feasible based on water depth and ice conditions, depending on the vessel type. Specifically, a simulation was run for the year 2020, based on key drivers that may lead to changes in traffic in terms of activity type, vessel mix, volume by vessel type, location, and timing. The search for, and extraction of, resources are major drivers of arctic traffic, encompassing oil and gas, mining and fishing. Increased cruise ship tourism is likely in the North, and the sealift operation to supply communities is contingent on population changes and spending patterns. Pleasure boating levels are largely tied to community population as well. However, there is great uncertainty around most of these factors as well as the ice predictions for the year 2020, therefore the simulation model relies on Monte Carlo simulation to account for the range of possible values. Maps are generated for the forecast traffic, and the simulation model was designed to be easily rerun using different parameters.

Résumé

Le présent document décrit les résultats de l’étude menée dans le cadre de la phase 2 – partie 2 du projet d’analyse du trafic maritime, exécuté en vertu du contrat W7714-093795. Le but de la deuxième partie est de concevoir un modèle spatio-temporel qui peut être utilisé pour représenter le trafic maritime actuel dans l’Arctique et dans le subarctique du Canada, et pour simuler les prévisions de trafic futur. Le modèle de simulation comprend un réseau de voies praticables reliant des endroits où les navires pourraient se rendre, comme des communautés, des mines, des développements extracôtiers et des lieux de pêche. On dit qu’une voie est praticable en fonction de la profondeur de l’eau et de l’état des glaces, selon le type de navire. Plus précisément, une simulation a été faite pour l’année 2020, en fonction de facteurs clés qui pourraient entraîner des changements dans le trafic pour ce qui est du type d’activité, des types de navires, du volume par type de vaisseau, de l’emplacement et des temps de navigation. La recherche des ressources et leur extraction sont des facteurs importants du trafic arctique et englobent le pétrole et le gaz, ainsi que les secteurs des mines et de la pêche. Il est probable qu’il y ait une hausse du tourisme de croisière dans le Nord, et le transport maritime servant à approvisionner les communautés dépend des changements démographiques et des habitudes de dépenses. La navigation de plaisance est également liée à la population de la communauté. Cependant, il règne une grande incertitude quant à la plupart de ces facteurs et aux prévisions liées à l’état des glaces pour l’année 2020. Par conséquent, le modèle de simulation repose sur des simulations Monte Carlo pour tenir compte de la gamme des valeurs possibles. Des cartes ont été créées pour le trafic prévu et le modèle de simulation a été conçu pour pouvoir facilement être exécuté de nouveau au moyen de paramètres différents.

Executive Summary

Enhancing safety and security in Canadian Arctic waters involves monitoring maritime activities and improving preparedness to respond to unexpected events. Both of these strategies have long lead times, therefore it is important to not only consider current maritime activity levels in the north, but to produce traffic forecasts so that resources for monitoring and managing traffic can be effectively deployed over time. The Analysis of Marine Traffic (AMT) project was initiated by DRDC with an overall goal of producing spatial and temporal analyses of marine traffic in Canadian waters, including Arctic waters. This phase of the study concentrates on modelling current activity in the Canadian Arctic and sub-arctic, and simulating future maritime traffic characteristics in the North. To this end, projections of traffic densities for the year 2020 are generated in this study. The Area of Interest (AOI), defined by the project sponsor, corresponds to waters north of 60° Latitude, extending up to and including 300 nautical miles (nm) from the shoreline of Canadian territory, and also encompasses Hudson Bay and James Bay (see Figure 3-1).

There is a variety of traffic types in the AOI associated with diverse activities such as northern community re-supply, commercial shipping out of Churchill, Manitoba, commercial fishing, and cruise ship voyages. The traffic projections must distinguish between categories of activity for three reasons. First, the factors that may affect changes in traffic levels in the coming decade do not apply equally to all activity types. For example, exploration for oil and gas or minerals will be heavily dependent on the world economy in general, and demand for resources in particular. In contrast, fishing levels will depend on the relative effectiveness of fishing in the north versus other geographic areas as fish stocks dwindle worldwide. Second, the types of problems, or risks, associated with different categories of ships and activities vary tremendously, so the analysis must produce separate forecasts for each. For example, a major accident involving a large cruise ship may engender drastically higher consequences than the sinking of a relatively small fishing vessel. Third, the quality of existing data, and of factors that may produce changes in activity levels by 2020, are not consistent across categories. Large ships are tracked very closely in the north, and economic drivers that would alter the levels of community resupply vessels for example, are fairly well understood. Conversely, trying to predict the number of small pleasure craft that will venture into the Northwest Passage (NWP) as the ice recedes is as much art as science. Thus, the simulations distinguish between diverse activities and associated vessel types to produce more accurate and useful outputs (see Table 2-1).

Aside from drivers that may increase or decrease traffic levels in the near future, the feasibility of increased traffic is tightly coupled to the changing ice conditions. The duration, extent, and nature of ice coverage are all changing relatively quickly due to global warming, and therefore the opportunity to ply the arctic waters depends on forecasts of spatial projections of ice presence in 2020. There are other system-wide factors that can significantly influence future traffic levels, such as geopolitical factors, northern infrastructure development, and environmental governance, but these are excluded from this study as they are assumed to remain static over the short term.

Since the amount of data on maritime traffic in northern Canada is low, it is not possible to produce a reliable numerical forecast based on statistics for traffic levels in the year 2020. Therefore, the approach needed is to generate feasible scenarios which are derived from possible changes in demand drivers and ice conditions. For each demand driver a base case, low case, and high case have been projected based on information found in the literature, and the effect of each driver on the relevant types of traffic has been estimated. All of these factors are then input into a spatio-temporal maritime traffic simulation tool based on a route network in the Arctic that can generate realistic traffic patterns based on feasibility (forecasted ice conditions) and likelihood (Monte Carlo simulations to accommodate the uncertainty in the demand factors). This model can generate a wide variety of scenarios, and within this study we have conducted traffic projections in the Canadian Arctic for the year 2020 by vessel type, location, and month, including the most likely volume of traffic, as well as low and high cases. There is no simple way to describe the projected traffic patterns, hence one must refer to the sample maps provided in the report for diverse vessel categories and time periods (see Sections 7.3.1 and 7.3.2).

This Analysis of Maritime Traffic study (AMT Phase 2 – Parts 1 and 2) has produced several notable outcomes. First, a thorough literature review provides a synthesis of two fundamental aspects required for Arctic traffic projections: (a) previous work done on related topics concerning current or anticipated northern traffic, and descriptions of what drivers and conditions are associated with potential changes in ship activity; and (b) projections of ice conditions in 2020 and forecasts or anticipated trends in the major drivers of northern vessel traffic, including natural resource exploration and extraction, tourism activity, and population changes. This information was essential for framing the traffic model and estimating the input parameters.

Second, a network of feasible shipping routes had to be designed using a graphical node-network to allow traffic forecasted for the year 2020 to follow additional paths in addition to the currently used routes. The nodes on the network, current and potential future ones, are constructed on the basis of zones of interest (ZOI), an approach which 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 Arctic Area of Interest (AOI) through which traffic enters or leaves the vessel traffic network. To allow the maximum possible flexibility for traffic to move between the ZOI, graph edges (also called arcs) are created. 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 ice projections for the year 2020 into the model, which affects traffic in terms of where it can go and when it can go, as a function of the ice coverage, ice type, and ship 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 third major contribution from this study was developing a mechanism to include uncertainty about several factors simultaneously into the 2020 traffic forecast. The model allows for five categories of changes relative to current Arctic traffic patterns: new end points (ZOI), new paths, altered mix of vessel types, traffic volume increases or decreases (by type and location), and timing of trips. The node network is essential to enable the first two types of variations, and the temporal traffic-spreading algorithm supports the final adaptation. Using a Monte Carlo simulation method, probabilistic variations in diverse traffic drivers such as the minimum, maximum, and likely number of ships going to and from a resource extraction site, or variability in population growth or purchasing power of northern communities, can all be modeled using a standard form such as a triangular probability distribution. Running the model thousands of times by sampling from the distributions for each input factor generates overall estimated traffic patterns throughout the north, with the output itself represented as the most likely value (mode) by ship type, location and time (month), as well as the statistical range for each of these output values.

The fourth significant contribution is the output from the simulations. The spatio-temporal traffic projections, categorized by vessel type, location, and month provide a solid foundation for strategic planning for improved safety, such as search and rescue resource planning and enhanced vessel traffic monitoring. Incorporating the uncertainty into the model allows decision makers to assess the implications of low case traffic scenarios versus high case traffic scenarios. The fact that these output scenarios result from Monte Carlo simulation is valuable, because the alternative of assuming a low case scenario for all the factors simultaneously, or high case for all the factors simultaneously, is much more unrealistic.

Finally, the fifth, and perhaps most important contribution, is that all of the model elements have been organized into a user-friendly simulation tool for Arctic traffic spatio-temporal projections. While one can argue that having a simulation model available to rerun under a different set of input parameters is commonly required (i.e. versus using the model to just produce a specific one-time outcome), it is particularly valuable in this context because the complexity and volatility of many of the input factors are expected to compel more runs of the model as drivers evolve significantly in time and/or additional expertise is brought to bear to clarify the relationships between the factors and traffic patterns.

Sommaire

Pour améliorer la sécurité dans les eaux arctiques du Canada, il faut surveiller les activités maritimes et améliorer la capacité d'intervention en cas d'événements imprévus. Ces deux stratégies ont de longs délais d'exécution; il est donc non seulement important de tenir compte de la quantité actuelle des activités maritimes dans le Nord, mais aussi de produire des prévisions du trafic afin que les ressources requises pour la surveillance et la gestion puissent être déployées de façon efficace au fil du temps. Le projet d'analyse du trafic maritime a été lancé par RDDC et avait comme objectif global de produire des analyses spatiales et temporelles du trafic maritime dans les eaux canadiennes, y compris dans les eaux arctiques. Cette partie de l'étude est axée sur la modélisation des activités actuelles dans l'Arctique et le subarctique du Canada, et sur la simulation des caractéristiques maritimes futures dans le Nord. À ces fins, on élaborera des prévisions sur la densité du trafic pour l'année 2020. La zone d'intérêt (ZI), définie par le parrain du projet, correspond aux eaux qui se trouvent au Nord du 60° parallèle, et s'étend sur une distance de 300 milles marins à partir du rivage du territoire canadien et englobe aussi la baie d'Hudson et la baie James (voir la Figure 3-1).

Il existe divers types de trafic dans la ZI, associés à certaines activités comme le ravitaillement des communautés du Nord, la navigation commerciale à partir de Churchill, au Manitoba, la pêche commerciale et les voyages à bord de navires de croisière. Les prévisions du trafic doivent faire la différence entre les types d'activités, pour trois raisons. Premièrement, les facteurs qui peuvent influer sur le niveau de trafic dans la décennie à venir ne s'appliquent pas de façon égale à tous les types d'activités. À titre d'exemple, l'exploration pétrolière, gazière ou minière dépendra beaucoup de l'économie mondiale en général, et de la demande des ressources en particulier. Par contre, le niveau de pêche dépendra de l'efficacité relative de la pêche dans le Nord comparativement aux autres zones géographiques, compte tenu du fait que les stocks de poissons diminuent à l'échelle mondiale. Deuxièmement, les problèmes ou les risques associés aux différentes catégories de navires ou d'activités varient grandement; par conséquent, l'analyse doit produire des prévisions séparées pour chaque catégorie. À titre d'exemple, un accident important mettant en cause un grand navire de croisière peut entraîner des conséquences plus beaucoup plus graves que dans le cas d'un petit navire de pêche. Troisièmement, la qualité des données existantes, et des facteurs qui peuvent engendrer des changements dans le niveau d'activités d'ici 2020, n'est pas la même pour toutes les catégories. On effectue le suivi des grands navires de très près dans le Nord et les facteurs économiques qui modifieraient la quantité de navires de ravitaillement pour les communautés, à titre d'exemple, sont bien compris. Par contre, tenter de prévoir le nombre de petites embarcations de plaisance qui s'aventureront dans le passage du Nord-Ouest lors du recul des glaces est autant un art qu'une science. Par conséquent, les simulations effectuent une distinction entre les diverses activités et les types de navires qui leur sont associés pour produire des résultats plus exacts et plus pratiques (voir la Table 2-1).

À part des facteurs qui peuvent accroître ou diminuer le niveau de trafic à court terme, la possibilité d'une hausse de trafic dépend beaucoup de la condition changeante de la glace. La durée, l'envergure et la nature de la couverture de la glace sont des facteurs qui changent rapidement en raison du réchauffement climatique; par conséquent, la navigation dans les eaux arctiques dépend des prévisions

spatiales quant à la présence de glace en 2020. Il existe d'autres facteurs à l'échelle du système qui peuvent influer de façon importante sur le niveau du trafic à l'avenir, comme les facteurs géopolitiques, le développement de l'infrastructure du Nord et la gouvernance environnementale, mais ils sont exclus de cette étude, car on suppose qu'ils demeurent les mêmes à court terme.

Puisqu'il existe peu de données sur le trafic maritime dans le Nord du Canada, il est impossible de fournir une prévision numérique fiable fondée sur les statistiques pour le niveau de trafic en 2020. Par conséquent, l'approche requise doit être l'élaboration de scénarios qui reposent sur les changements pouvant survenir en raison de facteurs liés à la demande et à l'état des glaces. Pour chaque facteur de demande, on a prévu un scénario de référence, un scénario bas et un scénario élevé, en fonction des renseignements trouvés dans la documentation. On a ensuite fait une estimation des répercussions de chaque facteur sur les types de trafic pertinents. Ces renseignements sont ensuite saisis dans un outil de simulation spatio-temporelle du trafic maritime, qui est fondé sur un réseau de voies dans l'Arctique et qui peut créer des voies de trafic réalistes selon la faisabilité (condition prévu des glaces) et la probabilité (simulations de Monte Carlo pour tenir compte de l'incertitude lié aux facteurs de demande). Ce modèle peut générer une grande variété de scénarios, et nous avons, au sein de cette étude, élaboré des prévisions liées au trafic dans l'Arctique canadien pour l'année 2020 par type de navire, par emplacement et par mois, y compris le volume de trafic le plus probable, et des scénarios bas et élevés. Comme il est difficile de décrire les voies de trafic prévues, il faut consulter les cartes fournies dans le rapport pour les diverses catégories de navires et périodes de temps (voir les sections 7.3.1 et 7.3.2).

La présente analyse du trafic maritime (phase 2 – parties 1 et 2) a produit plusieurs résultats importants. Premièrement, l'examen approfondi de la documentation fournit une synthèse de deux aspects fondamentaux requis pour les prévisions du trafic dans l'Arctique : (a) le travail déjà effectué sur des sujets connexes concernant le trafic actuel ou prévu dans le Nord, et la description des facteurs et des conditions qui pourraient modifier les activités des navires; (b) les prévisions quant à l'état des glaces en 2020, et les prévisions ou les tendances possibles liées aux facteurs principaux du trafic de navires dans le Nord, y compris l'exploration et l'extraction de ressources naturelles, les activités touristiques et les changements démographiques. Ces renseignements étaient essentiels à la formulation du modèle de trafic et à l'estimation des paramètres d'entrée.

Deuxièmement, il a fallu concevoir un réseau de voies de navigation possibles au moyen d'un réseau de nœuds graphique qui permet au trafic prévu pour l'année 2020 d'utiliser des voies additionnelles en plus des voies actuellement utilisées. Les nœuds du réseau, qu'ils soient actuels ou futurs, sont construits en fonction des zones d'intérêts (ZI), une approche qui peut englober plusieurs types d'origines et de destinations : des zones précises comme des ports et des communautés; des zones spatiales associées à des types précis d'activités comme la pêche ou l'exploration extracôtière, et des points d'entrée à l'Est et à l'Ouest de la ZI de l'Arctique, par lesquels les navires entrent dans le réseau de navigation et en sortent. Pour que les navires puissent le plus facilement possible se déplacer entre les ZI, des arêtes de graphe (aussi nommées arcs) sont créées. Comme la plupart des types de trafic assurent un déplacement aussi direct que possible entre la zone d'origine et la zone de destination, un algorithme d’optimisation a été utilisé pour lier les ZI de façon efficace, qui tenait compte de contraintes comme l’évitement de la terre et les eaux peu profondes. Pour réaliser un modèle de réseau réaliste et possible, il a ensuite fallu intégrer les prévisions en matière de glace pour l’année 2020 dans le modèle, ce qui influera sur le trafic pour ce qui est des destinations et des temps de navigation possibles, selon la couverture des glaces, le type de glace et le type de navire. La dernière étape consistait à élaborer un algorithme temporel pour la dispersion du trafic; en effet, puisque les contraintes en matière de glace changent, le modèle doit permettre aux navires de naviguer pendant les mois où ils ne peuvent le faire à l’heure actuelle.

Troisièmement, on a produit, dans le cadre de cette étude, un mécanisme pour inclure un élément d’incertitude lié à plusieurs facteurs simultanés aux prévisions du trafic pour 2020. Le modèle comprend cinq catégories de changements liés au trafic actuel dans l’Arctique : nouveaux points d’arrivée (ZI), nouveaux trajets, mélange modifié de types de navires, augmentation ou diminution du volume du trafic (par type et emplacement) et horaire des voyages. Le réseau de nœuds est essentiel à l’exécution des deux premiers types de variations et l’algorithme temporel de dispersion du trafic est utilisé pour le dernier. Grâce à la méthode de simulation de Monte Carlo, on peut modéliser les variations probables de divers facteurs de trafic comme le minimum, le maximum et le nombre probable de navires à destination ou en provenance d’un site d’extraction de ressources, ainsi que les variations dans la croissance démographique ou dans le pouvoir d’achat des communautés nordiques, au moyen d’une formule standard comme une distribution triangulaire de probabilité. Le fait d’exécuter le modèle des milliers de fois en procédant à un échantillonnage des distributions pour chaque facteur d’entrée génère des prévisions de voies de trafic globales dans l’ensemble du Nord; le résultat représente la valeur la plus probable (mode) par type de navire, emplacement et horaire (mois), de même que l’étendue statistique pour chacune de ces valeurs de sortie.

La quatrième contribution importante du projet est le résultat découlant des simulations. Les prévisions spatio-temporelles, classées par type de navire, par emplacement et par mois, permettent une planification stratégique pour améliorer la sécurité, comme la planification de ressources pour les activités de recherche et sauvetage, et l’amélioration de la surveillance maritime. L’intégration de l’élément d’incertitude dans le modèle permet aux décideurs d’évaluer les répercussions des scénarios bas comparativement à celles des scénarios élevés. Le fait que les résultats des scénarios proviennent de la simulation de Monte Carlo est utile, car il est beaucoup moins réaliste d’utiliser un scénario bas pour tous les facteurs simultanément ou un scénario élevé pour tous les facteurs simultanément.

Enfin, la cinquième et la plus importante contribution du projet est que tous les éléments du modèle ont été intégrés au sein d’un outil convivial de simulation pour les prévisions spatio-temporelles du trafic dans l’Arctique. Bien que l’on puisse soutenir que le fait d’avoir un modèle de simulation qui peut exécuter différents ensembles de paramètres est habituellement nécessaire (au lieu d’un modèle qui ne peut produire qu’un résultat précis), il est particulièrement pratique dans ce contexte, car la complexité et la volatilité de nombreux facteurs d’entrée signifient que de nombreux essais seront requis au fur et à mesure que les facteurs évoluent avec le temps ou que des renseignements additionnels permettent de clarifier les relations entre les facteurs et les voies de trafic.

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1. Introduction

1.1. Analysis of Marine Traffic: Purpose

As ice conditions evolve in the Arctic and natural resources prices increase, maritime activity in the Canadian Arctic is expected to grow over time. Zones of interest across the arctic are related to human activity, mostly to exploit natural resources such as mines, oil and gas, and fish. Therefore, a projection of maritime traffic in the Arctic for the year 2020 depends on what is feasible, which is largely tied to forecasted ice conditions, and what is likely given the different factors that drive demand for various types of ships.

The Analysis of Marine Traffic (AMT) project was initiated with an overall goal of producing spatial and temporal analyses of marine traffic in Canadian waters and their approaches, including Arctic waters. The information is required by Defence Research and Development Canada (DRDC) and the Canadian Forces for analysis and planning purposes. Specific end use purposes are best described by the text from the original Statement of Work from DRDC:

> *Canada First* Defence Strategy calls for the Canadian Forces (CF) to work closely with federal government partners to ensure the constant monitoring of Canada's territory and all air and maritime approaches, including in the Arctic, in order to detect threats to Canadian security as early as possible. Canada Command[1] is the national military authority responsible for the conduct of all domestic operations. As such, Canada Command will conduct operations to detect, deter, prevent, pre-empt and defeat threats and aggression aimed at Canada within its area of responsibility (AOR). The Command is also responsible for the effective operation of the federal maritime and aeronautical search and rescue (SAR) system.
>
> Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) is conducting various research activities aiming to help Canada Command and subordinate organizations to improve how operations are planned and conducted. In order for DRDC CORA to accurately simulate marine traffic, surveillance activities, as well as SAR activities, a comprehensive understanding of marine traffic occurring inside and near Canadian waters is required. Analyses of seasonal and geographical patterns in marine traffic help to build this understanding. They also contribute to better estimate the risks of various types of undesired activities and marine incidents to occur inside the Canada Command AOR, and will help Canada Command to allocate resources for maximizing maritime domain awareness and operational effectiveness.

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[1] Since October 2012, Canada Command functions are now under the responsibility of the Canadian Joint Operations Command (CJOC).

This study has been conducted in phases, as described in Section 1.2 below. Within this overall plan set out by DRDC, this second phase of the project focuses on producing projections of shipping densities in the Arctic for the year 2020, as described in the Statement of Work:

> In this phase, the Contractor must produce projections of shipping densities in the Arctic for the year 2020. The projections must be based on a number of scenarios and assumptions agreed with, and accepted with, the Technical Authority. As in the first phase, the results must be delivered in the form of shipping density maps and reports. The Contractors must again identify, develop and use appropriate track generation algorithms or statistical techniques (as required) to mitigate gaps in the data and produce accurate projections of the estimated densities.

Thus the final outcome of this study is twofold:

1. a spatio-temporal maritime traffic simulation tool based on a route network in the Arctic that can generate realistic traffic patterns based on feasibility (forecasted ice conditions) and likelihood (Monte Carlo simulations to accommodate the uncertainty in the demand factors);
2. traffic projections in the Canadian Arctic for the year 2020 by vessel type, location, and month, including the most likely volume of traffic, as well as a low case and a high case.

1.2. Analysis of Marine Traffic: Study phases

The Analysis of Marine Traffic (AMT) project was broken into phases, with the Phase 1 study yielding density maps of shipping and boating activity in the maritime areas on Canada's three coasts (Hilliard and Pelot 2012). Phase 2 of the project focuses on producing projections of shipping densities in the Arctic for the year 2020. This second phase was broken down into two major parts.

1. ***Phase 2 – Part 1:*** This stage of the study produced a detailed literature review of the major factors that affect shipping traffic levels in the Canadian Arctic (Engler and Pelot 2012). Climate factors underlie projections of the sea ice geographic extent and monthly variations expected in the year 2020, which in turn determines the feasibility of passage for various classes of ships. The review of demand drivers encompassed all the key factors that determine vessel traffic in the Arctic: mines, oil & gas exploration and production, tourism, commercial fisheries, community resupply, and government services.

2. ***Phase 2 – Part 2:*** This final part of the Arctic maritime traffic simulation, as reported herein, comprises two major contributions. Firstly, literature review updates were conducted for two of the most volatile sectors, mining and oil & gas, to ensure that we are using the most up-to-date information, to account for significant changes in prognostications in the intervening months since the Phase 2 – Part 1 report was completed, and to extract the best possible information to suit the traffic simulation as the model structure was established. These sector updates are presented in Appendices C and D of this report. Secondly, the development of the traffic simulation model, including the effects of forecast ice conditions and maritime traffic

drivers, is described in detail. The traffic levels for the year 2020 resulting from the spatio-temporal simulation are presented in the form of maps and histograms.

It is important to note that the present report is not designed to be a stand-alone report. While the simulation methodology and results are wholly contained herein, the model parameters rely heavily on the literature reviewed in the previous part of this Phase 2 study, and the context for the entire project is also established in the Phase 1 study. Therefore, to avoid redundancy, it is assumed that the reader has referenced the two prior reports. Furthermore, frequent reference is made in this report to sections of the previous reports, so for convenience, abbreviations are used as follows:

- Analysis of Maritime Traffic, Phase 1: **AMT-Ph1**
- Analysis of Maritime Traffic, Phase 2 - Part 1: **AMT-Ph2-Part1**

2. Procedure for Simulating and Forecasting Arctic Maritime Traffic

2.1. Activities and Vessel Type

As the current level of maritime traffic, and the effect of drivers on changes in future activity levels, are different for different types of vessels, it is necessary to classify the vessels to perform the analyses. The classification scheme, developed in AMT-Ph1 commensurate with data availability and the requirements of the traffic models, resulted in the following groupings: Merchant/Bulk/Cargo (M); Fishing (F); Tanker (T); Cruise Ship/Passenger (C); Pleasure Craft (L); Gov't Non-Military (G); Research and Exploration (R); Tugs and Service Vessels (S). These categories are described in more detail in Section 3.2: Ship Position Tracking Systems. Another essential vessel characteristic for our model is the ice class of a ship, as this affects under what ice conditions a passage is feasible (see Section 4). To associate the diverse types of activities in the Arctic to the relevant ship types, Table 2-1 shows the cross-references that were developed in AMT-Ph2-Part1.

Table 2-1: Relationship between vessel category and activity

		Activity								
		Trans-Arctic Shipping	Inter-Modal Shipping	Community Re-Supply	Resources: Oil and Gas	Resources: Minerals	Resources: Fisheries	Resources: other industrial developments	Tourism	Government services and Research
VESSEL CATEGORY	Merchant - Bulk- Cargo	●	●	●	●	●				
	Tanker	●	●	●	●	●				
	Fishing						●			
	Cruise Ship Passenger								●	
	Pleasure Craft								●	
	Gov't Non-Military	●	●	●	●	●				●
	Research & Exploration									●
	Tugs & Service		●	●	●	●				

2.2. Building Scenarios

Developing a methodology for forecasting shipping densities for the year 2020 and mapping the maritime traffic in a Geographic Information System (GIS) involves the following steps:

1. Mapping the current levels of Arctic shipping traffic: The data derived from the Coast Guard managed Long-Range Identification and Tracking (LRIT) database provides time-stamped position information about large ships (see Section 3.2, and AMT-Ph1 report).
2. Identifying the drivers of Arctic shipping traffic: The specific activities that determine the demand for vessel traffic were developed in AMT-Ph2-Part1, with important updates provided in Appendices C and D of the current report.
3. Projecting changes in the identified drivers: The potential changes in activity levels were covered to some extent in AMT-Ph2-Part1, with new information and more details provided in Appendices C and D of the current report.
4. Projecting changes in Arctic shipping traffic: The general impact on maritime traffic for each driver is described in the literature reviews (the full one in AMT-Ph2-Part1, and the updates in Appendices C and D of the current report), but the specific parameters used as the basis of the simulations are listed and justified in each section of the model development. In most cases, this requires setting a range (minimum and maximum values) for each factor, and a most likely value (mode) somewhere between these extremes.
5. Determining the spatial distribution of current and projected traffic: To allow the maximum flexibility in ship routing in the Arctic, a network model (graph) must be constructed which allows potential traffic to travel between Zones of Interest (ZOI). ZOI represent destinations of the traffic (such as a community or mine), origins of the traffic (such as “gateways” into the arctic area of interest on the East of West sides), or areas where activity takes place (such as a fishing zone). Traffic can then be simulated on this network, as a function of the demand for services, and the feasibility or the routes (see Sections 3.3 and 6).
6. Considering current ice coverage and projected changes: The ice conditions needed for this study are acquired form Canadian Ice Service data and projections. The model requires information on the spatial extent, temporal variation throughout the year, and ice type in order to determine accessibility of various ZOI (see Section 4.3)
7. Considering feasibility of passage: The feasibility of passage in any given area at a specified time of the year is determined not only by the ice conditions, but also by the bathymetry and the ice class of the vessel (see Section 4.3.2). Thus scenarios for 2020 traffic levels are run for ships with different ice classes.

Having all these necessary ingredients in place concerning who can go where and why, and what the activity levels are likely to be depending on the drivers, sets the stage to construct the comprehensive spatio-temporal traffic simulation tool.

2.3. Simulation Model Overview

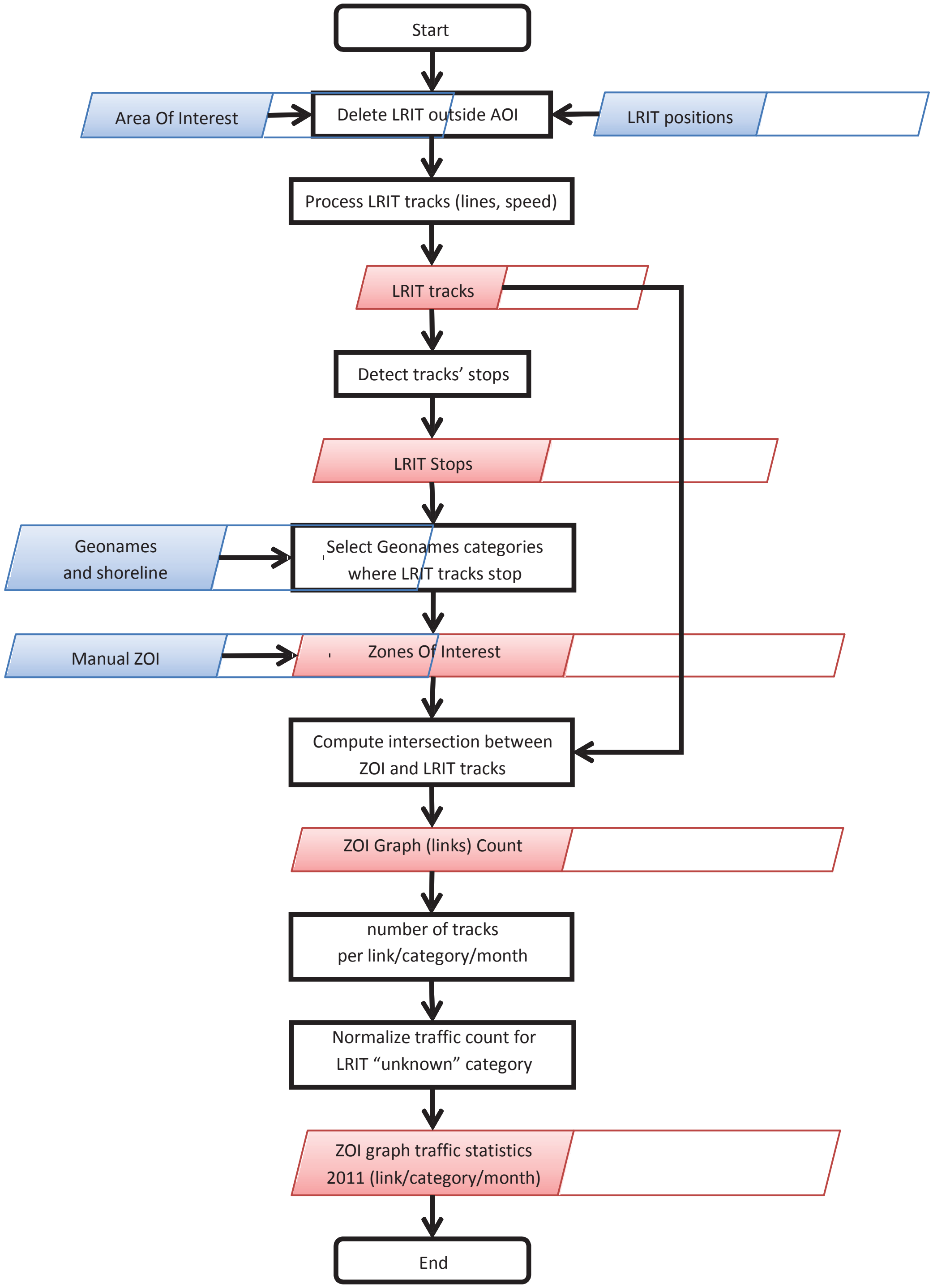
The methodology to develop a comprehensive traffic simulation model comprises three distinct consecutive stages. The detailed steps for each stage are presented using flowcharts. In these flowcharts, blue parallelograms represent inputs to the process and red parallelograms are outputs generated by the different computation steps shown in the black boxes. Some of the outputs shown in red also serve as inputs for subsequent process steps.

- The first stage consists of modeling current maritime traffic using recent LRIT data to define a ZOI graph based on existing traffic destinations, and quantify the amount of traffic per "graph edge", the links that connect zones of interest. The detailed steps of this process are presented in Flowchart 2-1.

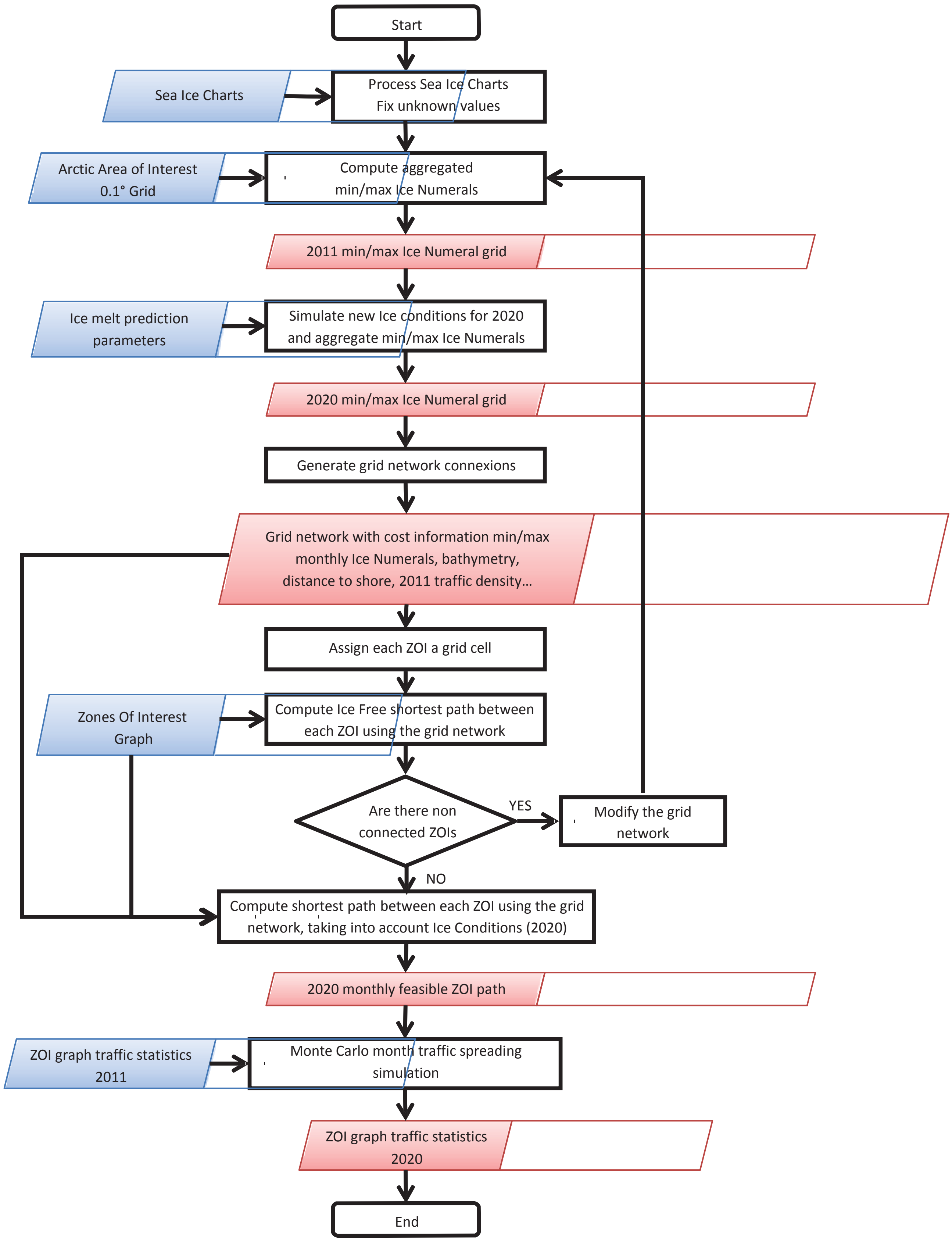
- The second stage of the analysis consists of processing arctic sea ice predictions for the year 2020 and using these predictions to compute monthly ZOI graphs of feasible shipping paths. Based on these monthly feasible path graphs, a simulation tool was designed in order to distribute the potential traffic across the months using a spreading algorithm. This second part of the methodology is presented in Flowchart 2-2.

- Finally, a spatio-temporal multi-criteria Monte Carlo simulation process is applied to generate distributions of future maritime traffic, as illustrated in Flowchart 2-3. The results are stored in a spatio-temporal postgresql database and are visualized using QGIS software to produce maps.

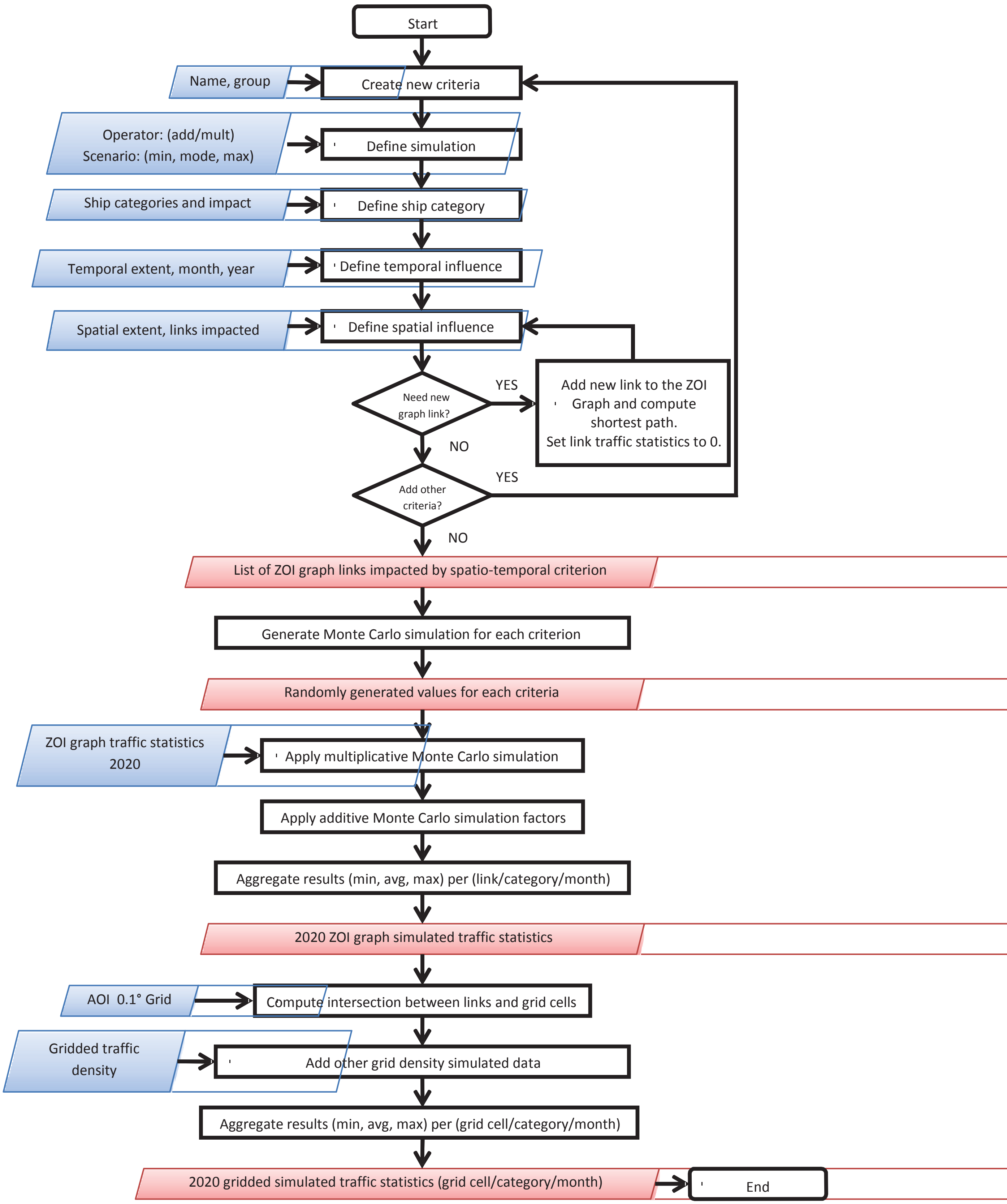
To deal with the fact that most of the factors that affect the traffic levels in 2020 have significant uncertainty in their estimates, the Monte Carlo simulation method is applied for this study (Kroese *et al*. 2011). To do that, each parameter in our model that is uncertain is represented by a probability distribution. We generally used a triangular distribution, using the minimum and maximum estimates for the parameter in question, and the most likely value (represented by the peak of the triangle) somewhere in between (see Section 7.2). "Running" the Monte Carlo simulation implies that a value is randomly sampled from the probability distribution for each factor, and then the selected values are combined using the relationships in the model to determine a specific output for this set of values. The output from such a single run can be referred to as an instance of the model. Then the model can be run thousands or millions of time, and the results from all of the instances aggregated, so that for each model output of interest we obtain a probability distribution, showing its most likely value and range. For example, estimates on the range of production from an arctic mine in 2020 combined with likelihood of ice coverage in the area can be translated into probabilistic estimates of the number of vessels required along associated feasible routes to ship out the product.



Flowchart 2-1: Base layer of arctic maritime traffic statistics



Flowchart 2-2: Monthly feasible path graph and month traffic spreading



Flowchart 2-3: Spatio-temporal multi-criteria Monte Carlo simulation process

3. Arctic Maritime Traffic Model

This section introduces the first part of the Arctic traffic simulation model. The main goal of this section is to compute and analyze the maritime traffic in the Arctic in 2011, as a basis for developing the network model required for future traffic projections. The methodology used in this section is presented in the Flowchart 2-1.

3.1. Area of Interest

The first element to take into account is the spatial scope of the study and the required precision of the results. The area of interest (AOI) of this study has been defined using the AMT-Ph1 300 nautical miles (nm) buffer zone around Canada's northern shoreline to capture maritime traffic in the Canadian Arctic waters. The buffer, as computed and validated in AMT-Ph1, is presented in Figure 3-1.

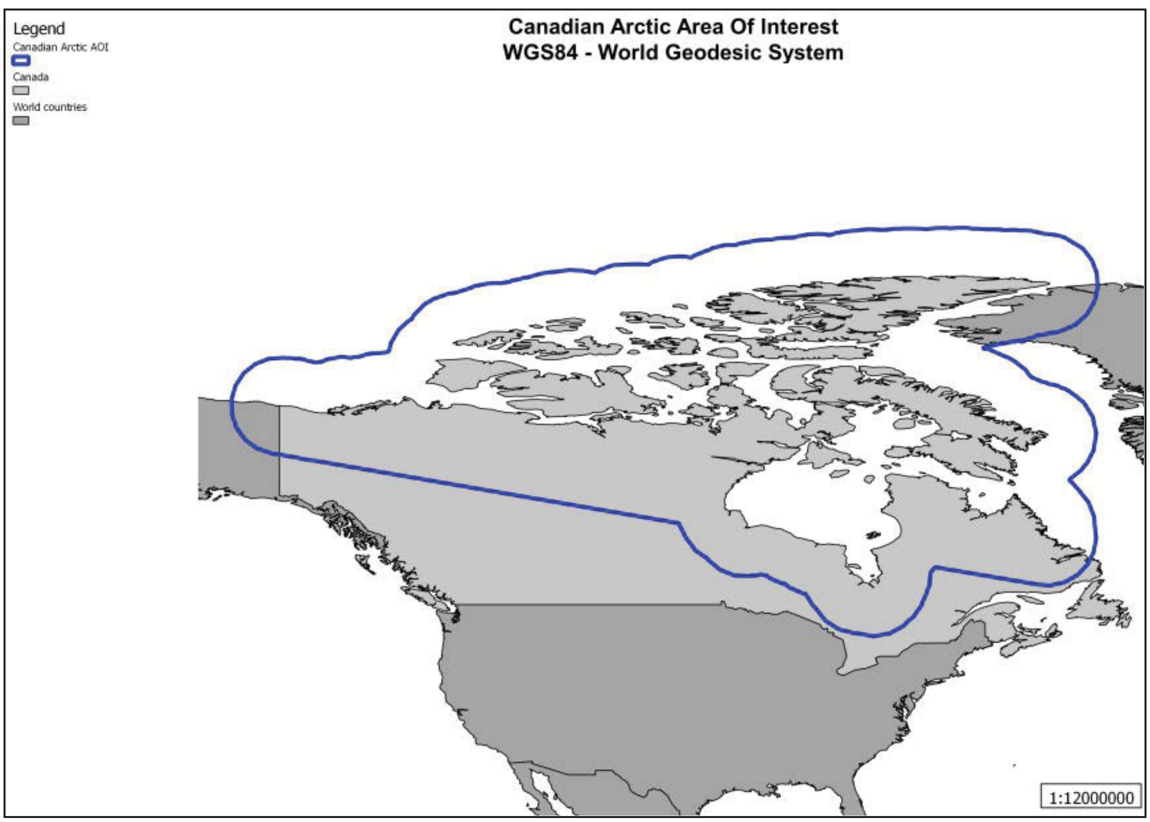


Figure 3-1: Canadian Arctic Area of Interest (WGS84)

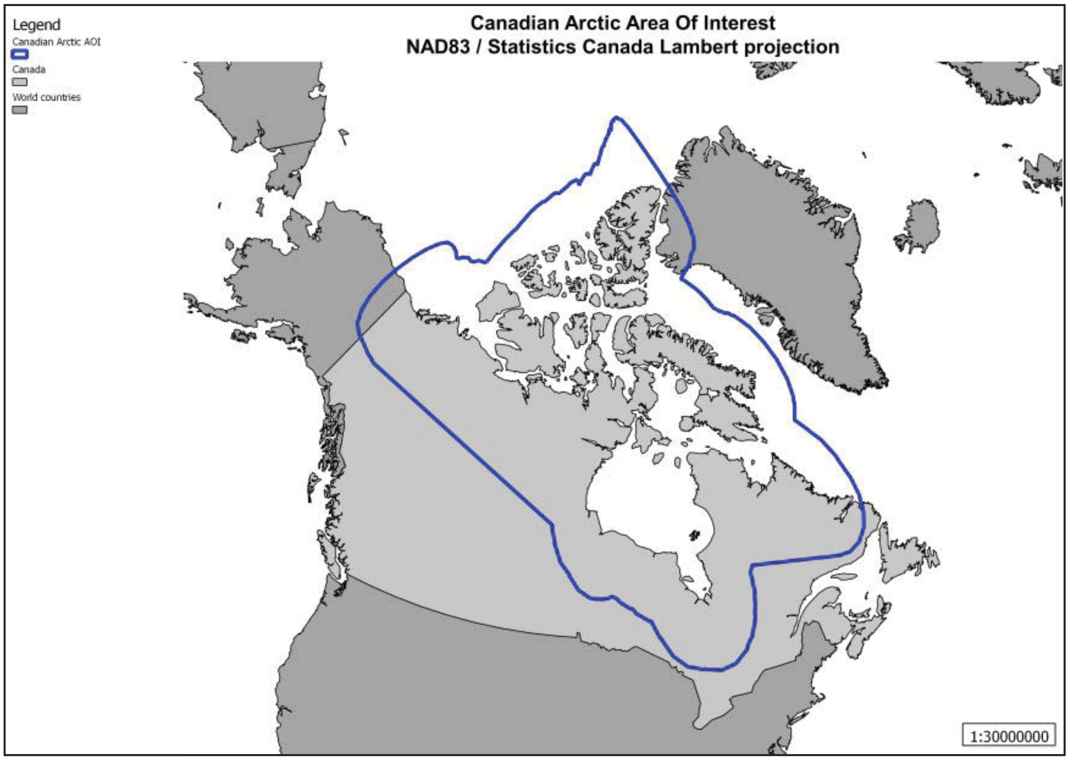


Figure 3-2: Canadian Arctic Area of Interest (NAD83)

To ease visualisation, the maps in this report are projected using NAD83 / Statistics Canada Lambert as presented in Figure 3-2. NAD83 / Statistics Canada Lambert is a projected coordinate reference system suitable for use Canada-wide (onshore and offshore). It uses the NAD83 geographic 2D coordinate reference system and a Lambert Conic Conformal projection defined by Statistics Canada. This projection is referenced as EPSG:3347[2].

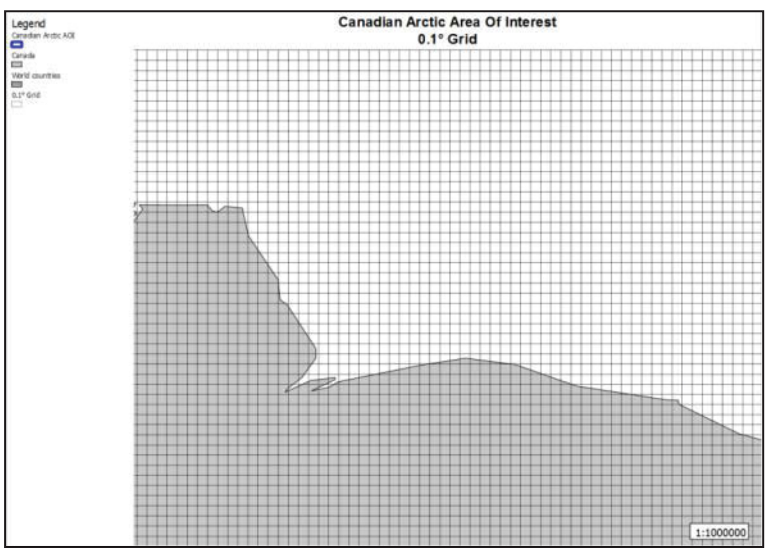


Figure 3-3: 0.1° grid (WGS84)

[2] http://spatialreference.org/ref/epsg/3347/

The requested output of this study is a raster file having a precision of 0.1° expressed in WGS84 coordinate reference system (EPSG:4326[3]). A 0.1° grid has been computed in AMT-Ph1. This grid is presented in the WGS84 coordinate reference system in Figure 3-3 and in NAD83 in Figure 3-4.

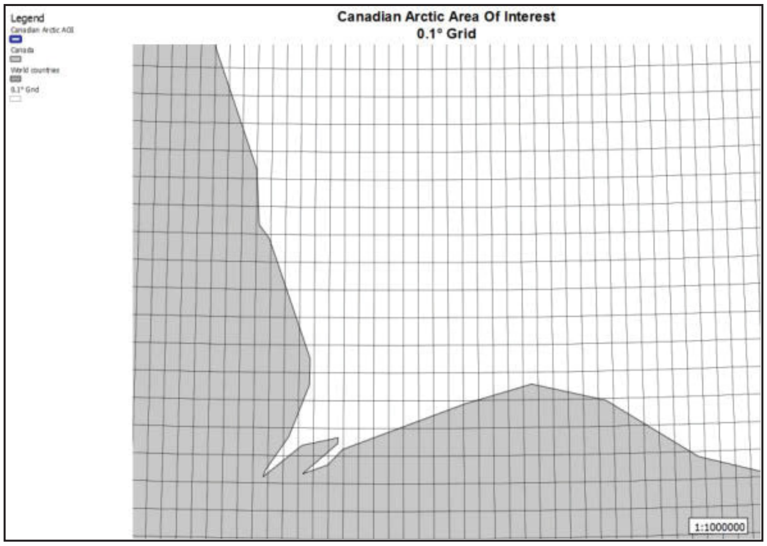


Figure 3-4: Canadian Arctic 0.1° grid (NAD83)

In order to limit computations, grid cells lying on land have been removed from the 0.1° grid using the Shapefile of the Canadian Shoreline. The simplified 0.1° grid is referred to in this report as "arctic 0.1° grid". Figure 3-5 shows the preserved grid cells once the shoreline removal process was applied to the example of Figure 3-4. Note that in AMT-Ph1, three different grid sizes were defined. However during the simplification process, larger grid sizes gave problematic results around small islands. Hence only the smaller size of grid has been used for this study.

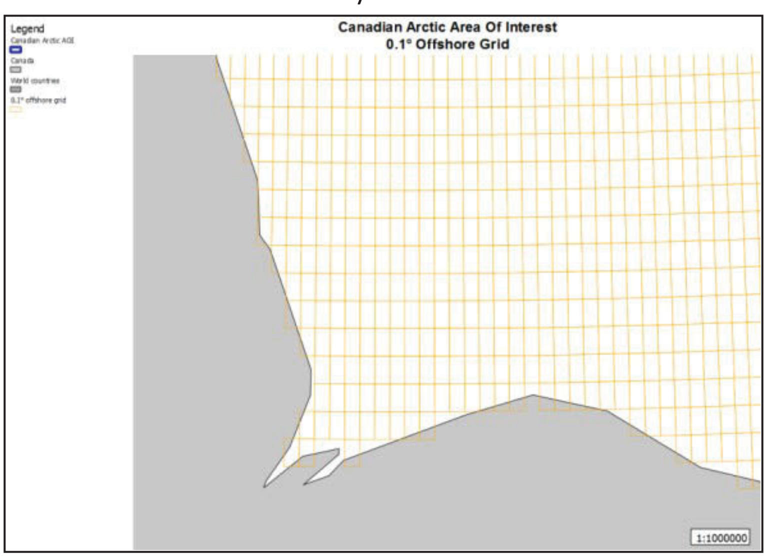


Figure 3-5: Simplified Canadian Arctic 0.1° grid (NAD83)

[3] http://spatialreference.org/ref/epsg/4326/

3.2. Ship Position Tracking Systems

Different systems exist in order to track ship location at sea. The first one is the Long Range Identification and Tracking (LRIT) system. It is an international ship position reporting system established by the International Maritime Organization (IMO), operated through agreements between Maritime nations (Hammond *et al.* 2006). LRIT is mandatory for all SOLAS Contracting Governments as outlined in the IMO's SOLAS Convention. The reporting of the vessels' positions (IMO – LTIR, n.d.) is achieved through signals provided by the Inmarsat GMDSS satellite-based distress system, implemented in order to provide a relatively low cost means of tracking ships given that the distress systems are mandatory carriage on most oceangoing vessels. The tracking scope includes all passenger carrying vessels, as well as merchant vessels with Gross Tonnage (GT) of 300 or more and all Mobile Offshore Drilling Units (MODUs) worldwide from signatory countries. For signatory nations, Coastal States are permitted to receive collated signals of vessels within 1000 nm of their shores, Port States can track vessels out to 2000 nm, and Flag States receive signals from their flagged vessels worldwide.

Another tracking system used to monitor ship positions from shore is the Automatic Identification System (AIS). This system uses a VHF transponder in order to electronically exchange identity and location data between nearby ships, shore-based stations or satellites. The International Maritime Organization's International Convention for the Safety of Life at Sea (SOLAS 1974) make the AIS mandatory for international voyaging ships with gross tonnage of 300 or more tons and all passenger ships. The initial and main purpose of this system was to enhance RADAR abilities in order to avoid ship collisions.

In the Canadian Arctic, there are very few AIS base stations able to collect AIS signal from ships navigating in the arctic (sparse AIS base station network). There are land-based receivers at Resolute Bay and Iqaluit, with the aim at adding more stations in the future. Satellite AIS has recently been introduced in this area. However, the satellite AIS data source we had access to at the beginning of our study had significant temporal gaps that prevented it from being used for a yearlong analysis. Hence this study is limited to the LRIT dataset available for this analysis. Nevertheless, the methodology developed for this project can also be applied to Satellite AIS position reports as they become more widely available for the arctic.

The LRIT maritime traffic dataset used in this study has been collected by the Canadian Coast Guard for the full year 2011. First of all, the LRIT positions outside the Area of Interest were filtered out of the database (Methodology, Flowchart 2-1, process 1). The LRIT positions reported inside the AOI are presented in Figure 3-1.

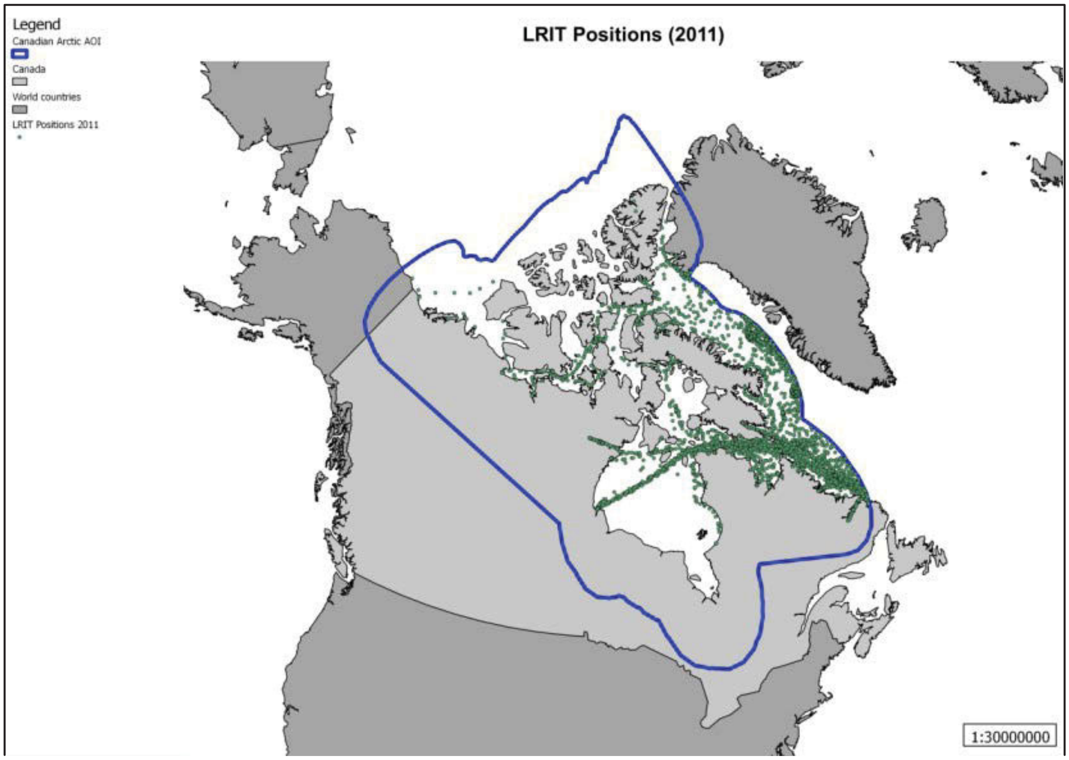


Figure 3-6: LRIT positions (2011)

In order to be consistent with the AMT-Ph1 report, LRIT position reports for the arctic area have been classified into 8 categories (AMT-Ph1, Annex A, Tables 1 and 2). Single letter labels (categories) were assigned to each ship type, to be used throughout the project as a simple reference (Table 3-1). In this report, Tugs and Service Vessels are differentiated from merchant vessels, and are assigned the category label "S" as stated in Table 3-1.

Table 3-1: Vessel Category Labels

Category	Category Label
Merchant / Bulk / Cargo	M
Fishing	F
Tanker	T
Cruise Ship / Passenger	C
Pleasure Craft	L
Gov't Non-Military	G
Research and Exploration	R
Tugs and Service Vessels	S

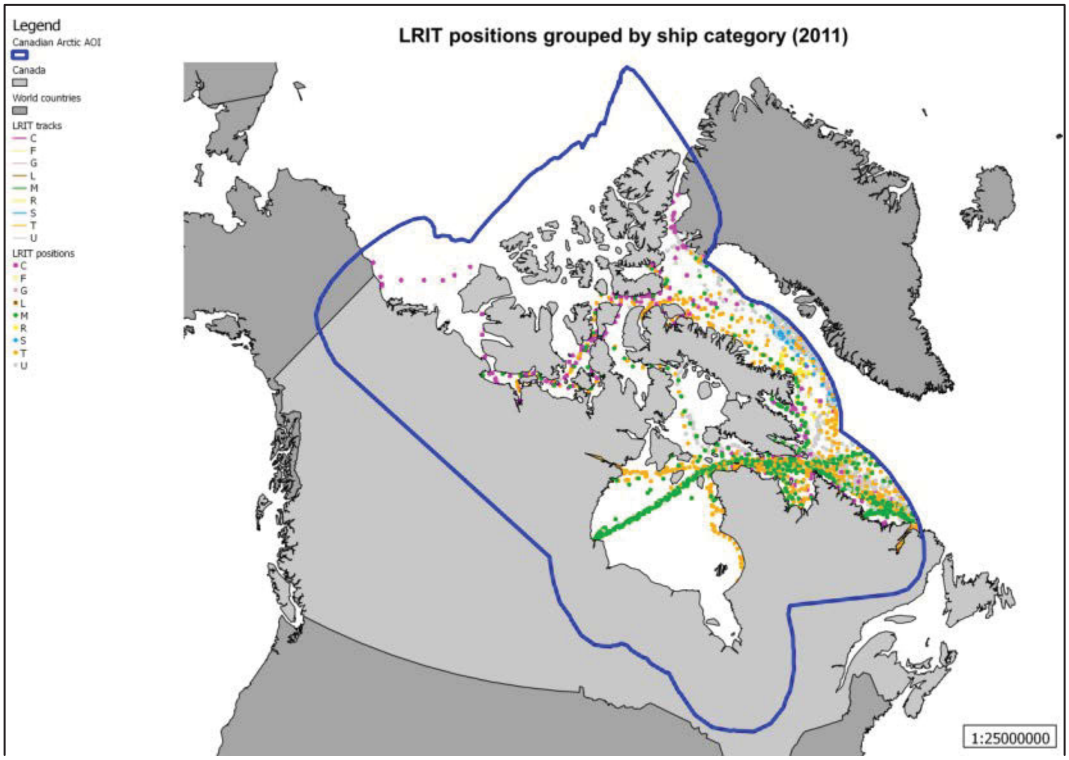


Figure 3-7: LRIT positions grouped by ship category (2011)

For each type of vessel in the arctic LRTI 2011 dataset, the category and number of position reports are shown in Table 3-2. Once aggregated, the LRIT positions per ship categories (2011) are presented in Table 3-1. Figure 3-7 displays the map of the LRIT positions from 2011, grouped by category.

Table 3-2: LRIT positions record by ship type (2011)

Type	Category	Positions
Anchor Handling Tug Supply	S	244
Bulk Carrier	M	1003
Bulk/Oil Carrier (OBO)	T	565
Chemical/Products Tanker	T	2047
Container Ship (Fully Cellular)	M	16
Factory Stern Trawler	F	12
General Cargo Ship	M	714
General Cargo Ship (with Ro-Ro facility)	M	1
Offshore Tug/Supply Ship	S	396
Passenger/Cruise	C	226
Passenger Ship	C	66
Products Tanker	T	279
Research Survey Vessel	R	41
Stern Trawler	F	3
Tug	S	295
Unknown	U	2732
TOTAL		**8640**

Table 3-3: LRIT positions record by ship category (2011)

Category	Positions
C	292
F	15
M	1734
R	41
S	935
T	2891
U	2732
TOTAL	**8640**

Once the LRIT positions have been selected, the second stage of the methodology consists in creating tracks from the LRIT positions (Methodology, Flowchart 2-1, process 2). LRIT positions are connected together using the ship ID and ordered based on the LRIT position report timestamp. The geometric line produced by this process is called hereafter a track of a ship. Figure 3-8 present the 76 different LRIT ship tracks collected in 2011.

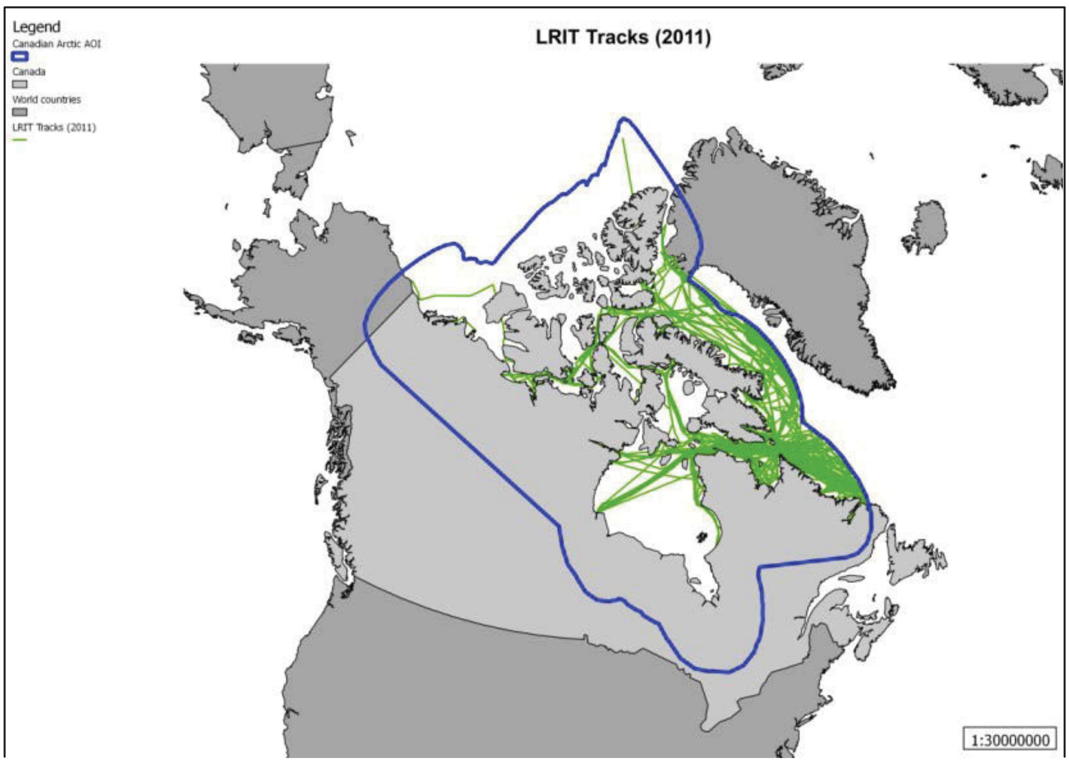


Figure 3-8: LRIT Tracks (2011)

Table 3-4 summarizes the number of tracks generated by ship category, as plotted in Figure 3-9.

Table 3-4: Number of tracks per category (2011)

Category	Number of tracks (2011)
C	5
F	2
M	17
R	1
S	5
T	14
U	32
TOTAL	76

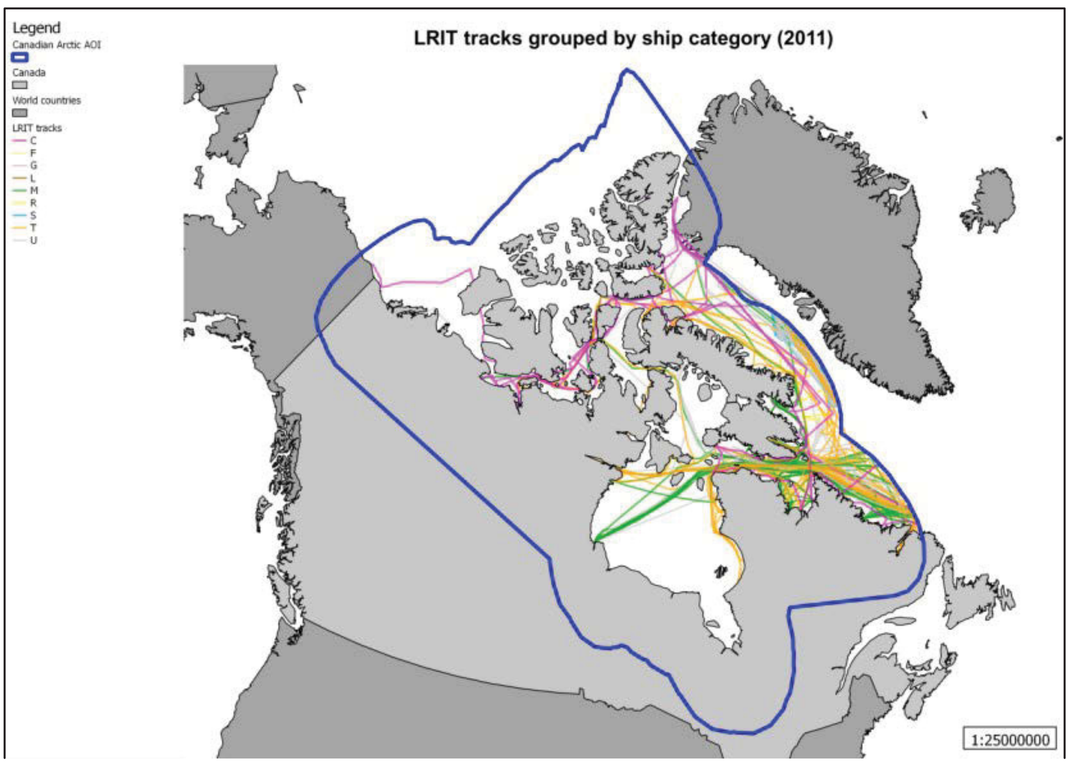


Figure 3-9: LRIT Tracks by ship category (2011)

Based on the relative time order between the LRIT position reports, it is possible to compute the time difference and the straight line distance between two consecutive positions of a track. Using this time and distance difference, the speed of the ship can be computed. This information can then be used to filter out outliers and erroneous data. It can also be used to detect where the ships are making stops (null speed) as described in the methodology (Flowchart 2-1, process 3). Figure 3-10 shows the LRIT position reports having a null computed speed.

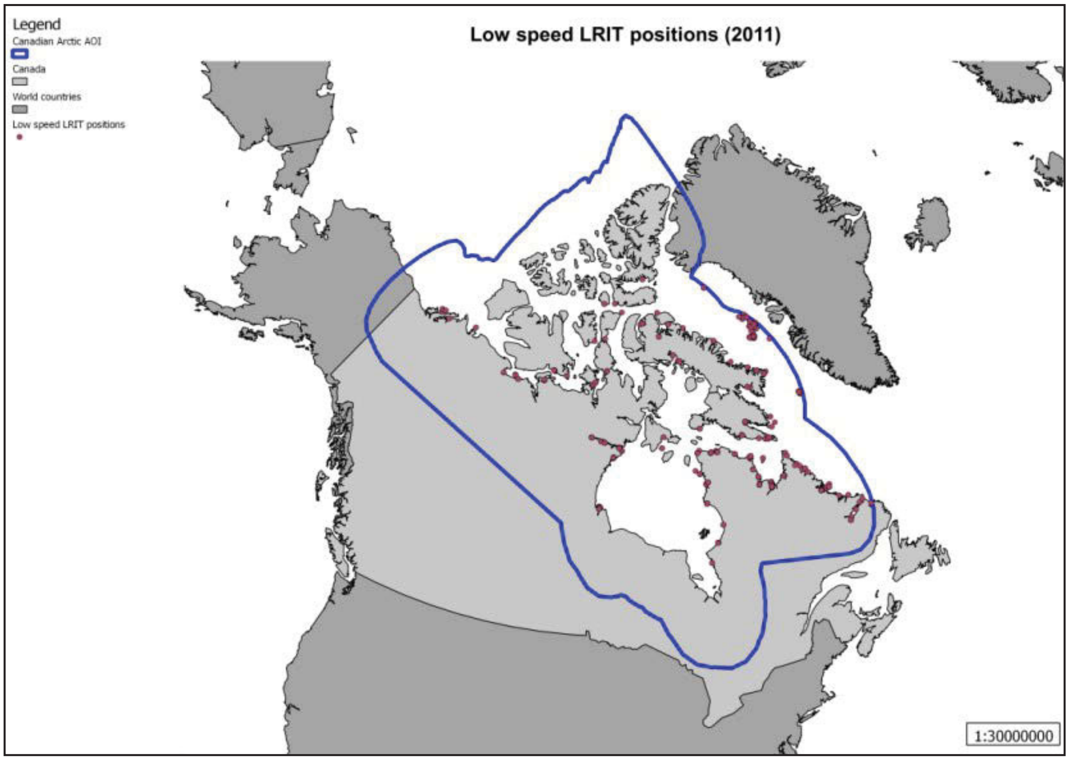


Figure 3-10: Low speed LRIT positions.

Notice in Figure 3-10, that most of the LRIT stops are located along the shoreline as expected. This information is useful to establish where ships are going in the Arctic to conduct their activities.

3.3. Current Location of Ships in the Arctic

In this section, we are interested in determining where ships are going in the Arctic. To do so, we used the Canadian Geographical Name Database (Natural Resources Canada 2003). This database contains many different places grouped by categories. A map of all the different locations referenced in this database is presented in Figure 3-11.

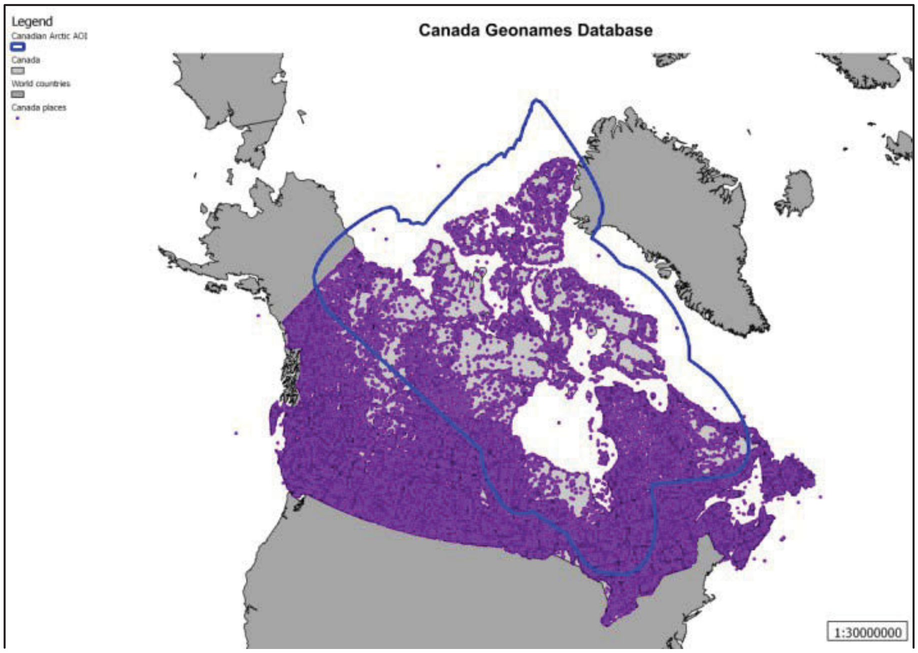


Figure 3-11: Canada Geonames Database.

The next step of the methodology (Flowchart 2-1, process 4) consists in selecting geonames from the database where ships usually stop. First of all, geonames located inland are deleted using a negative shoreline buffer as shown in Figure 3-12.

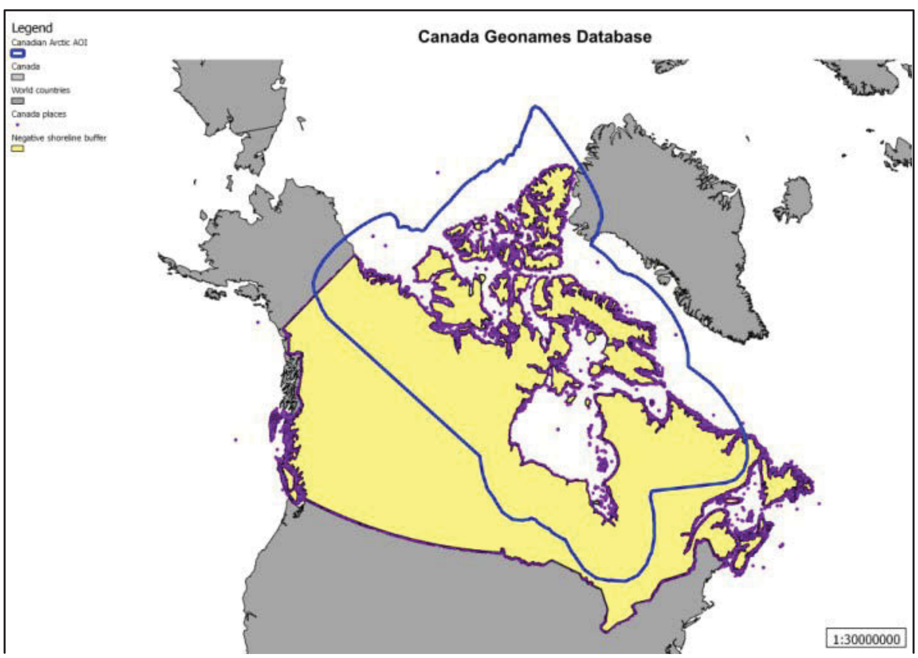


Figure 3-12: Close to shore Canadian Geonames.

Then a visual analysis is conducted in order to select categories of places where ships usually stop. Every resulting geoname location is then selected as a potential Zone of Interest (ZOI) where ships might stop. The map of selected ZOI is presented in Figure 3-13.

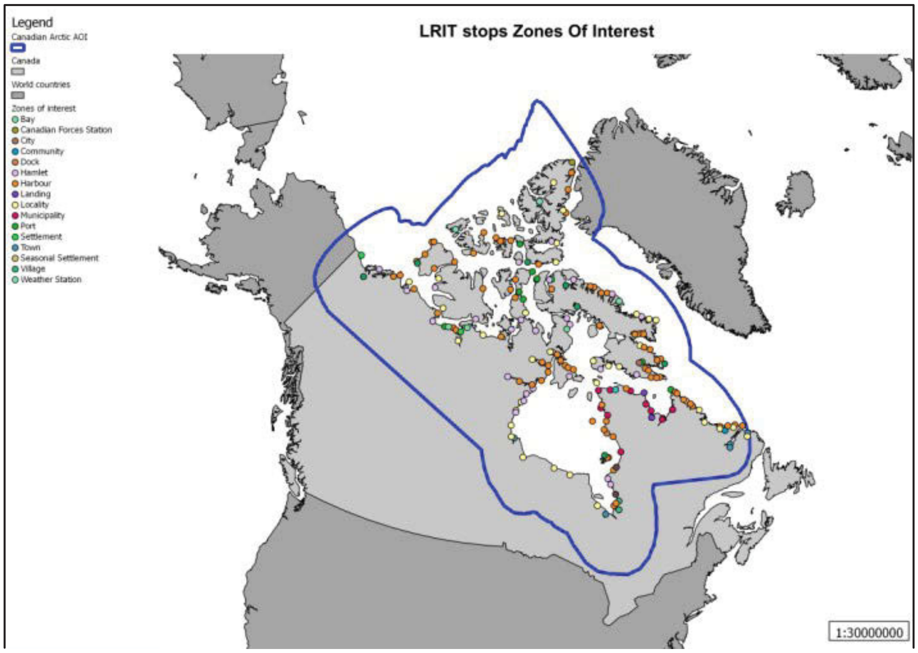


Figure 3-13: LRIT Stops Zones Of Interest.

In addition to the ZOIs determined using the Canadian Geographical Name Database and the LRIT stops, manual zones can also be added to the list. Two manual zones have been added to the list in order to represent the "portals" where ships usually enter or leave the arctic AOI. These two zones have been named EAST and WEST ZOI. Two other areas related to Greenland Oil and Gas exploitation have also been added to the network, as presented in Figure 3-14.

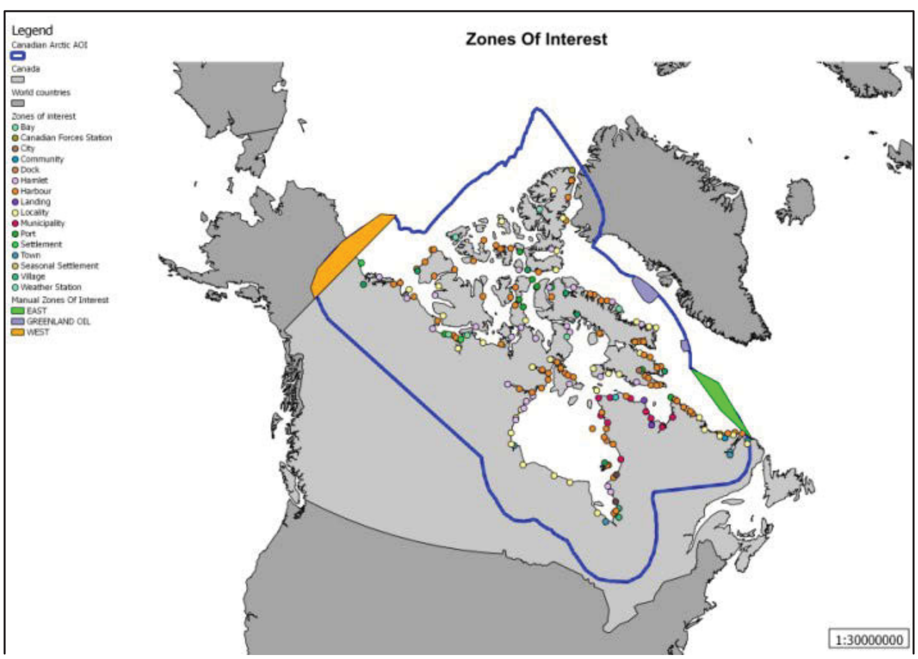


Figure 3-14: Canadian Arctic Zones Of Interest.

Once the Zones of Interest were defined, the next step of the methodology is to analyse how these Zones of Interest are connected via LRIT tracks (Methodology, Flowchart 2-1, process 5). To do so, a buffer was computed around each ZOI position. In this study, the buffer size around a ZOI location was set to 0.1° in order to be aligned with the existing grid precision. This buffer size is big enough to capture LRIT positions inside the ZOI while preventing adjacent ZOI buffers from overlapping. The buffer zone around a sample ZOI location is shown in orange in Figure 3-15.

Figure 3-15: ZOI buffers and LRIT tracks intersections.

Once the ZOI buffer is defined, intersections between the buffer and LRIT tracks can be computed. Special functions were added to the database in order to process the intersection between tracks and the ZOI and to retain temporal information about the time of intersection (i.e. when did the LRIT track enter or leave the ZOI buffer). The results of the intersection computation between ZOI buffers and LRIT tracks are presented in Figure 3-15.

If an LRIT track intersects a ZOI_1 at time t_1 and also intersects another ZOI_2 at time t_2 and $t_1<t_2$, we consider that there is a connection between these two zones of interest. This connection is called hereafter a **link** between two ZOIs. As soon as there is at least one ship navigating between two ZOIs, an edge of the ZOI Graph is created. The intersection points are then sorted by time in order to generate the ZOI links table.

The ZOI links table is then filtered in order to delete the links self-intersecting with the same ZOI. This situation happens when an LRIT track enters a ZOI and leaves it few hours later (navigation inside the ZOI buffer is discarded from the analysis). As we have classified every LRIT ship into the different ship categories during AMT-Ph1, and we have also interpolated the time of the intersections between tracks and ZOI, it is possible to classify ship movements according to the link (i.e. arc) of the graph, the month of the year, and the ship category.

An algorithm was created to extract all the links between ZOI of the graph and count the number of occurrences per ship category and per month (Methodology, Flowchart 2-1, process 6).
Table 3-5 indicates the number of arcs of the graph (links) navigated monthly per category of ship (2011).

Table 3-5: Number of arcs of the graph (links) traversed per category of ship per month

Month	M	F	T	C	L	G	R	S	U	Total
1	1	0	8	0	0	1	0	0	0	**10**
2	0	0	2	0	0	0	0	0	0	**2**
3	2	0	2	0	0	0	0	0	0	**4**
5	0	0	2	0	0	0	0	0	0	**2**
6	6	0	6	0	0	0	0	1	5	**18**
7	23	0	31	0	0	0	0	2	8	**64**
8	20	0	26	34	0	0	0	1	18	**99**
9	18	0	26	30	0	0	0	0	19	**93**
10	46	0	29	0	0	0	1	0	14	**90**
11	17	0	7	0	0	0	0	0	0	**24**
12	2	0	4	0	0	0	0	0	0	**6**
Total	**135**	**0**	**143**	**64**	**0**	**1**	**1**	**4**	**64**	**412**

Although not evident in the table, 164 different (undirected) arcs between nodes of the ZOI graph (links) were navigated by arctic ships in 2011. Some of these links were traversed more than once. The segmentation algorithm results in the LRIT tracks being split into **412** different trips connecting ZOIs. This total number of trips per link is an interesting indicator of the density of maritime traffic and activity on each arc of the graph. The function *count_nb_tracks_per_lin*k was used to count the traffic per link, ship category and month. The results of this function have been saved into the *table link_cat_traffic_count_2011*.

Unfortunately, some LRIT tracks fall into the "unknown" category. We elected to assign these tracks to named categories in proportion to the traffic weight for each link and each month. In other words, we assume that the ships of "unknown" type are distributed in the same way as those whose category is known. This step of the process is called traffic count normalization (Methodology, Flowchart 2-1, process 7). The function *normalize_link_cat_traffic_count* was defined in order to re-assign these portions of the traffic from unknown ship types to a specific category depending on the relative weights of the categories in the 2011 traffic count.

The table *link_cat_traffic_count_normalized_2011* is used to store the results of the normalized traffic count. Based on Table 3-5, the following parameters were used to re-assign the unknown traffic to other categories (Table 3-6). Then the unknown category was removed from the analysis. Note that the results are consistent with the AMT-Ph1 report regarding the simulation of Fishing vessels and Pleasure craft that are not captured by LRIT, which will be simulated using another technique. As the normalization parameters are numeric values, the traffic counts per link are no longer integer values.

The fact that the number of trips per link will be fractional is taken into account when simulating traffic changes.

Table 3-6: Traffic count normalization parameters.

Month	M	F	T	C	L	G	R	S	Total	U
Total	135	0	143	64	0	1	1	4	**348**	**64**
Percentage	**38.79**	**0.00**	**41.09**	**18.39**	**0.00**	**0.29**	**0.29**	**1.15**	**100.00**	

The normalized traffic count per link, ship category and month is the base output of the first part of the process (Methodology, Flowchart 2-1). The results of the normalization process are presented in Table 3-7.

Table 3-7: Monthly traffic count per ship category after normalization.

Month	M	F	T	C	L	G	R	S	Total
1	1	0	8	0	0	1	0	0	**10**
2	0	0	2	0	0	0	0	0	**2**
3	2	0	2	0	0	0	0	0	**4**
4	0	0	0	0	0	0	0	0	**0**
5	0	0	2	0	0	0	0	0	**2**
6	7.94	0	8.05	0.92	0	0.01	0.01	1.06	**18**
7	26.10	0	34.29	1.47	0	0.02	0.02	2.09	**64**
8	26.98	0	33.40	37.31	0	0.05	0.05	1.21	**99**
9	25.37	0	33.81	33.49	0	0.05	0.05	0.22	**93**
10	51.43	0	34.75	2.57	0	0.04	1.04	0.16	**90**
11	17	0	7	0	0	0	0	0	**24**
12	2	0	4	0	0	0	0	0	**6**
Total	**159.83**	**0**	**169.30**	**75.77**	**0**	**1.18**	**1.18**	**4.74**	**412**

Finally, the normalized arctic maritime traffic density count on each link can be grouped by month and summed for each arctic 0.1° grid cell. Figure 3-16 represents the LRIT traffic density links count for the full year 2011.

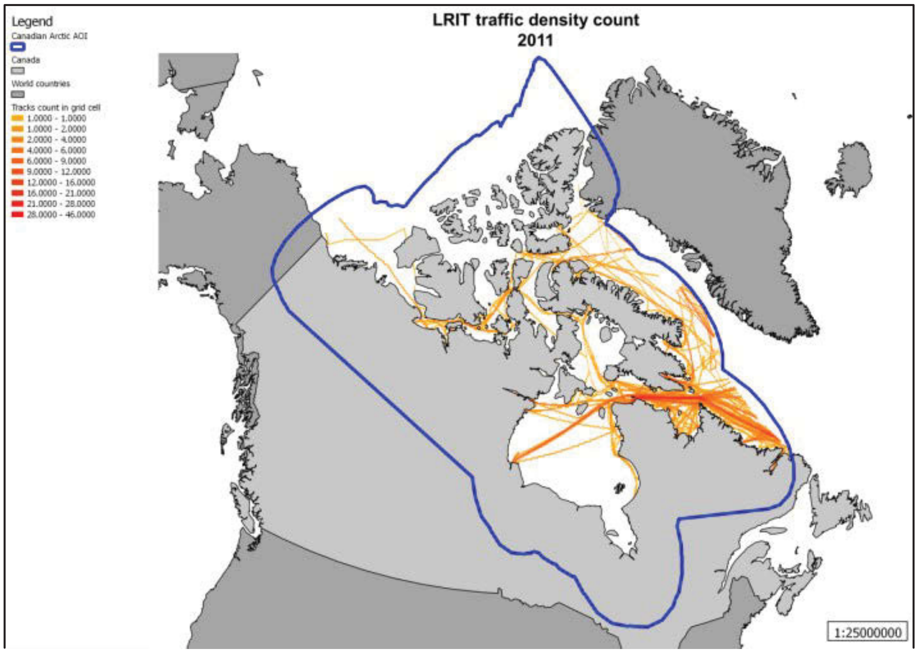


Figure 3-16: LRIT gridded traffic density count (2011)

4. Taking Ice Into Account

This section of the report focuses on the temporal distribution of the Canadian Arctic maritime traffic taking into account the sea ice conditions. The methodology used to address this issue is presented in Flowchart 2-2.

4.1. Impact of Sea Ice on Arctic Maritime Traffic

In order to be able to navigate into sea ice conditions, a ship must have a special hull that can resist collisions with, and pressure from, sea ice and permit it to navigate into these risky waters. Such ships are classified depending on the type of sea ice in which they can operate. A classification system designating Polar Class ships has been promulgated by the International Association of Classification Societies (IACS), (IMO, 2010). IACS Unified Requirements (URs) for Polar Class Ships (UR I1, I2 and I3) took effect in March 2008. New ships built to these URs are assigned a Polar Class (PC) notation ranging from PC1 to PC7 listed in Table 4-1. A Polar Class notation may also be assigned to an existing vessel by applying to an IACS member to have the vessel assessed in accordance with the URs for Polar Class Ships. The IACS URs for Polar Class Ships were developed as a result of international efforts originating at IMO to harmonize the many systems of requirements for polar ice-class vessels.

Table 4-1: Polar Class description

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice, which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice, which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice, which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice, which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice, which may include old ice inclusions

Canada has also its own regulations, and has defined the Canadian Arctic Class type of as described in the Arctic Ice Regime Shipping System (AIRSS) Standards defined in Transport Canada (1998) (Table 4-2).

Table 4-2: Canadian Arctic Class description

CAC	Ice description
CAC 1	An icebreaker that can operate anywhere in the Arctic and can proceed through multiyear ice continuously
CAC 2	A commercial cargo-carrying ship capable of navigation in any ice regime found in the Canadian Arctic
CAC 3	A commercial cargo-carrying ship that can proceed through multiyear ice only when it is unavoidable
CAC 4	A commercial cargo carrying ship that can trade anywhere in the Arctic and can navigate in any thickness of first-year ice
Type A	Operates in thick first-year ice
Type B	Operates in second-stage, thin first-year ice
Type C	Operates in first-stage, thin first-year ice
Type D	Operates in grey–white ice
Type E	Operates in grey ice

4.2. Temporal Distribution of Arctic Maritime Traffic

Ice conditions have a considerable temporal impact on the maritime traffic in the Arctic. As ice melts in the summer, but creates barriers in the winter, the temporal distribution of the Arctic maritime traffic on links of the ZOI graph displays a strong seasonal variation. In order to visualize this phenomenon, the results of the first part of the methodology (i.e. normalized LRIT links count for 2011) have been aggregated using the 0.1° arctic grid. The results produced are the monthly sums of LRIT tracks intersecting the grid cells. Table 4-3 presents the monthly evolution of traffic count aggregated by grid cell in 2011 and Figure 4-1 represents the aggregated normalized traffic in 2011.

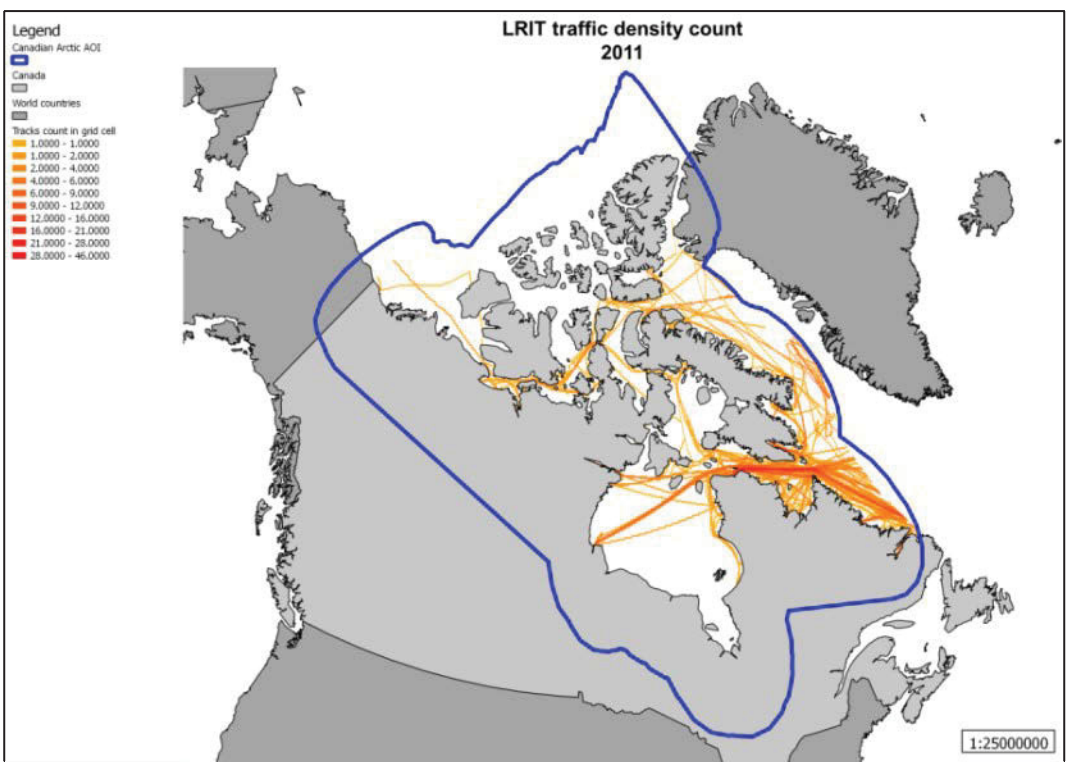


Figure 4-1: LRIT gridded traffic density (2011)

Table 4-3: Monthly evolution of traffic count aggregated by grid cell (2011)

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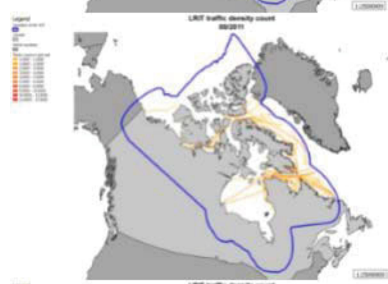

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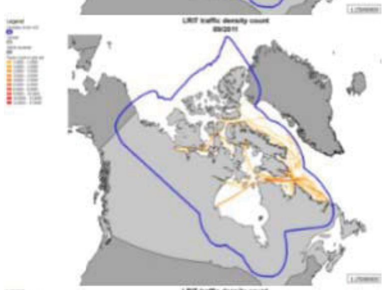

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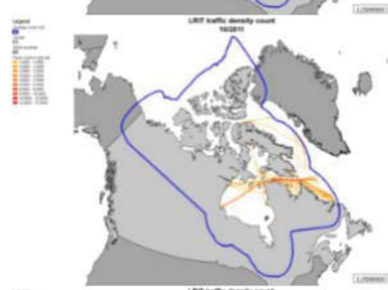

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This significant variation in the temporal traffic density distribution is related to sea ice conditions. Thus, the ice needs to be taken into account in the model. The first step of the second part of the methodology consists in integrating the sea ice charts in our model (Flowchart 2-2, process 1).

4.3. Ice Model

Once the ZOI graph is created, a spatio-temporal analysis of feasible paths between nodes of the graph can be done. Ships can navigate in different types of sea Ice depending on their Arctic class category. Canadian Arctic Class (CAC) ships range from an icebreaker that can operate virtually anywhere in the Arctic and can proceed through multiyear ice continuously (CAC1), down to CAC4 which would be capable of navigating in any thickness of first-year ice found in the Canadian Arctic. Less capable ships are classified as Type A, which can operate in thick first-year ice, through to Type E, which can only handle grey ice. The ships types relevant for our study appear across the top of Table 4-4.

The Canadian Ice Services is the government agency that creates Sea Ice Charts for the Canadian Arctic. These sea ice charts, using the SIGRID-3 format[4] (Canadian Ice Service 2009), give information about the location, concentration, stage of development and form of ice. These datasets can be downloaded from the National Snow & Ice Data Center website (nsidc.org). The SIGRID-3 format can give information about ice conditions in a specific geographic area. It can accommodate three different forms of ice (Fa, Fb, Fc), their stage of development (Sa, Sb, Sc), and their concentration (Ca, Cb, Cc) for each location. For this project, one full year of Sea Ice Charts (2011) was downloaded and integrated into a spatio-temporal database.

A numerical index can be computed in order to determine whether a ship can navigate into an icy area depending on the form, stage of development and concentration of the ice. This index, called the Ice Numeral, is defined in the Arctic Ice Regime Shipping System of Transport Canada (Transport Canada 1998). A ship can navigate in icy areas having a positive Ice Numeral for their ship category (Howell & Yackel 2004, Wilson et al. 2004, Somanathan et al. 2009). The Ice Numeral (IN) is based on the ice form and concentration, as well as the Ice Multiplier (IM) for each arctic class category of ship (Table 1). The two highest ship categories, CAC 1 & CAC 2, are designed for unrestricted navigation in the Canadian Arctic, hence their Ice Multiplier is positive for any Ice Type.

4.3.1. Sea Ice Charts

In order to simulate the feasible paths between ZOI, ice conditions have been computed and aggregated for each month of the year. We collected from the Canadian Ice Services server all the Sea Ice Charts for the year 2011. SIGRID-3 Ice data are summarized in Figure 4-2. The combination of the ice form, stage of development and concentration is frequently referred to as the "Egg Code" due to the oval shape of

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[4] http://www.natice.noaa.gov/products/sigrid.html

the symbol. We encountered a problem during the importation of these data as the Coordinate Reference System used by Canadian Ice Services changed during the year and the projection file was inconsistent with the geographic data of the Shapefile. After investigation with the Canadian Ice Services, they provided additional information to correct for this mistake.

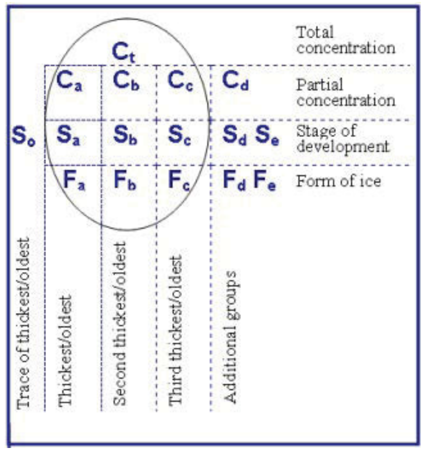


Figure 4-2: Ice categories in Egg Code

Once all the files were downloaded from the National Snow & Ice Data Center[5] and integrated into the database, maps of the Sea Ice Charts zones could be produced. Sea Ice charts data are split into five different zones, as shown in Figure 4-3. Note on that map that these five zones overlap, which can lead to redundant and inconsistent overlapping sea ice charts. In order to get rid of these problems, sea ice conditions were aggregated using the Canadian arctic 0.1° grid. The maximum and minimum ice condition per month in each cell was thus computed.

[5] http://nsidc.org

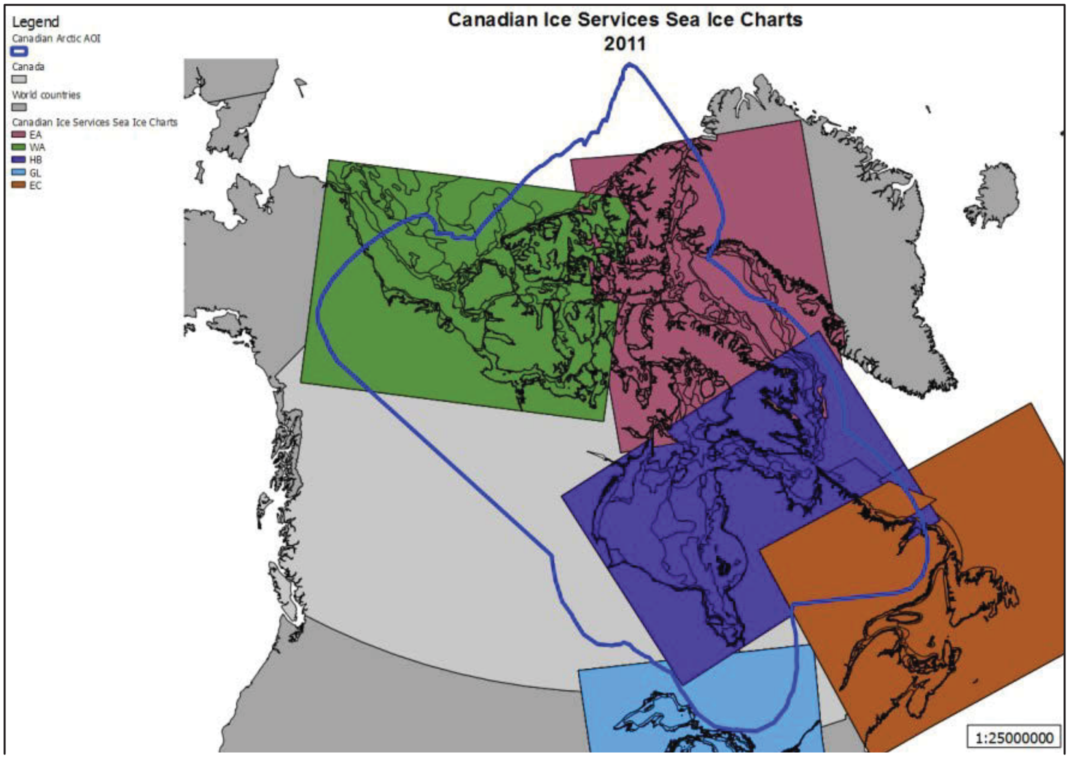


Figure 4-3: Canadian Ice Services Sea Ice Charts : coloured zones (2011)

4.3.2. Ice Numeral

Once the sea ice chart was integrated into the database, the next task was to plot the areas into which a ship can navigate depending on ice conditions. We used the Ice Numeral system defined in the Arctic Ice Regime Shipping System of Transport Canada (Transport Canada 1998). The Ice Numeral (IN) is calculated based on previously defined Ice Forms and Concentration, yielding an Ice Multiplier (IM) table for each arctic class category of ship. For any ice regime, an Ice Numeral (IN) is the sum of the products of:

- Concentration in tenths of each Ice Type;
- Ice Multipliers relating to the Type or Class of the ship in question.

( ) ( ) ( ) (equation 1)

where:

is the Ice Numeral result
is the concentration (in tenths) of Ice Type "a"
is the Ice Multiplier for Ice Type "a" (Table 4-4)

The term(s) on the right hand side of the equation (a, b, c, etc.) are repeated for as many Ice Types and each of their respective concentrations that may be present, including Open Water, in a given ZOI. Ice

Numerals can be calculated from ice conditions as shown in the Canadian Ice Service's MANICE (Canadian Ice Service 2005) or WMO[6] ice "eggs", presented earlier in Figure 4-2.

Table 4-4: Ice Multiplier Table

		Ice Multipliers for each Ship Category						
Ice Types	**Thickness**	**Type E**	**Type D**	**Type C**	**Type B**	**Type A**	**CAC 4**	**CAC 3**
Old/Multi-Year Ice		-4	-4	-4	-4	-4	-3	-1
Second-Year Ice		-4	-4	-4	-4	-3	-2	1
Thick First-Year Ice	**> 120 cm**	-3	-3	-3	-2	-1	1	2
Medium First-Year Ice	**70-120 cm**	-2	-2	-2	-1	1	2	2
Thin First-Year Ice	**30-70 cm**	-1	-1	-1	1	2	2	2
Thin First-Year Ice - 2nd stage	**50-70 cm**	-1	-1	-1	1	2	2	2
Thin First-Year Ice - 1st stage	**30-50 cm**	-1	-1	1	1	2	2	2
Grey-White Ice	**15-30 cm**	-1	1	1	1	2	2	2
Grey Ice	**10-15 cm**	1	2	2	2	2	2	2
Nilas[7], Ice Rind	**< 10 cm**	2	2	2	2	2	2	2
New Ice	**< 10 cm**	2	2	2	2	2	2	2
Brash (Ice fragments < 2 m across)		2	2	2	2	2	2	2
Bergy Water		2	2	2	2	2	2	2
Open Water		2	2	2	2	2	2	2

The two highest (i.e. strongest) ship categories, CAC 1 and CAC 2, are designed for unrestricted navigation in the Canadian Arctic. The different types of Canadian Arctic Class ship can be found in the International Association of Classification Societies Unified Requirements for *Polar Class Ships - Application in Canadian Arctic Waters* and the source *Arctic Ice Regime Shipping System* ship types (Transport Canada, 1998). Table 4-2 describes the different ship class categories listed in these two documents.

The Ice Numerals have been computed for each arctic class of ships. Some assumptions were made while computing the Sea Ice Charts as there were missing data (Methodology, Flowchart 2-2, process 1). Sometimes, the Ice Type is known but the ice concentration is unknown (i.e. set to -9 in the database). Every Sea Ice Chart area from the Canadian Ice Services Sea Ice Charts dataset can have up to 3 different Sea Ice Stages of Development (S). These 3 stages are labeled Sa, Sb and Sc. It is stated in the International Ice Charting Working Group's SIGRID-3 Vector format description document that Sa should be the thinner Ice Type, Sb should be thicker than Sa, and Sc thicker than Sb. If concentrations are unknown, Table 4-5 indicates the assumptions that we made for ice concentration.

[6] World Meteorology Organization

[7] Nilas designates a sea ice crust up to 10 centimetres (3.9 in) in thickness. It bends without breaking around waves and swells. (Wikipedia)

Table 4-5: Concentrations assumptions for unknown data

	SIGRID-3 Data (%)			Assumption (%)		
	Ca	**Cb**	**Cc**	**Ca**	**Cb**	**Cc**
All unknown	**?**	**?**	**?**	50	30	20
One Unknown	**?**	Cb	Cc	100-(Cb+Cc)	Cb	Cc
	Ca	**?**	Cc	Ca	100-(Ca+Cc)	Cc
	Ca	Cb	**?**	Ca	Cb	100-(Ca+Cb)
Two unknown	Ca	**?**	**?**	Ca	[( )]	[( )]
	?	Cb	**?**	[( )]	Cb	[( )]
	?	**?**	Cc	[( )]	[( )]	Cc

Having complete information about ice coverage, type and concentration, the Ice Numeral can then be computed for every grid cell of the arctic AOI. Intersections between cells and Sea Ice Charts were computed for every month. As there may be multiple different Sea Ice Chart reports per month, the maximum value and minimum value of the Ice Numeral were computed for every cell per month to generate “best case” and “worst case” conditions.

Ice Numeral values can range from:

100% Ice Free → 10 * (**+2**) = **+20**

100% Multi Year Ice for Type E ships → 10 * (**-4**) = **-40**

These Ice Numerals are then computed for each category of ship and aggregated using the Canadian Arctic 0.1° grid. The maximum (IN_{max}) and minimum (IN_{min}) ice numeral per month and type of ship in each cell were computed. If we sum all the Ice Numeral values for each type of vessel, the Ice Numeral Sum (IN_S) value can range from:

100% Ice Free (for every ship category) → 7 * 10 * (**+2**) = **+140**

100% Multi Year Ice (for every ship category) → 5 * 10 * (**-4**) + 10 * (**-3**) + 10 * (**-1**) = **-240**

The minimum (IN_{Smin}) and maximum (IN_{Smax}) Ice Numeral Sum can be computed for each grid cell. These two values can finally be aggregated into an overall indicator called ‘Ice Numeral aggregated’ (IN_{agg}), ranging from **-480** to **+280**. These two extreme values will be reached when the minimum and maximum conditions are the same (no change in ice condition among the month), these equal minimum and maximum conditions can be either the best case (twice 100% Ice Free = 2***+140** = **+280**) or the worst case (twice 100% Multi Year Ice = 2***-240** = **-480**).

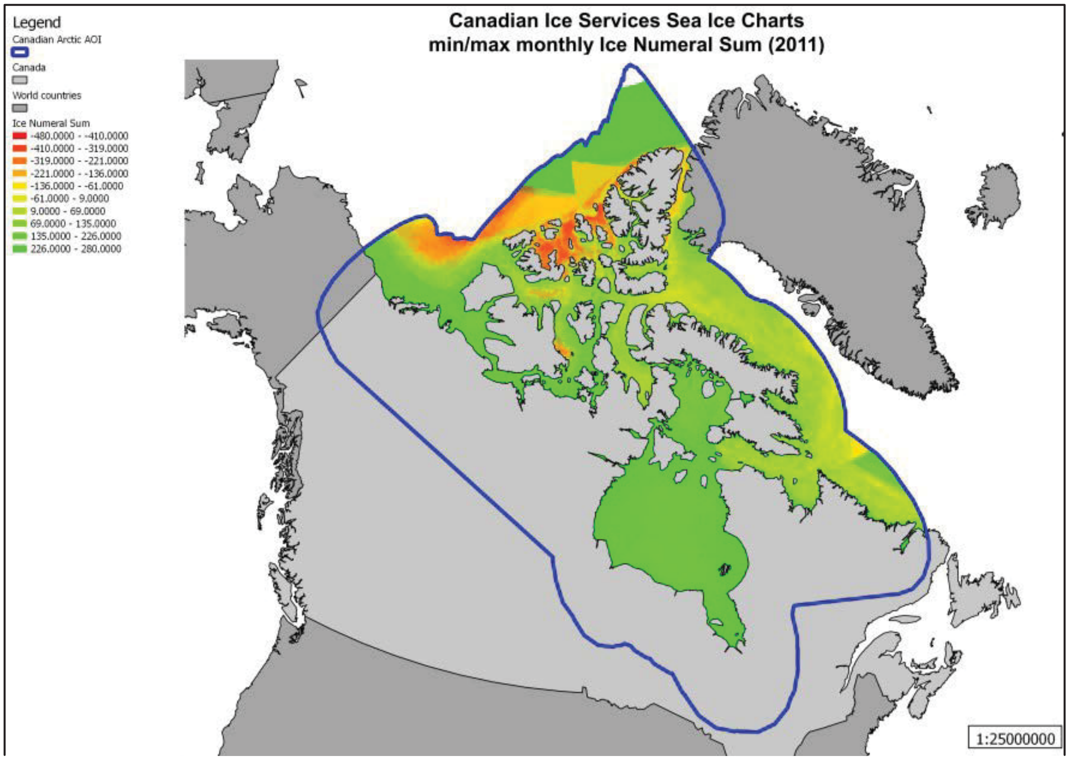
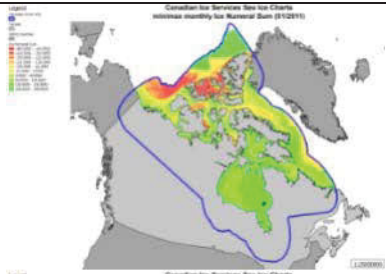
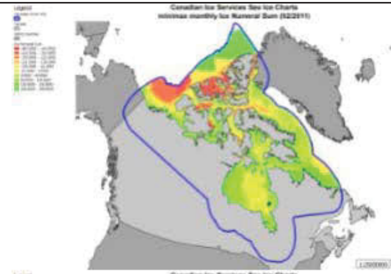
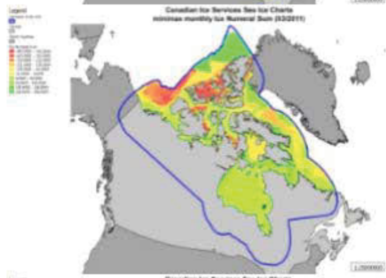
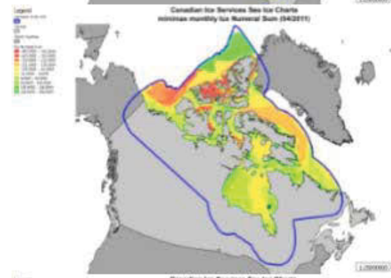
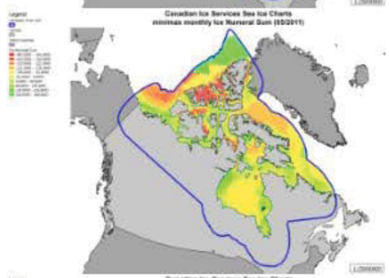
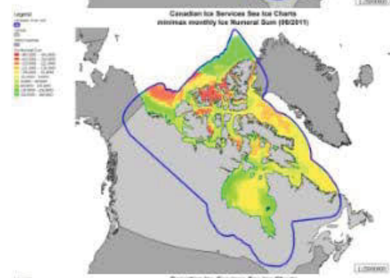
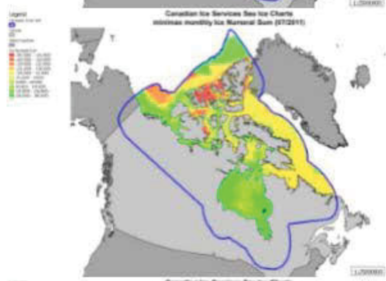
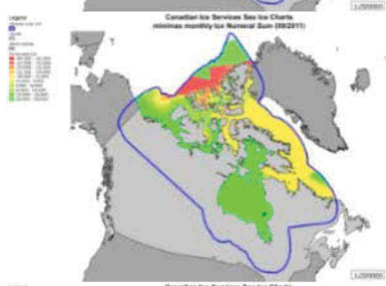
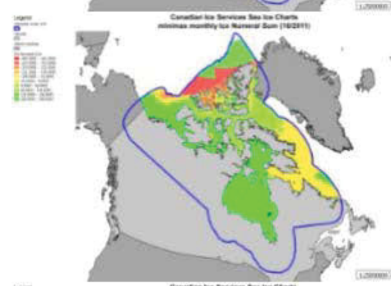
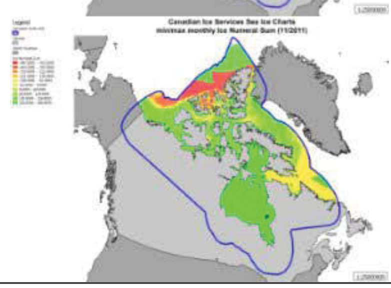
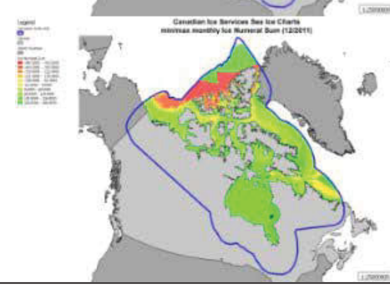


Figure 4-4: Ice Numeral Sum overlay (2011)

Figure 4-4 illustrates the sum of min/max Ice Numeral values computed for 2011 (Methodology, Flowchart 2-2, process 2). The red color indicates the lowest Ice Numerals (more dangerous for navigation) and the green color indicates the highest Ice Numerals (less dangerous). Table 4-6 depicts the monthly temporal variation of sea ice conditions using the Sum of Ice Numerals.

Having the Ice Numerals for each month and each cell of the Arctic AOI, we can know the areas where ship can navigate depending on their arctic class. Moreover, we have computed for each cell the maximum and minimum IN per class of ship. Thus, we have a minimum and maximum bound for each cell.

Table 4-6: Monthly evolution of Ice Numeral Sum aggregated by grid cell (2011)

1		2	
3		4	
5		6	
7		8	
9		10	
11		12	

4.3.3. Ice Prediction

Based on the Ice Numeral grid for 2011 and an ice prediction for the year 2020 from the literature, we computed an Ice Numeral Prediction Grid using the following assumptions. As quoted from Maurette (2010):

> *"Future projections indicate that as warming continues, first year ice is replacing multi-year ice, leading to a permanent thinning of the sea ice. It is expected that by 2020, the ice extent would be down another 20% in summer".*

Using our model for 2011, we can compute the Ice Numeral for each arctic class category of ship in 2020 assuming a decrease in Ice Type by 1 (e.g. multi-year ice becoming first year ice) and decreasing the concentration of ice by 20% (Methodology, Flowchart 2-2, process 3). Results of the Ice Numeral Sum for 2020 ice prediction model are presented in Figure 4-5.

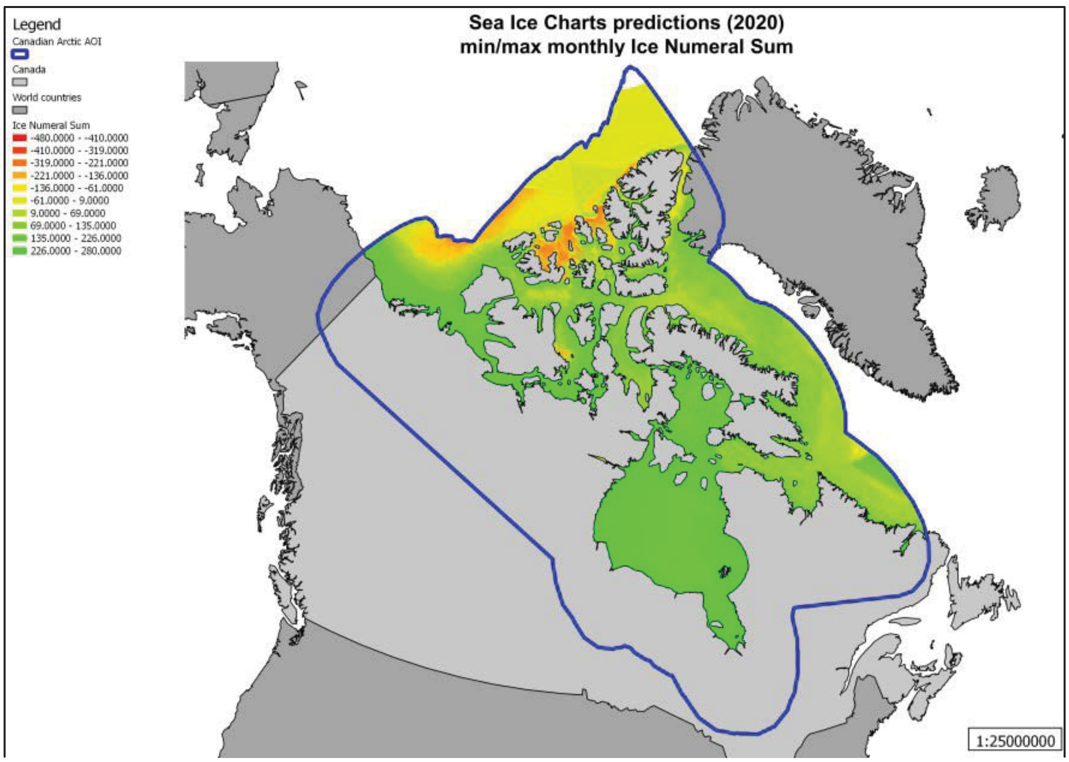
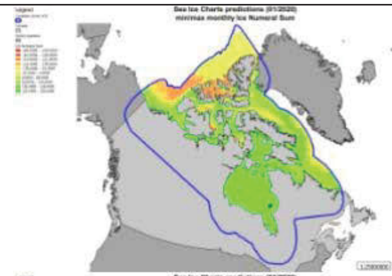
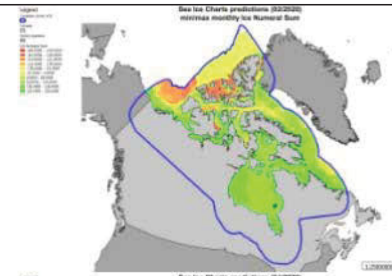
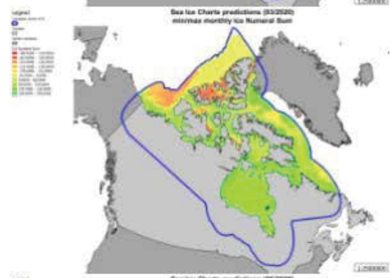
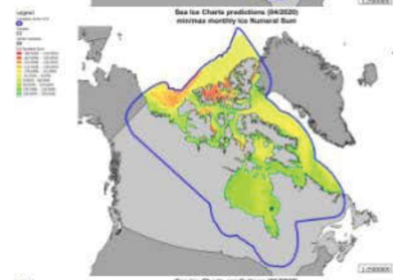
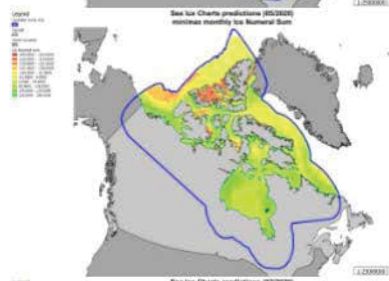
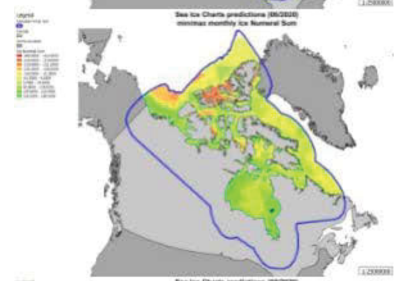
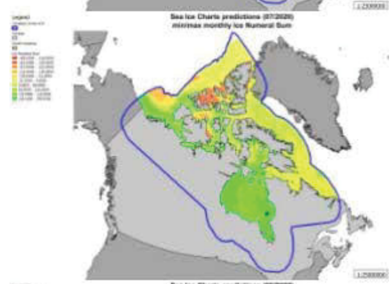
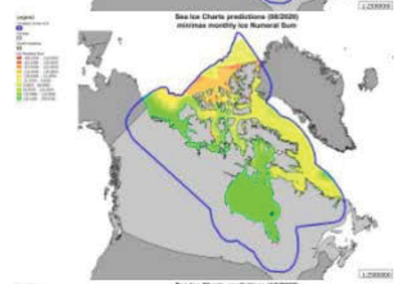
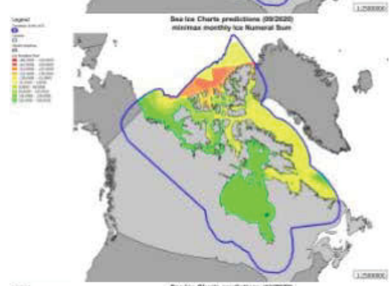
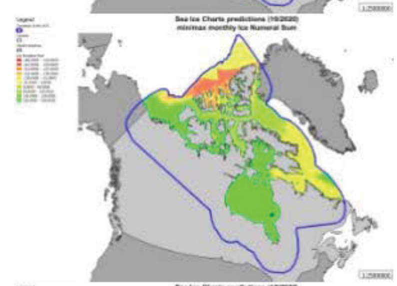
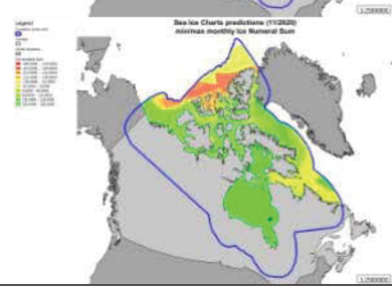
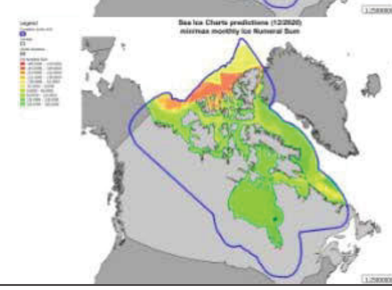


Figure 4-5: Ice Numeral Sum overlay (2020)

Also note that the results obtained for CAC3 arctic ice vessels would be the same for CAC1 and CAC2 ships, as there will not be any negative Ice Multiplier for this category of arctic ship (this means they can navigate all over the Arctic without restriction all year long). Table 4-7 depicts the monthly temporal variation of sea ice predicted condition for 2020 using the Ice Numeral Sum.

Table 4-7: Monthly evolution of Ice Numeral Sum aggregated by grid cell (2020)

1		2	
3		4	
5		6	
7		8	
9		10	
11		12	

5. Navigable Area

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 of the graph depending on the arctic class of the ship. Unfortunately, the LRIT database provided does not include information about the Canadian Arctic Class of the tracked ships. Moreover, this information could not be found on the internet as the ID of the ships has been anonymized. We performed an analysis of the Ice Numeral encountered by ships during the 2011 LRIT-tracked trips in order to classify them *post hoc* into different arctic class categories. It appears that most of the ships navigate in areas where only CAC3 ship could go at the time of the year indicated.

In order to perform the classification, we created a track for every trip and categorized them by month. Then we computed the intersection between tracks and Ice Numeral grid cells for each month. We took into account the maximum value for each ice grid cell (the best navigable ice condition for that month) and then retained the minimum of the maximums for each arctic class category. As a ship is not supposed to navigate into a negative Ice Numeral area for its arctic class, we classified the ship on each trip using the minimum required arctic class which has a non-negative Ice Numeral for those conditions. Table 5-1 summarizes the results for this ship classification. It appears that most of the ships operating in the Arctic are CAC3 Canadian Arctic Category ships.

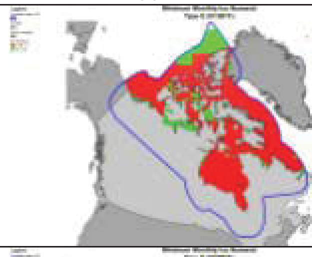
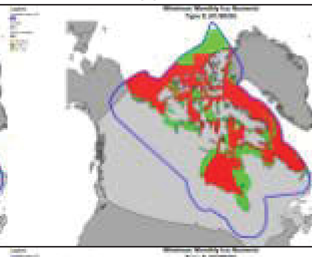
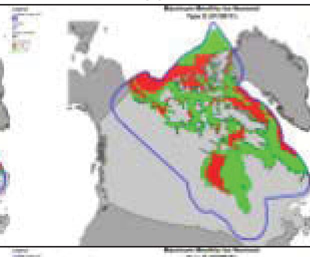
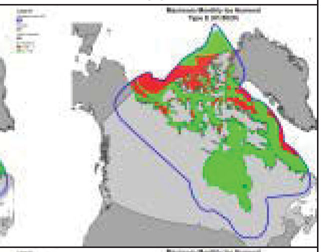
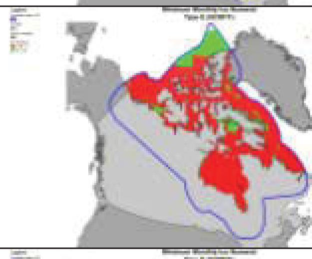
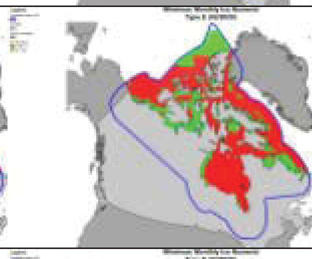
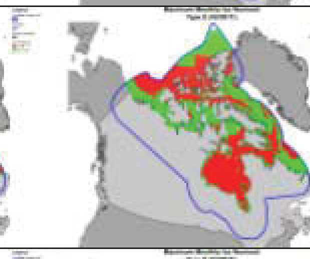
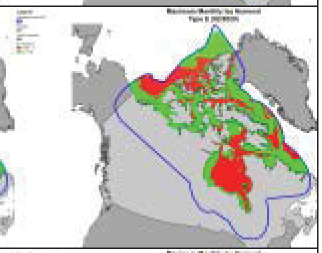
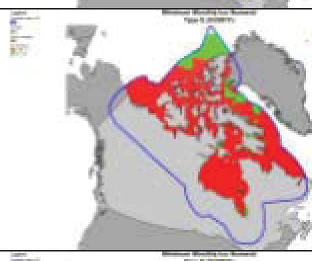
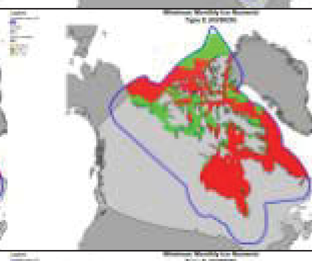
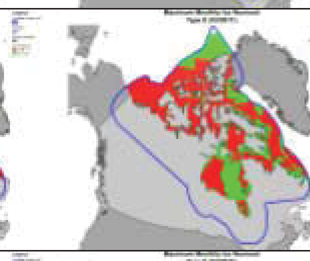
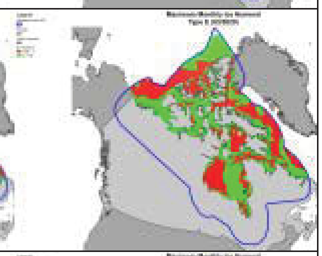
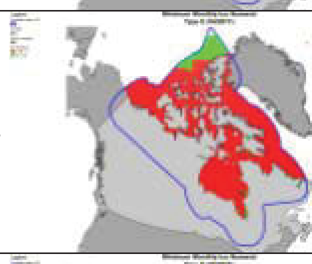
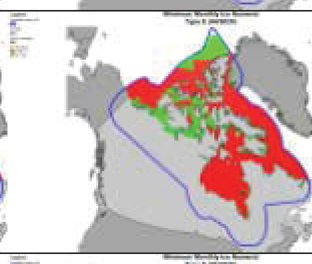
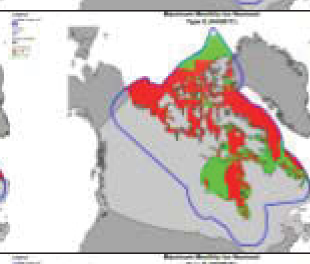
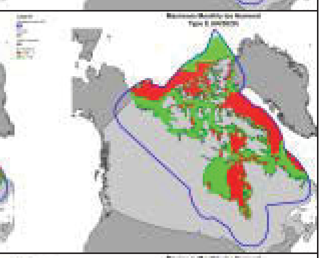
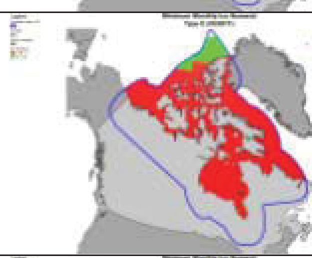
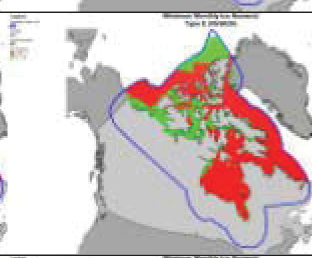
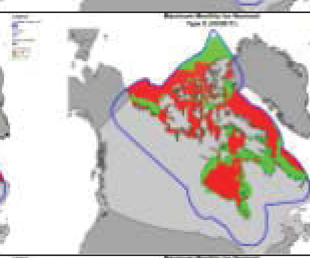
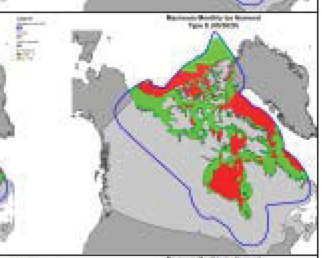
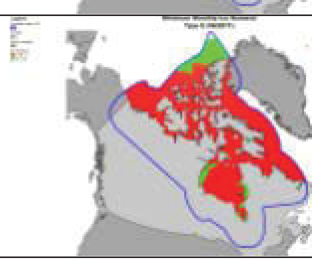
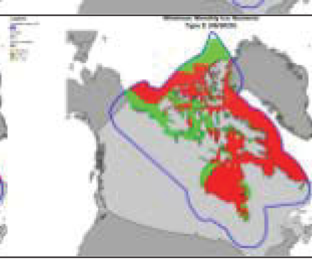
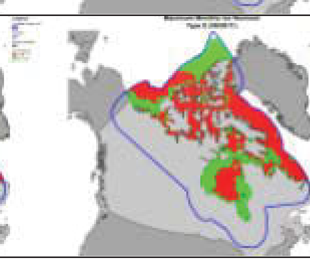
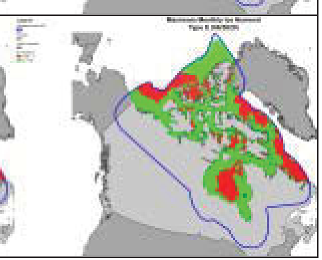
Table 5-1: Ship classification regarding Ice Numeral model (2011)

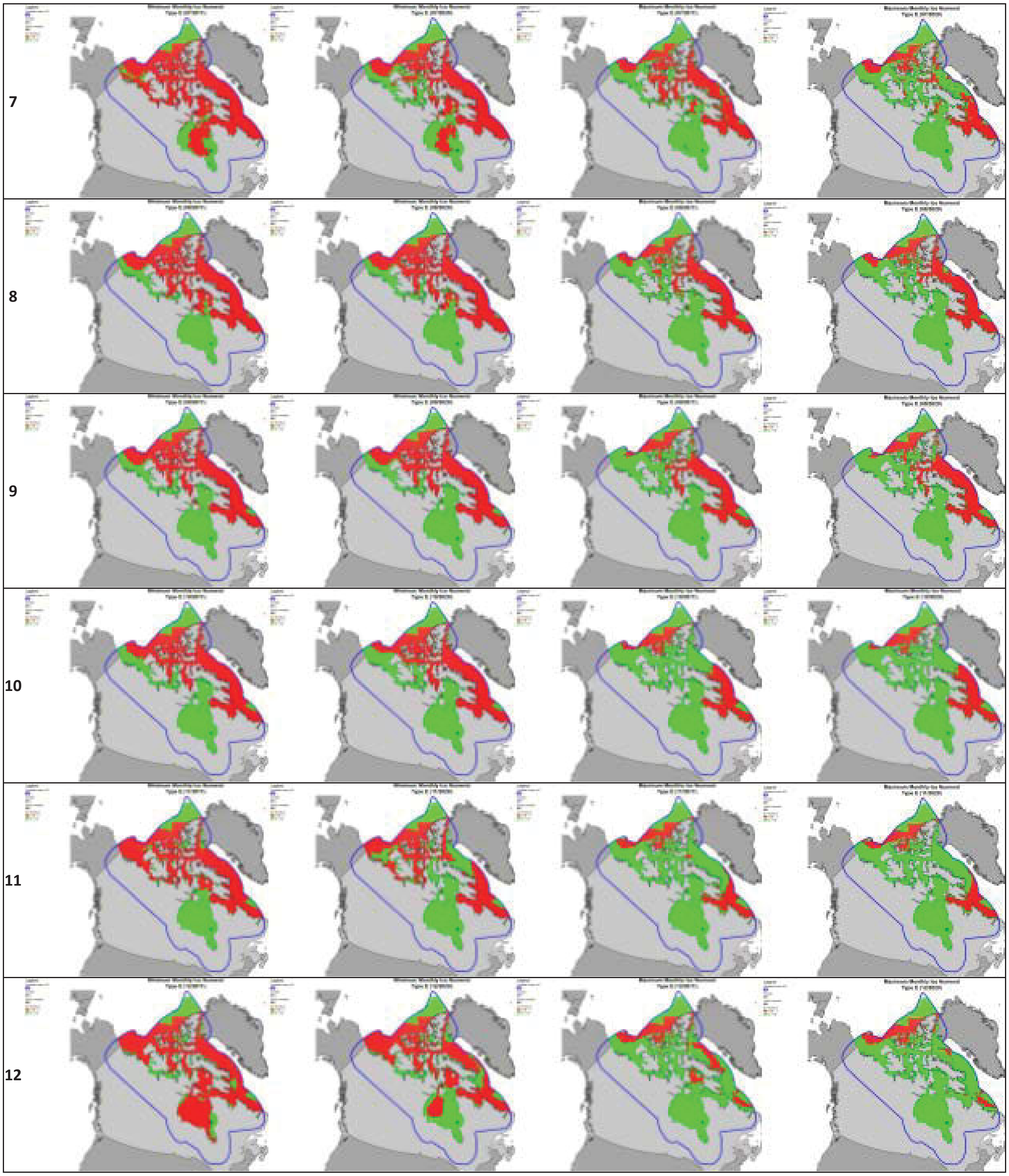
Canadian Arctic Category	Number of ships	%
CAC 3	149	96.75
TYPE E	5	3.25
TOTAL	154	100

It is also interesting to see that only 2 different categories of ships result from the *post hoc* classification based on our dataset. In terms of conducting simulations, this will limit the number of Ice Models to be investigated to only two, corresponding to the maximum and minimum category of arctic class ships. Using the Ice Numeral model grid for years 2011 and 2020, we computed a grid showing the area where ships of different arctic classes can navigate. Cells having a positive Ice Numeral are displayed in green and the negative ones in red.

An analysis of the evolution of the navigable area in May comparing 2011 and 2020 is presented in Table 5-2 and Table 5-3 for the arctic CAC 3 and Type E ship categories (maximum and minimum case studies). Red cells are areas which are not navigable (in 2011 and still in 2020). Brown cells show areas which were not navigable in 2011 but will be navigable in 2020. Green cells are areas already navigable in 2011 (which are expected to remain so in 2020). Note that the arctic CAC 3 category will be able to navigate everywhere in the artic in 2020 under this prediction simulation.

Table 5-2: Monthly (rows) Ice Numeral evolution for Type E ships (2011 and 2020)

	Min IN Type E (2011)	Min IN Type E (2020)	Max IN Type E (2011)	Max IN Type E (2020)
1				
2				
3				
4				
5				
6				


7
8
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12

Table 5-3: Monthly (rows) Ice Numeral evolution for CAC 3 ships (2011 and 2020)

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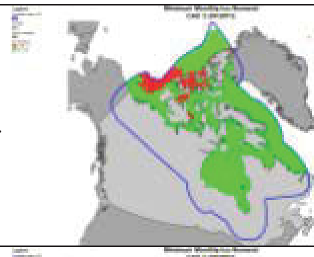
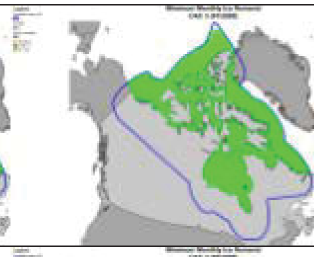
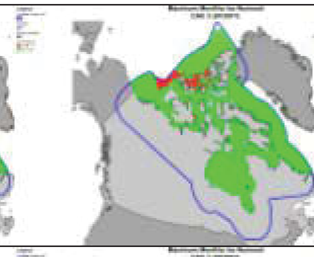
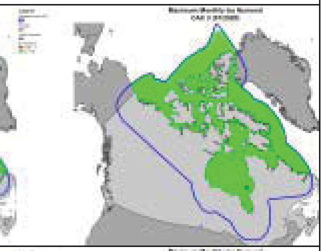
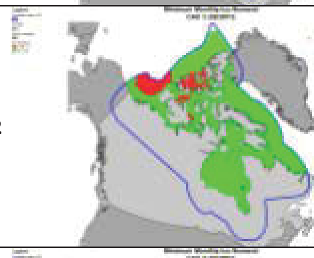
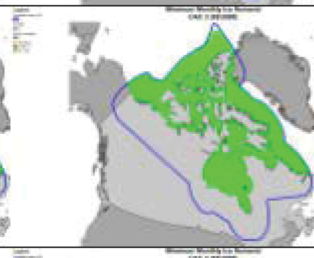
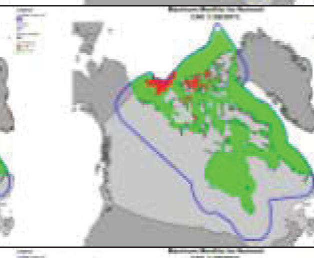
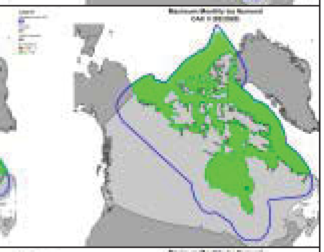
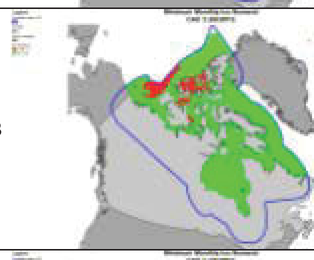
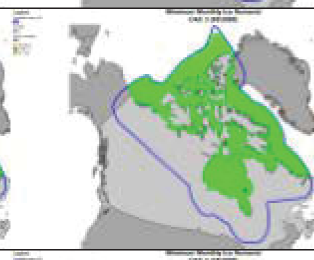
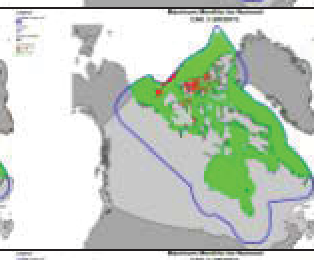
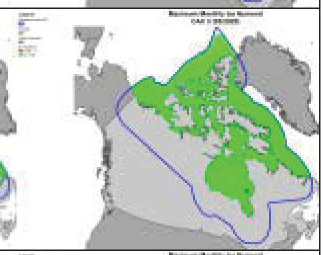
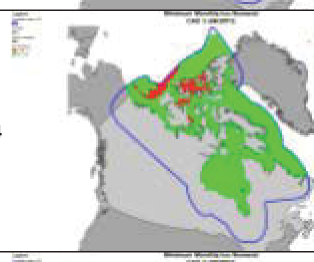
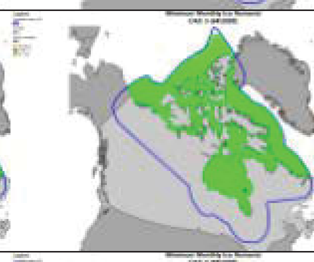
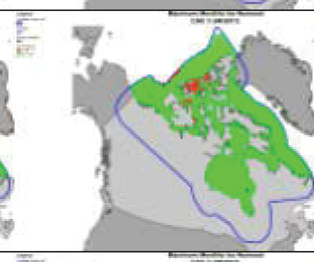
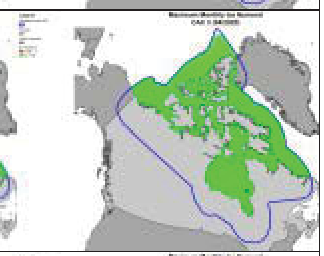
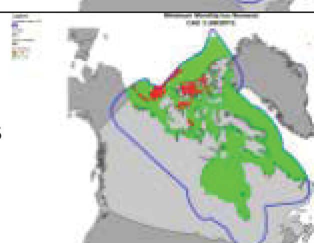
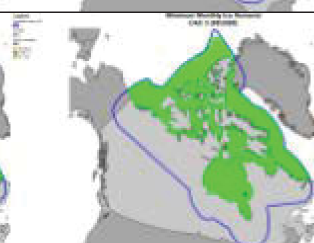
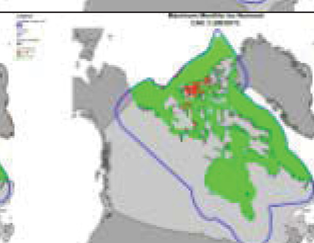
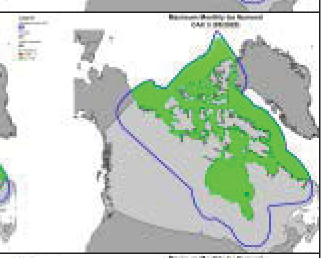
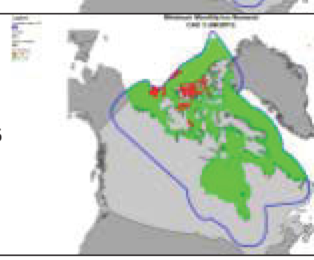
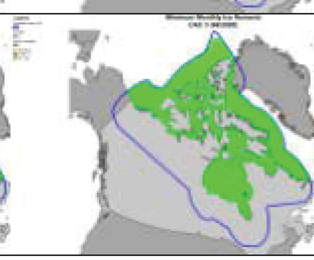
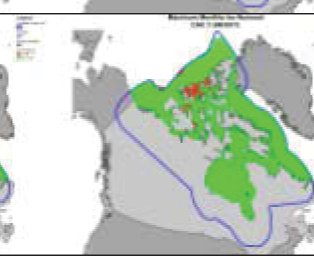
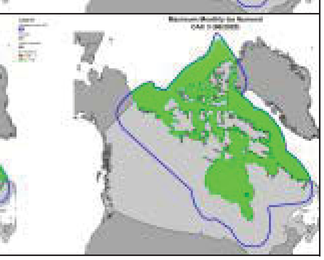
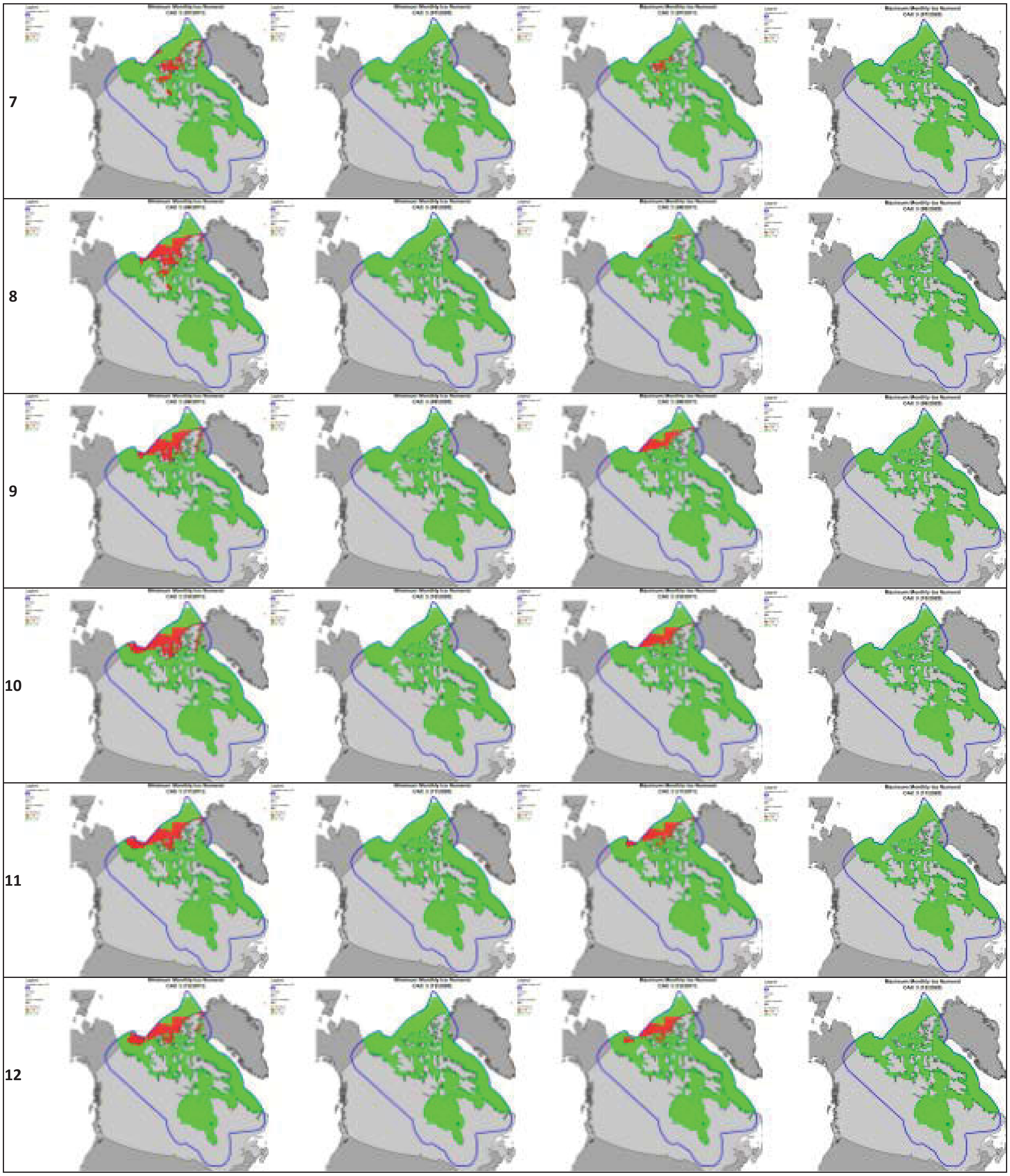
1				
2				
3				
4				
5				
6				



In order to analyse these Ice Numeral evolutions, Table 5-4, Table 5-5, Table 5-6 and Table 5-7 present comparative maps of Ice Numerals for Type E and CAC 3 ships for two different months in winter and summer (March and September) in both 2011 and 2020.

Table 5-4: March 2011 Ice Numeral comparison for Type E and CAC 3 ships

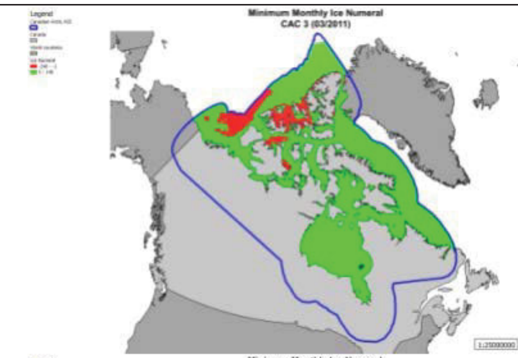
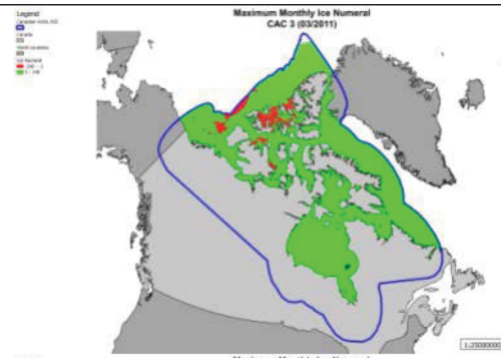
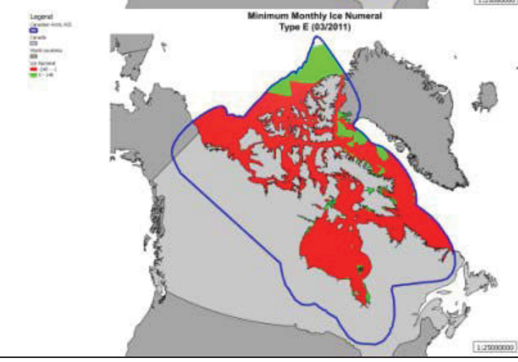
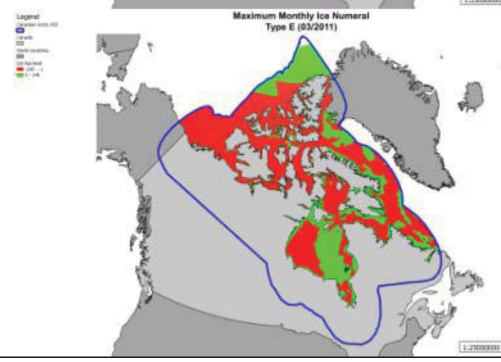
March 2011	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 5-5: March 2020 Ice Numeral comparison for Type E and CAC 3 ships

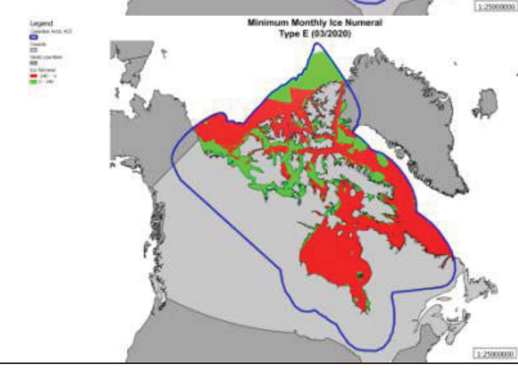
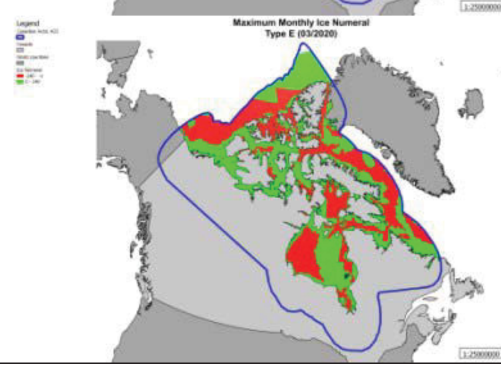
March 2020	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 5-6: September 2011 Ice Numeral comparison for Type E and CAC 3 ships

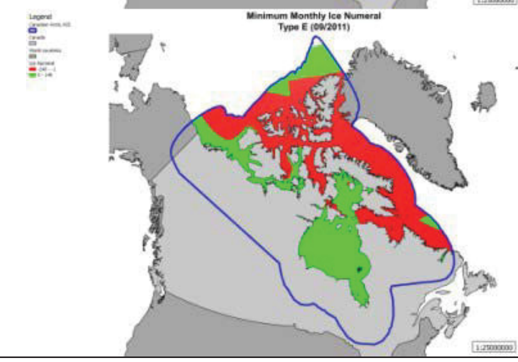
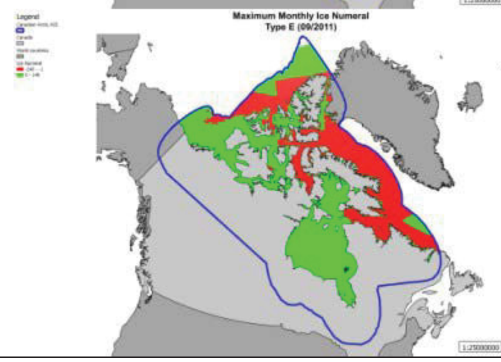
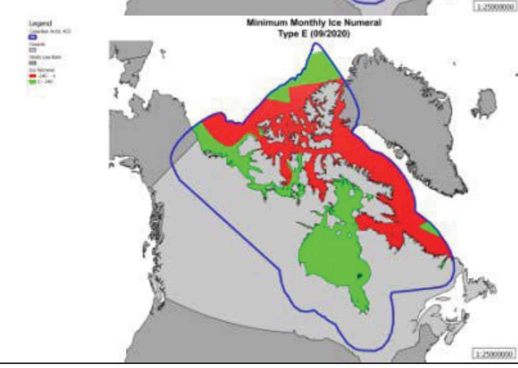
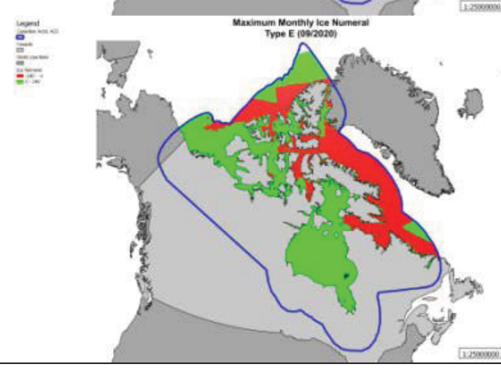
Sept 2011	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 5-7: September 2020 Ice Numeral comparison for Type E and CAC 3 ships

Sept 2020	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

6. Feasible Paths

Using the navigable area predicted for 2020, feasible paths can be modeled and computed for different arctic class ships. Then a network connecting all the ZOI was created (Flowchart 2-2, process 4). This network is based on the 0.1° x 0.1° gridding of the AOI as defined in AMT-Ph1. Every cell of this grid is connected to each neighbour by a link as presented in green in Figure 6-1.

Figure 6-1: 0.1 degrees grid network

Every ZOI is connected to the network using the grid cell within which the ZOI centroid lies (or the closest over-water cell if the centroid is on land) as illustrated by red cells in Figure 6-1 (Flowchart 2-2, process 5). Every ZOI of the graph can then be connected to every other one across the network. The shortest path can be found using Dijkstra's algorithm (Flowchart 2-2, process 6) (Winston and Goldberg 2004). An example of the shortest path between two ZOI is presented in blue in Figure 6-2. In order to validate the grid network and check for missing cells, the shortest path between every ZOI was computed (Flowchart 2-2, process 7).

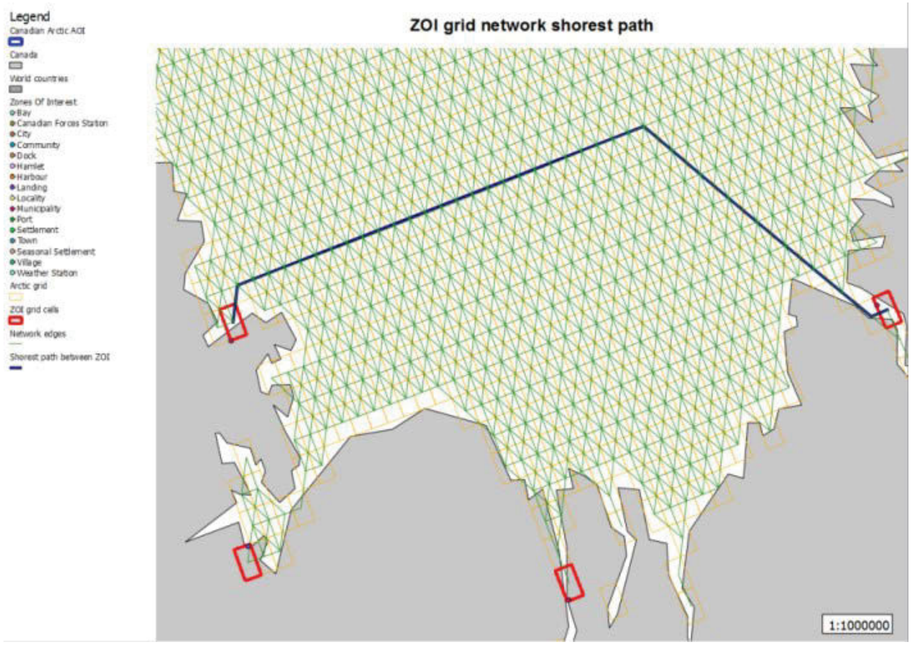


Figure 6-2: Grid network shortest path

As a ship can navigate through a cell depending on its arctic class category and the Ice Numeral conditions, nodes of the network having a negative Ice Numeral can be inactivated (i.e. when impassible) (Flowchart 2-2, process 8).

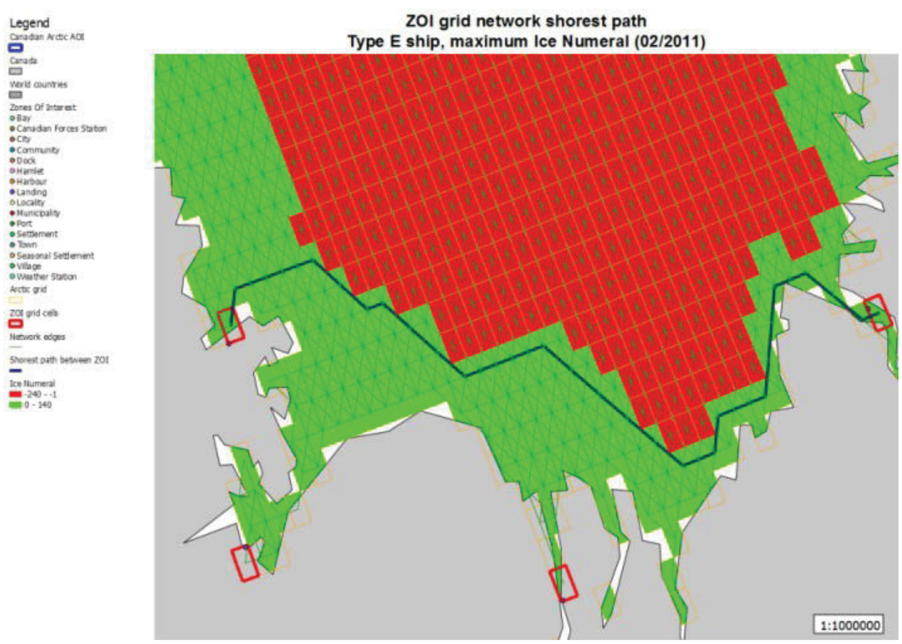


Figure 6-3: Grid network shortest path taking into account Ice Numeral (Type E, maximum IN, 02/2011)

Figure 6-3 represents the simulated shortest path in February 2011 for a Type E ship taking into account the Maximum Ice Numeral conditions for this month. The green indicates the navigable areas and red shows the forbidden ones. Sometimes, depending on the arctic class ships type and the Ice Numeral conditions selected, there is no feasible path to connect two ZOI as depicted in Figure 6-4.

Figure 6-4: Grid network shortest path taking into account Ice Numeral (Type E, minimum IN, 03/2011)

This model can also be improved to include information other than just the ice conditions and the distance to targeted area (i.e. destination), to also find the optimal path between any two nodes of the ZOI.

We added 3 different parameters to compute a cost function for the shortest path algorithm:

- The cell bathymetry.
- The cell traffic density.
- The cell distance to shore.

6.1. Bathymetry

One of the significant hazards of navigating in the Arctic is the quality of the bathymetric data. One frequently used routes, or in areas that are intensively survey for development such as an oil lease, the chart data can be quite accurate and precise. However, over the entire arctic Area of Interest, the chart data is generally very old and unreliable due to the challenges of performing surveys up north, the low traffic frequency, and the fact that gathering data and preparing charts is very resource intensive.

A good source of publicly-available bathymetric data worldwide is GEBCO (General Bathymetric Chart of the Oceans), a non-profit group operating under the joint auspices of the Intergovernmental Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO) (GEBCO n.d.).

Nevertheless, the resolution of the Arctic charts is only as good as the data provided by contributing organizations. As stated on their website:

> The GEBCO_08 Grid is a global 30 arc-second grid bathymetry data sets for the world's oceans. This dataset is largely generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data. However, in areas where they improve on the existing GEBCO_08 grid, data sets generated by other methods have been included. Land data are largely based on the Shuttle Radar Topography Mission (SRTM30) gridded digital elevation model. A 'source identifier', SID, grid is also available to download to accompany the GEBCO_08 Grid. This shows which grid cells have been constrained by bathymetry data during the gridding process. The GEBCO_08 Grid is a development product, which will undergo periodic update. Although every effort has been made to reduce the number of errors in the data set, we expect that some grid artefacts will be found.

Considering that ships try to navigate in deep water to avoid grounding, we integrated the arctic bathymetry into the shortest path cost function. The minimum depth was calculated for every cell of the 0.1° grid. Figure 6-5 illustrates the results of the computation of the bathymetry for this grid; lighter blue cells have lesser depth than dark blue cells. Unfortunately, the precision of the bathymetry dataset is not very accurate. The most important depth category for our analysis is the light blue one in the figure (between 0 and -25m deep) as ships usually have a maximum draft of 25m. However, note that this depth category covers 7018 of the 116,249 0.1° grid cells (6% of the arctic area of interest). In this analysis, we state that in order to be sure to avoid grounding, a ship had better travel in higher depth areas.

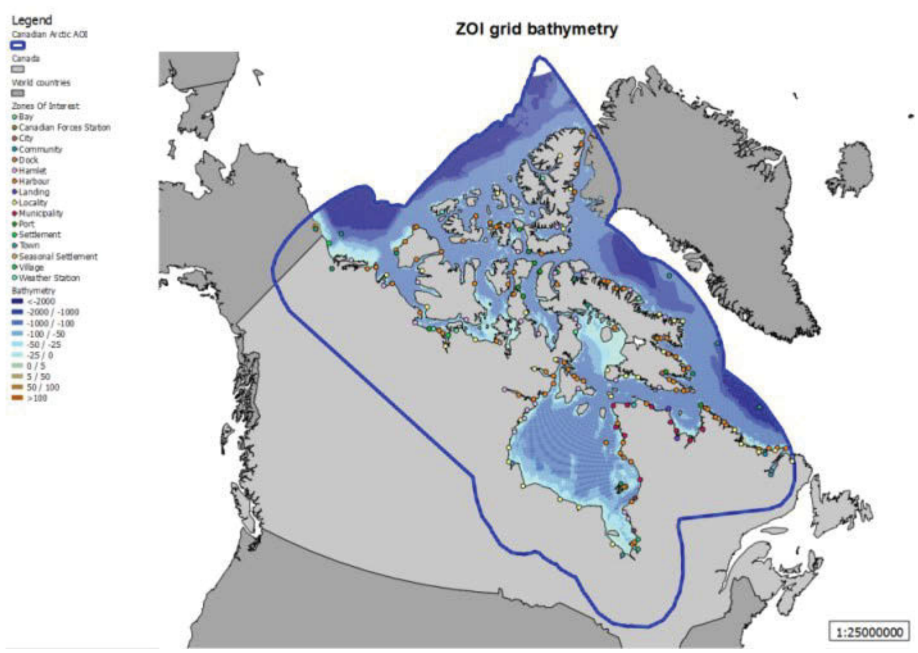


Figure 6-5: 0.1 grid arctic bathymetry

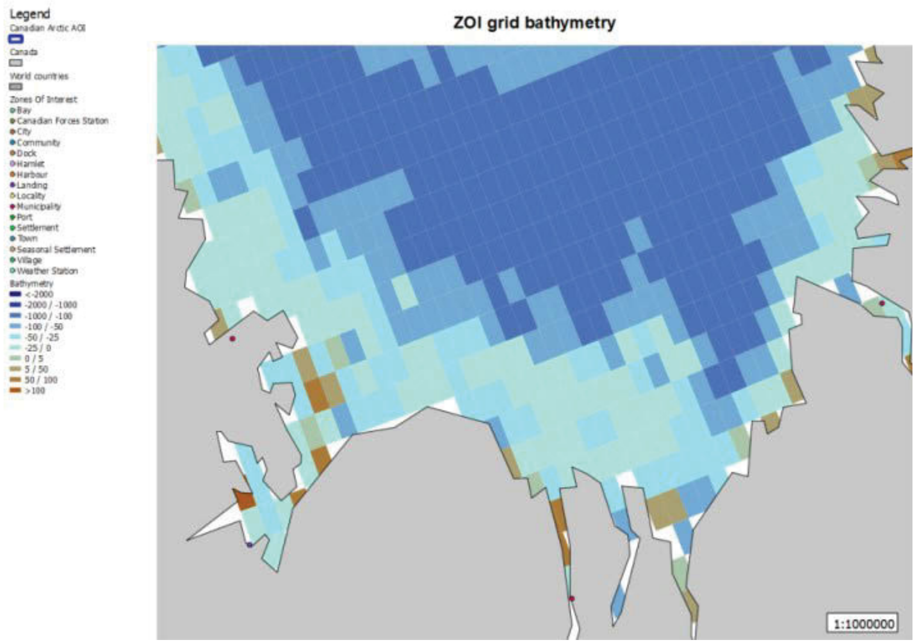


Figure 6-6: 0.1 grid arctic bathymetry close look

6.2. Maritime Traffic Density

Another important factor that we can take into account is the maritime traffic density, as a ship is more likely to navigate in areas which have already been traversed before (i.e. feasible paths). Using the LRIT tracks, we computed every intersection with grid cells and counted the number of different tracks navigating through these cells. Figure 6-7 presents the traffic density map of the AOI 0.1° grid for the year 2011 (high density cells are depicted in red). The highest density count for one cell is 46 different tracks.

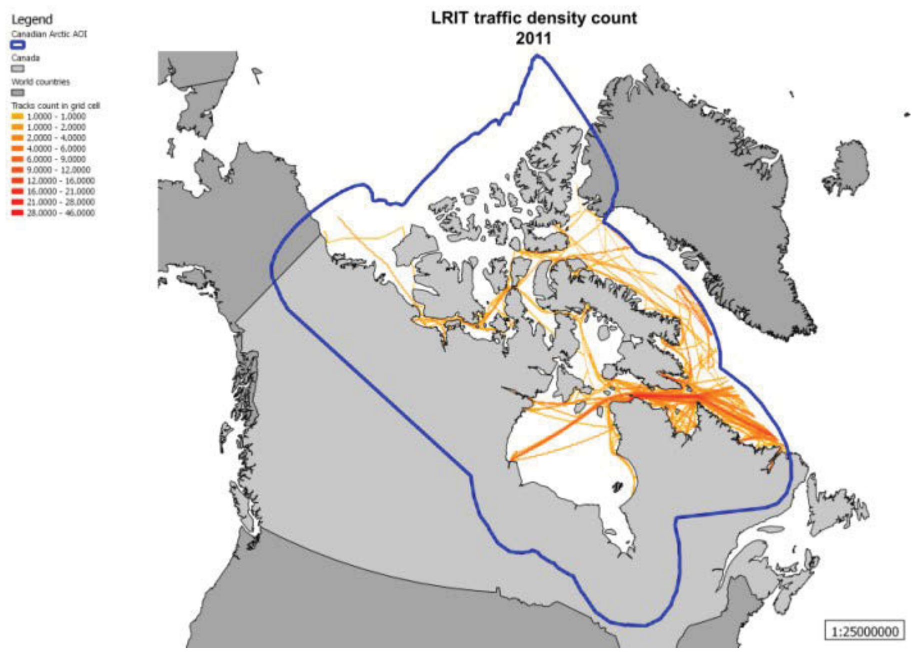


Figure 6-7: Traffic density map (0.1 degrees grid)

6.3. Distance to Shore

An issue arising from the shortest path algorithm involves the distance from shore. The shortest path algorithm tries to reach the target node as directly as possible, hence sticks close to an obstacle when trying to by-pass it (in our case the land). When comparing to actual LRIT tracks, we notice that ships usually stay away from the shore, which is usually more rocky and dangerous. Using geo-visual analysis, we measured the average distance between the arctic LRIT tracks and shoreline (around 30 km). We computed the distance to shore for every cell of the grid and assigned the cells that are less than 30km an index of 0 (and 1 for those above 30 km). Figure 6-8 visually represents the distance to shore for every cell of the 0.1° graph. The 30 km buffer is represented in red on this figure.

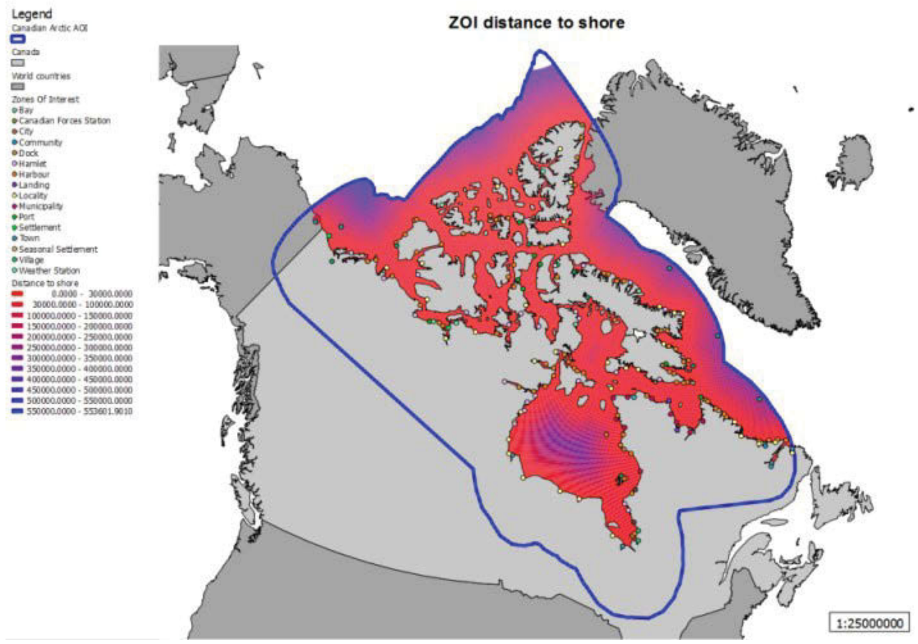


Figure 6-8: Distance to shore

6.4. Least-Cost Path Computation

Using the bathymetry, traffic density and distance to shore, a cost function can be computed. We proposed the cost function below which focuses on the target cell (B) we want to navigate to from source cell (A):

$$(\quad (\qquad \frac{}{})) \quad (\quad (\qquad \frac{}{})) \quad (\quad (\qquad \frac{}{}))$$

The parameters values of the cost function are presented in Table 6-1.

Table 6-1: Cost function parameters

Variable	Description	Value
	Cost to navigate from cell A to cell B	Result to compute
	Length of the arc between A and B	Distance in meters
	Weight of the bathymetry	0.25
	Value of the bathymetry in cell B	From the data
	Maximum range of the bathymetry	4.0
	Weight of the traffic density	0.8
	Value of the traffic density in cell B	From the data
	Maximum range of traffic density	46.0
	Weight of the distance to shore	0.25
	Value of the distance to shore in cell B	From the data
	Maximum range of distance from shore	1.0

Using the new cost function proposed above and Ice Numeral model previously defined, the shortest paths between ZOI were computed for the year 2011, and then overlaid with the actual LRIT traffic. The simulated routes are presented in green on Figure 6-9 and the LRIT tracks are overlaid in black for September 2011.

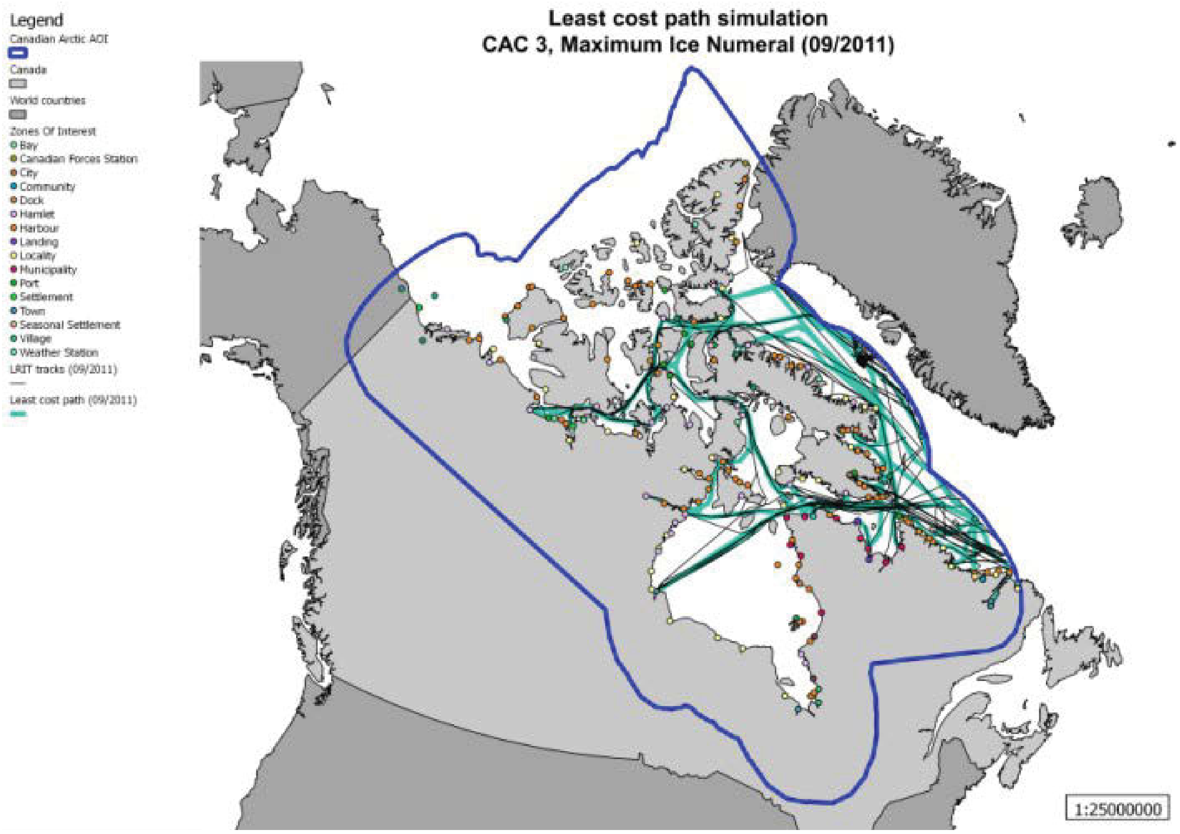
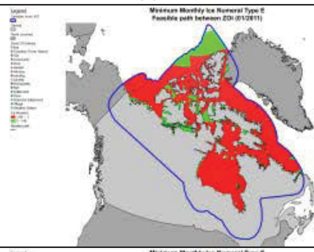
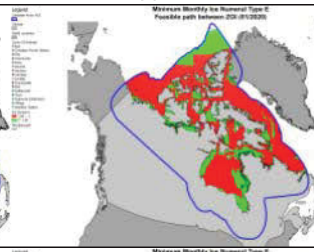
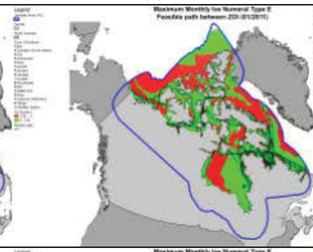
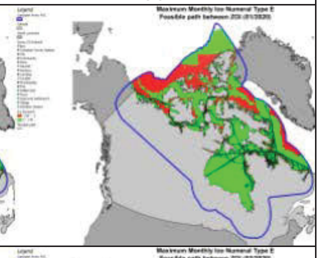
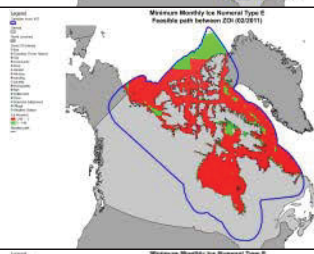
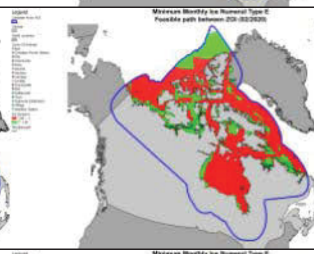
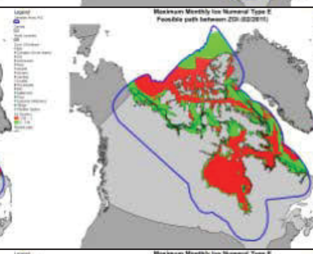
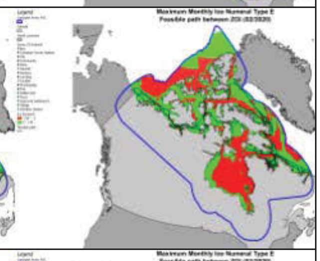
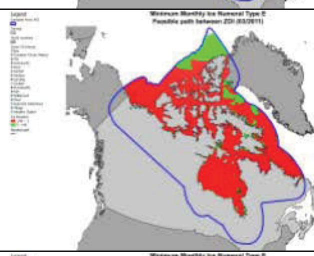
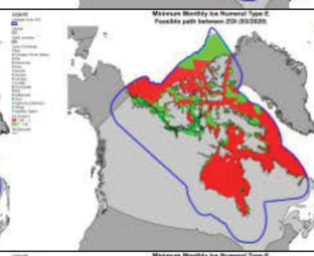
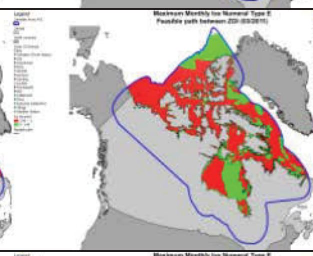
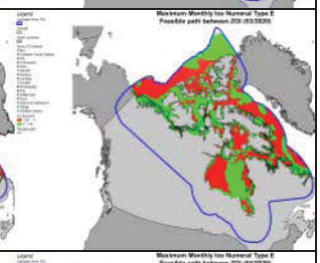
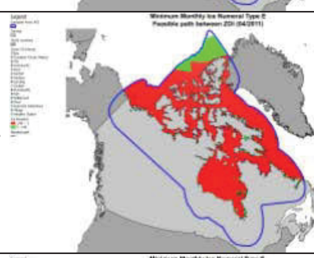
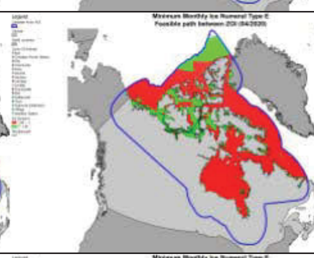
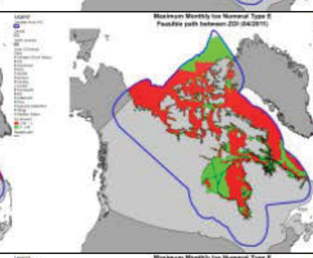
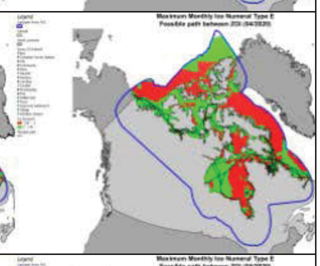
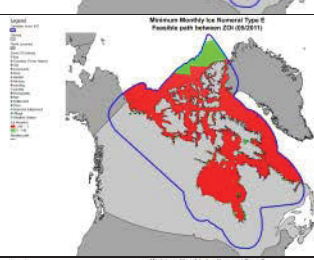
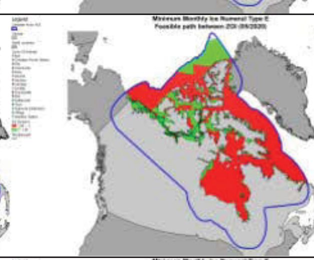
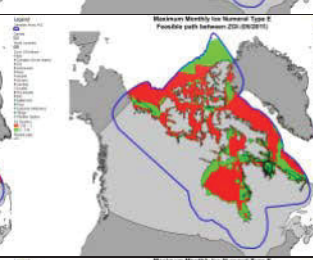
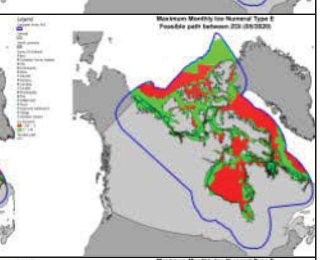
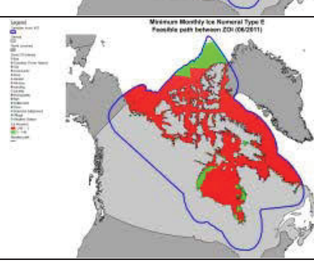
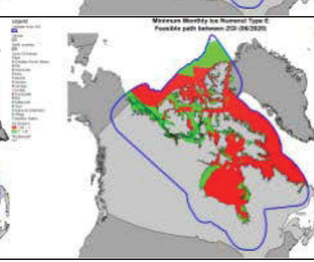
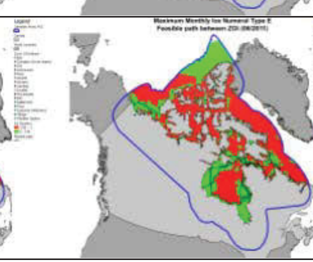
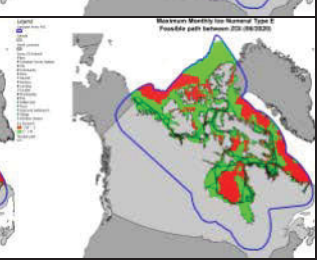


Figure 6-9: Simulated least cost path and LRIT tracks (09/2011)

Thanks to this shortest distance cost function and the Ice Numeral prediction for 2020, every path can be simulated over the ZOI grid network. This simulation tool can thus be used to create possible paths to accommodate new activities conducted in the arctic. All the monthly feasible path for CAC 3 and Type E ships have been computed using 2011 and 2020 Ice Numeral simulations (Flowchart 2-2, process 8). The monthly feasible path results are presented in black in Table 6-2 and Table 6-3. The Ice Numeral conditions used to simulate the path have been overlaid in these maps.

Table 6-2: Monthly feasible path evolution for Type E ships (2011-2020)

	Min IN Type E (2011)	Min IN Type E (2020)	Max IN Type E (2011)	Max IN Type E (2020)
1				
2				
3				
4				
5				
6				

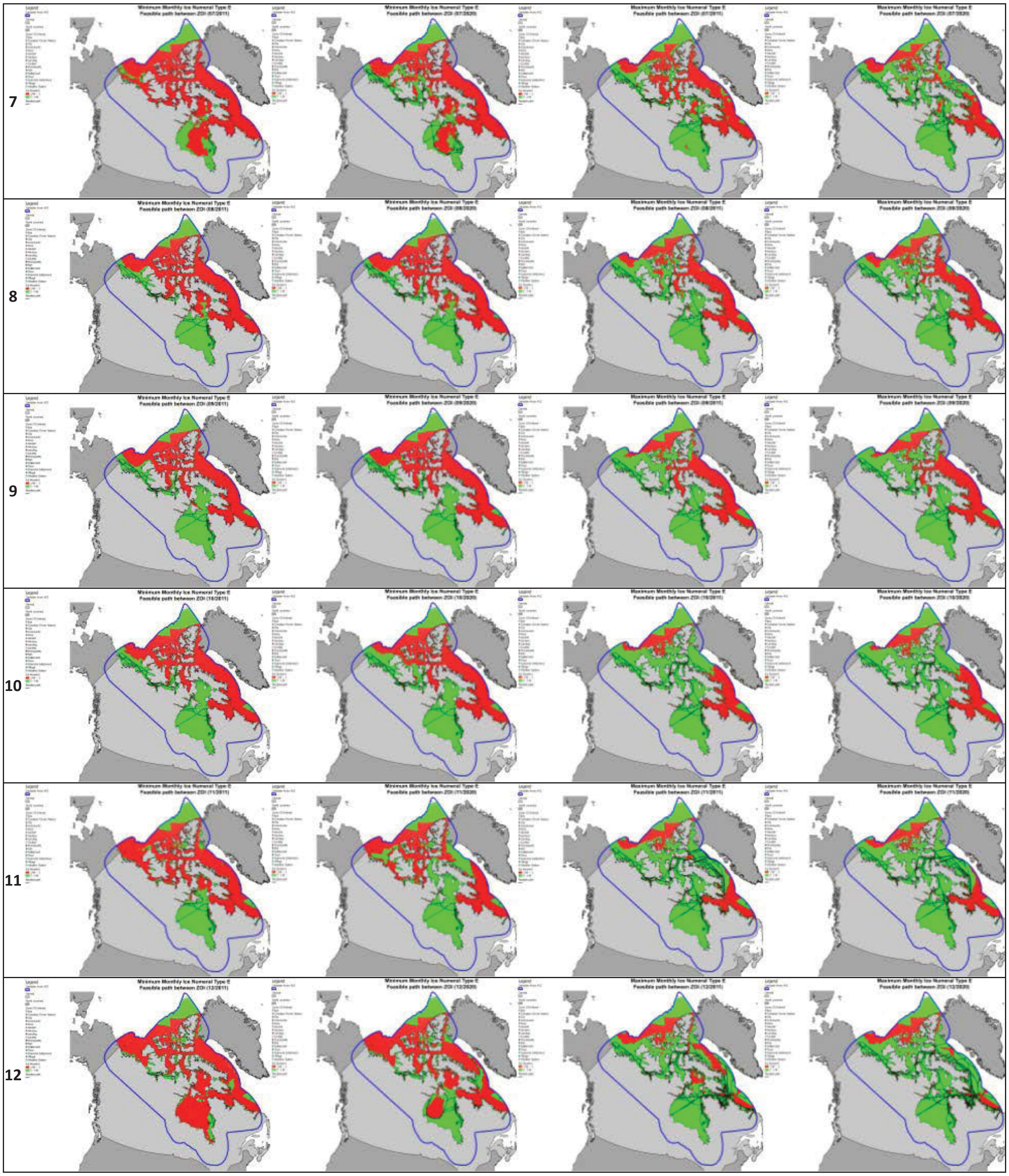
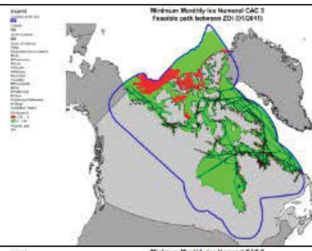
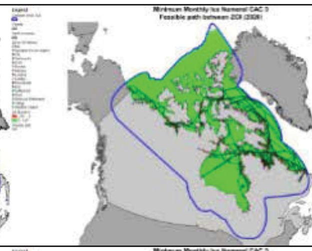
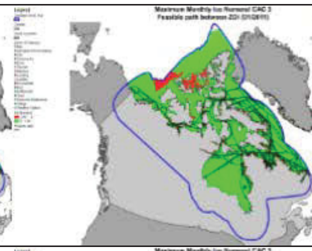
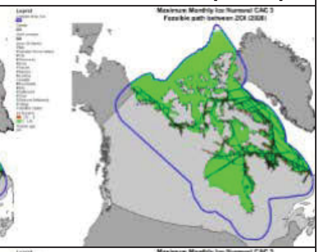
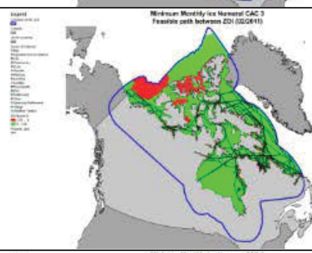
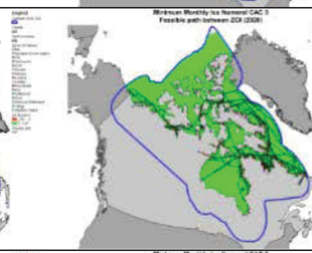
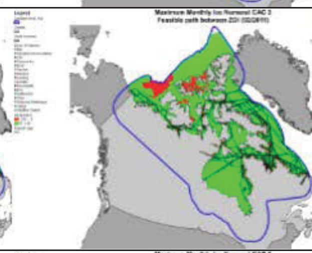
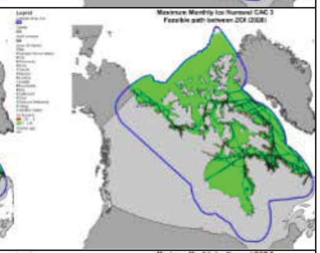
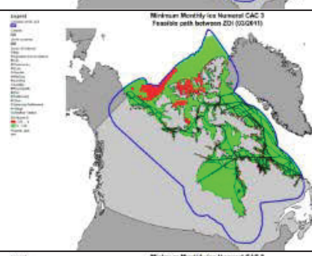
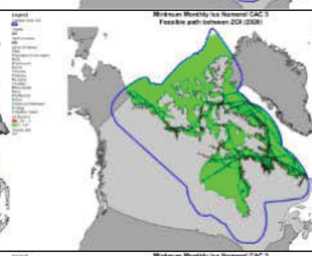
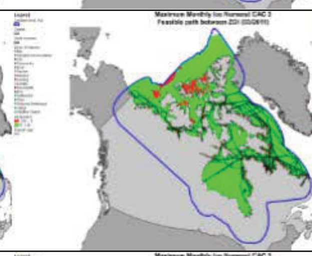
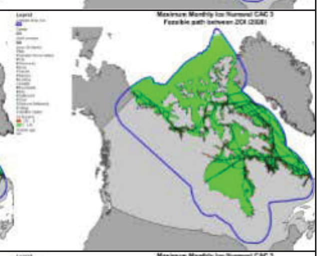
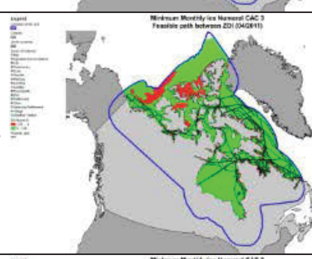
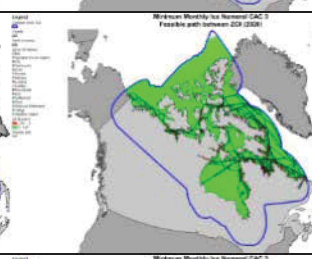
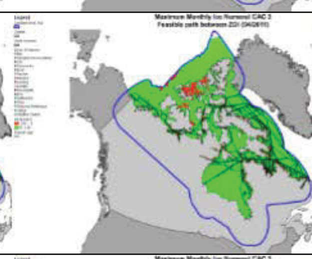
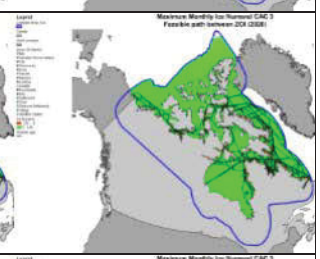
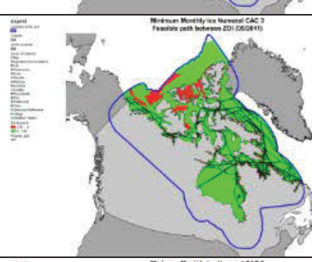
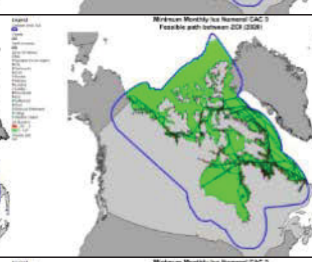
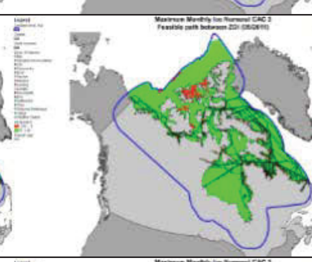
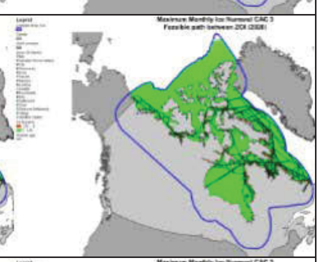
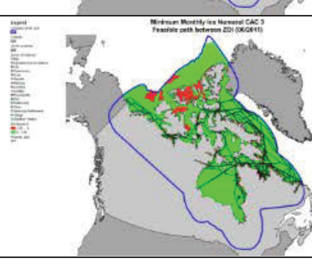
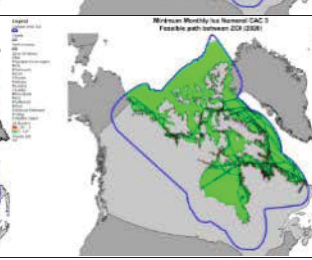
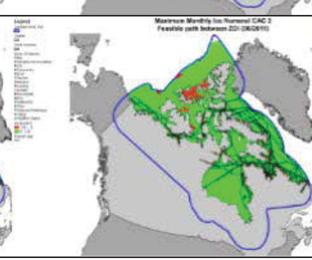
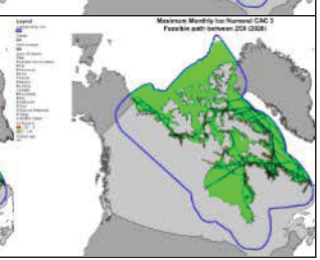
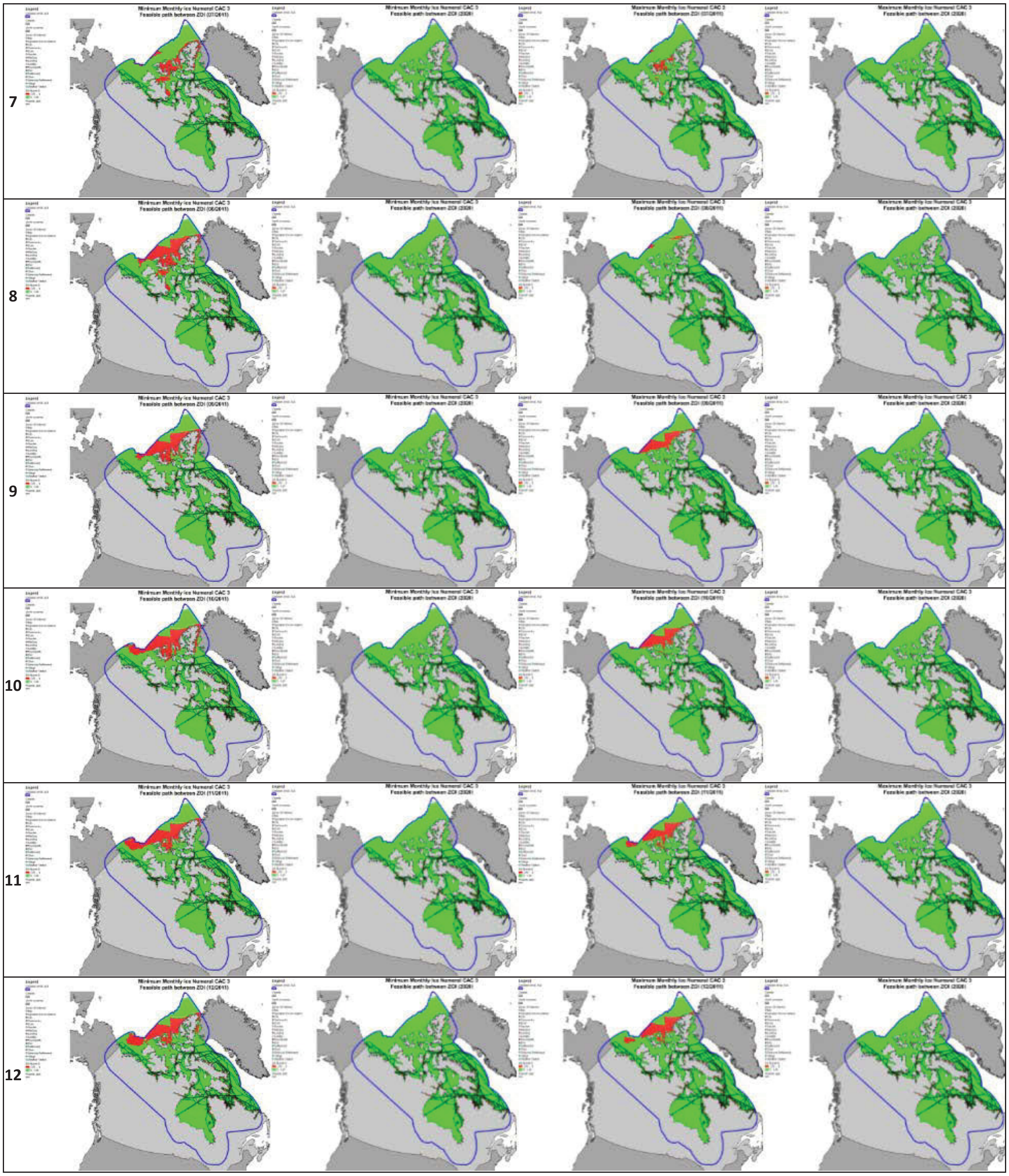

7
8
9
10
11
12

Table 6-3: Monthly feasible path evolution for CAC 3 ships (2011-2020)

	Min IN CAC 3 (2011)	Min IN CAC 3 (2020)	Max IN CAC 3 (2011)	Max IN CAC 3 (2020)
1				
2				
3				
4				
5				
6				



In order to analyse the feasible path monthly evolution between 2011 and 2020, Table 6-4, Table 6-5, Table 6-6 and Table 6-7 presents comparative maps of Ice Numerals and feasible path for Type E and CAC 3 ships within two different months in winter and summer (March and September).

Table 6-4: March 2011 feasible path comparison for Type E and CAC 3 ships

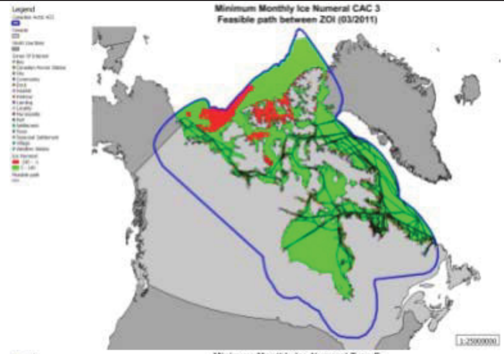
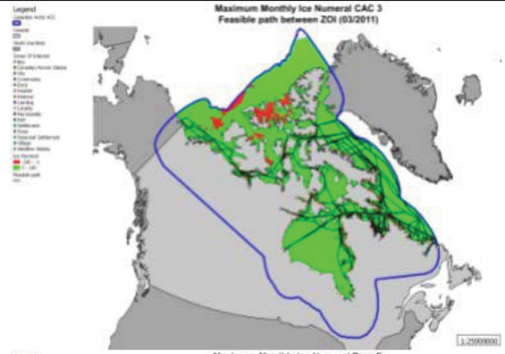
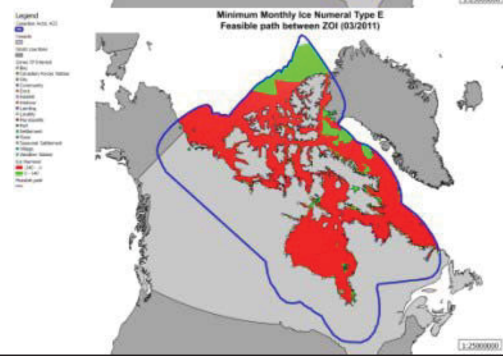
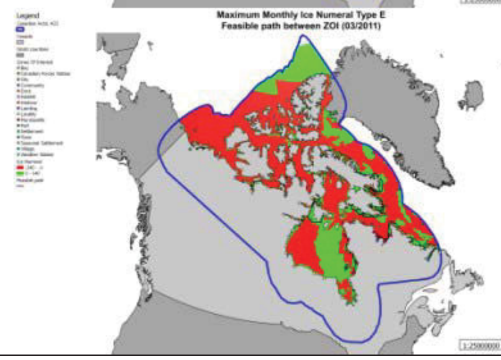
March 2011	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 6-5: March 2020 feasible path comparison for Type E and CAC 3 ships

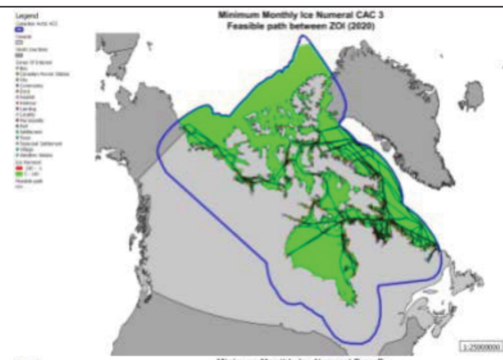
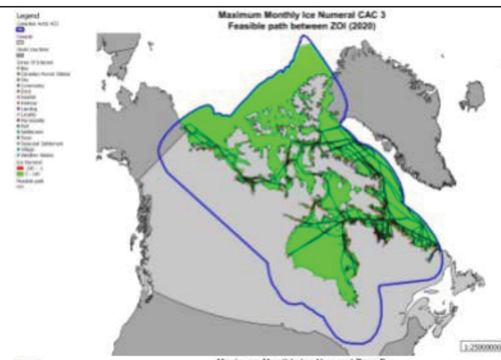
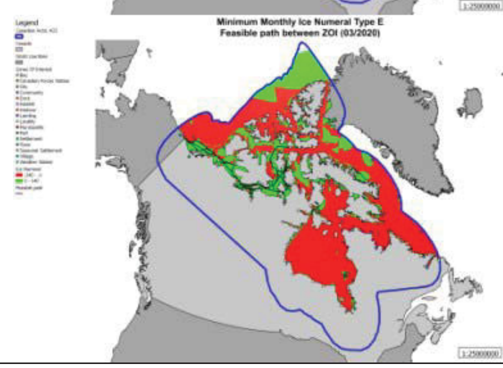
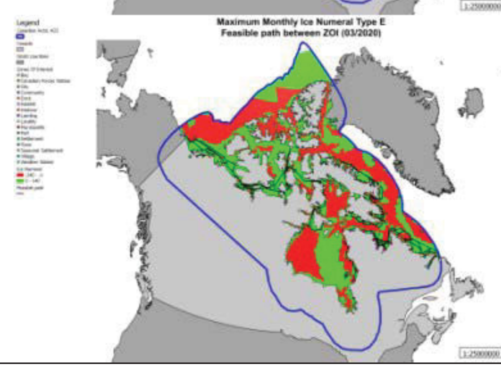
March 2020	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 6-6: September 2011 feasible path comparison for Type E and CAC 3 ships

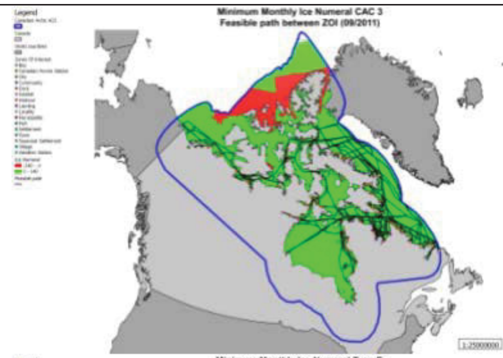
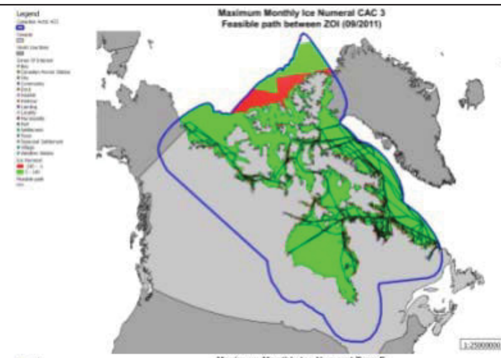
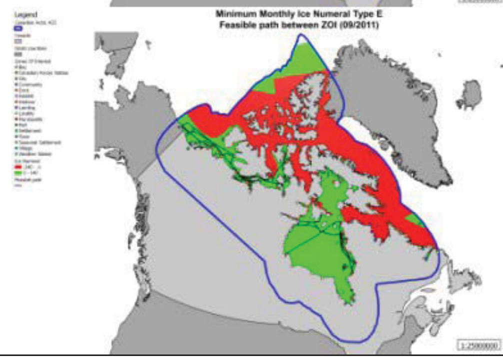
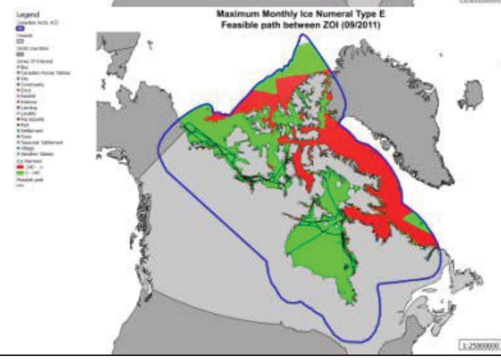
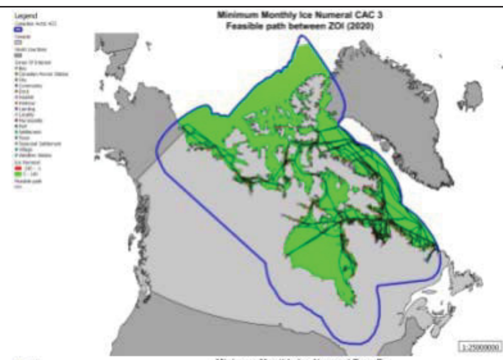
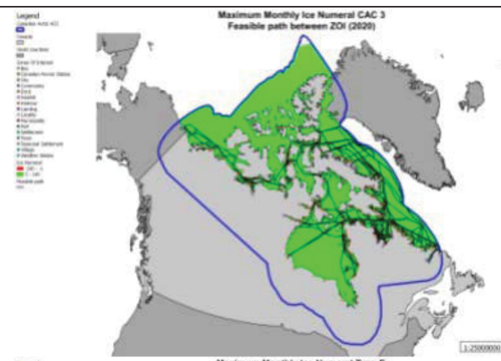
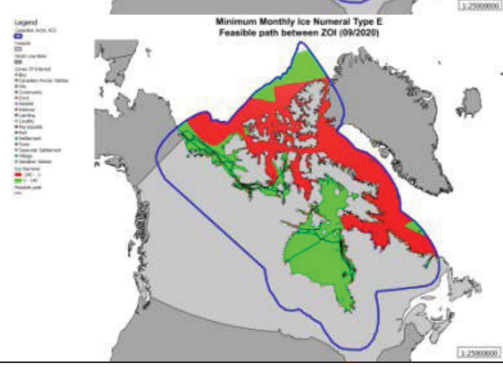
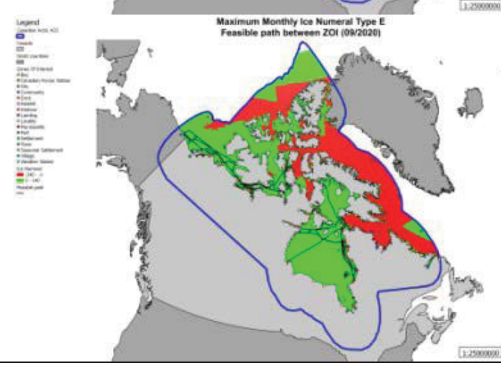
Sept 2011	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

Table 6-7: September 2020 feasible path comparison for Type E and CAC 3 ships

Sept 2020	Minimum Ice Numeral	Maximum Ice Numeral
CAC3		
Type E		

These results of the ice analysis and navigable areas will be used as the base layers for the next part of the methodology to simulate the traffic changes. The model allows us to recalculate feasible paths based on ice conditions and ship ice class for any existing, or new, route in the Area of Interest.

7. Maritime Traffic Simulation

In this section, the forecasting of Arctic maritime traffic levels is performed for the year 2020. The simulation model rests on the building blocks developed in the previous sections: the current traffic levels by ship type, month and destination; a graph network through which vessels can navigate to attain their zone of interest via the shortest path; and the feasibility of passage given the ice conditions and ship ice class. One important uncertain element involves *when* ships might navigate in the future as the sea ice recedes. If we simulate the year 2020 based on current time patterns, then even when the shipping season lengthens due to melting ice, the model will only reflect current schedules. Therefore, the next step in this section is to allow some probability that transits take place beyond the present navigable seasons.

Then, all of the drivers of maritime traffic demand are considered in turn, and represented with a probabilistic range of potential values. Once all of the uncertain factors are represented by their respective probability distributions, the Monte Carlo simulations are run to produce the range of outputs (traffic levels by vessel type, location, and month) to yield the comprehensive Arctic traffic picture for the year 2020.

7.1. Monthly Traffic Spreading

As the Arctic ice melts, it is expected that maritime traffic will spread out somewhat over the longer summer season. The Ice Numeral predictions for 2020 can be used to compute which links (graph edges) would be navigable for each ship type in each month. We use 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 continuing months (up to two months before and two after), as long as the link is also navigable these preceding and following months. However, in this simulation, we do not increase the total amount of traffic on the link; we only spread it temporally across the months (Flowchart 2-2, process 9).

First of all, the ice conditions have to be evaluated for each month and each link of the graph in order to know whether ships (or a given class) can navigate that link. The path analysis over the graph network was done using the Maximum Ice Numeral simulated for a Type E ship in 2020 (Flowchart 2-2, process 8). If the path is NULL, it means that there is no feasible path between these two ZOI for this particular month in 2020 (i.e. the ice is too strong for a Type E ship as depicted in Figure 6-4).

An algorithm was created to simulate the monthly spreading using Monte Carlo simulation (generate_link_cat_simulated_traffic_count_2020). This algorithm takes as arguments the starting and ending nodes of the network (a link), the category of ship selected, and the number of simulations to generate. In this study, we simulated 1000 different scenarios.

The different monthly numerical values of the simulation are stored in 3 different arrays:

- **N[1..12]** – monthly normalized 2011 traffic count for this ship category and ZOI link
- **I[1..12]** – monthly 2020 feasibility path for a Type E ship for that ZOI link (True = the ship can go)
- **S[1..12]** – monthly results of the simulation

First, the arrays are initialized with results from previous steps of the analysis (normalized traffic count, feasibility path). Figure 7-1 illustrates a monthly normalized traffic count example in blue. Greyed months (January, February, March, September, October, November, December) indicate that ice conditions are too strong to navigate on that link for a Type E ship.

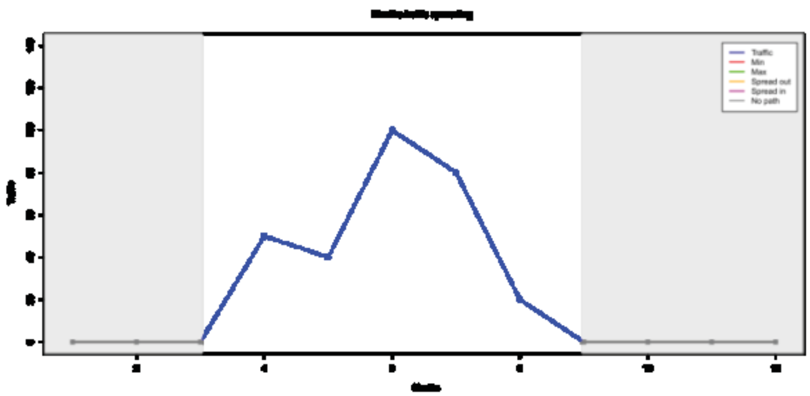


Figure 7-1: Normalized monthly traffic for a link

For each month M ranging from January (01) to December (12), indexes are initialized to point to preceding and following months. Special care is taken for January and December in order to wrap around the end of the year. For the example of June (06):

The two preceding months are:

- prev1 (one month before) = M-1 = May (05)
- prev2 (two months before) = M-2 = April (04)

The two following months are:

- next1 (one month after) = M+1 = July (07)
- next2 (two months after) = M+2 = August (08)

Referring to the array I[], the preceding and following months can be navigated by a Type E ship for that link. So, part of the traffic for month M can be distributed across these other months.

We used the following assumptions for our model:

- One month difference: Up to a maximum of **20%** of the month's normalized traffic count (using a uniform probability distribution)
- Two month difference: Up to a maximum of **10%** of the month's normalized traffic count (using a uniform probability distribution)

In the June example, the normalized traffic count for June can be spread to preceding and following months as presented in orange in Figure 7-2. It also means that the simulated traffic count for June might consequently decrease up to a maximum of -60% as the overall traffic across the months will remain constant. This assumption is used to compute the minimum simulated traffic count represented in red.

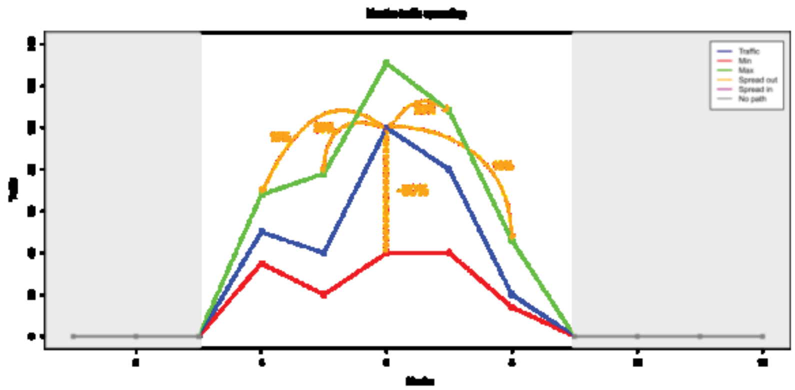


Figure 7-2: Monthly traffic spreading (minimum)

As the preceding and following months are navigable in this example, existing traffic in those months can also be spread, hence contribute to the June simulated maximum traffic as illustrated in green in Figure 7-3.

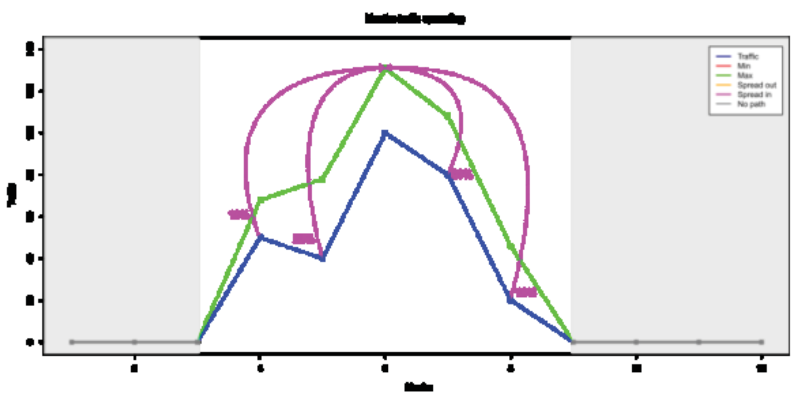


Figure 7-3: Monthly traffic spreading (maximum)

If preceding or following months are not navigable, then these months are not used in the simulation process, they will not incur any traffic increase or decrease as indicated in Figure 7-4 and Figure 7-5.

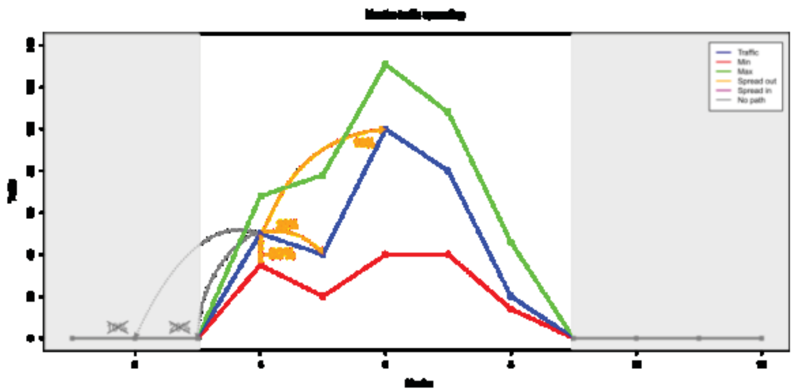


Figure 7-4: Partial monthly traffic spreading (minimum)

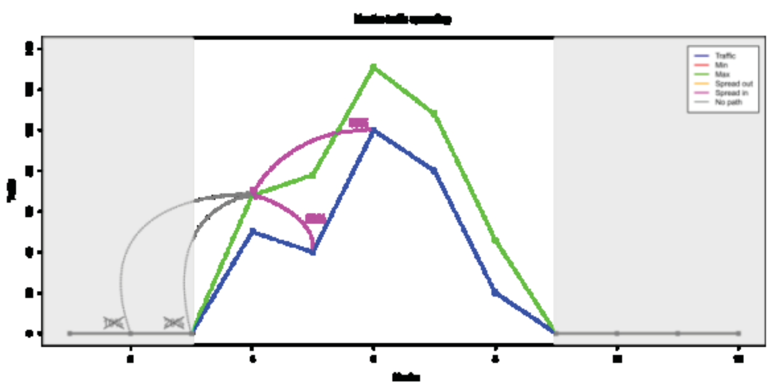


Figure 7-5: Partial monthly traffic spreading (maximum)

Once every month is evaluated (from 1 to 12), the results of this simulation are stored in the database. The simulation is reinitialized and run again until 1000 simulations have been computed and stored in the database. Each simulation keeps the total annual traffic count constant. Figure 7-6 presents one simulation instance in black. This simulation result lies within the maximum (in green) and minimum (in red) limits for this link. The PL/PGSQL function created to simulate this temporal traffic spreading is presented in Appendix B.

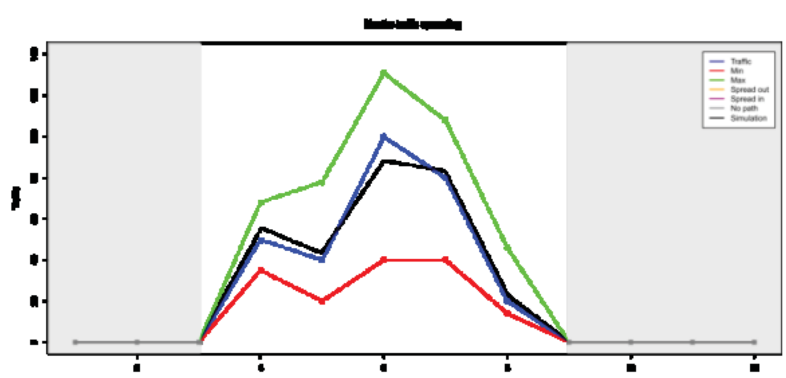


Figure 7-6: Month traffic spreading simulation

Once the simulations are completed for every link and ship category, they can be visualized using histograms. The traffic number histograms were generated by month and ship category. The monthly overall traffic simulation (all types of ships grouped together [A]) is presented in Figure 7-7. The blue line corresponds to the monthly normalized traffic count for 2011. Depending on Ice Numeral conditions simulated for 2020 and feasible paths, we used our assumption that some months will spread their traffic among preceding and following months (temporal spreading). Thus, we can verify this assumption by comparing the histogram mode value with the original normalized traffic (blue line). Depending on the location of this blue line, different scenarios can be observed.

Case 1: When the histogram is fully on the right side of the blue line, the month encounters an important traffic increase. It is usually the case when the traffic for that month was low or zero, and it is preceding or following other months with a relatively high traffic count. This arises when that 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 the 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 season (January, February - July).

Case 3: When the histogram is fully on the left side of the blue line, the month has an important traffic decrease. It is usually the case when the traffic for that month was high and it is preceding or following another month with low traffic count. It means that the traffic will spread to the other month which has had more ice melting over time (i.e. a month falling in the warm season, August, September, October)

Monthly temporal spreading histograms have also been computed for each different category of ships in order to visualize when the different categories of ships are usually navigating (Figure 7-8 to Figure 7-13).

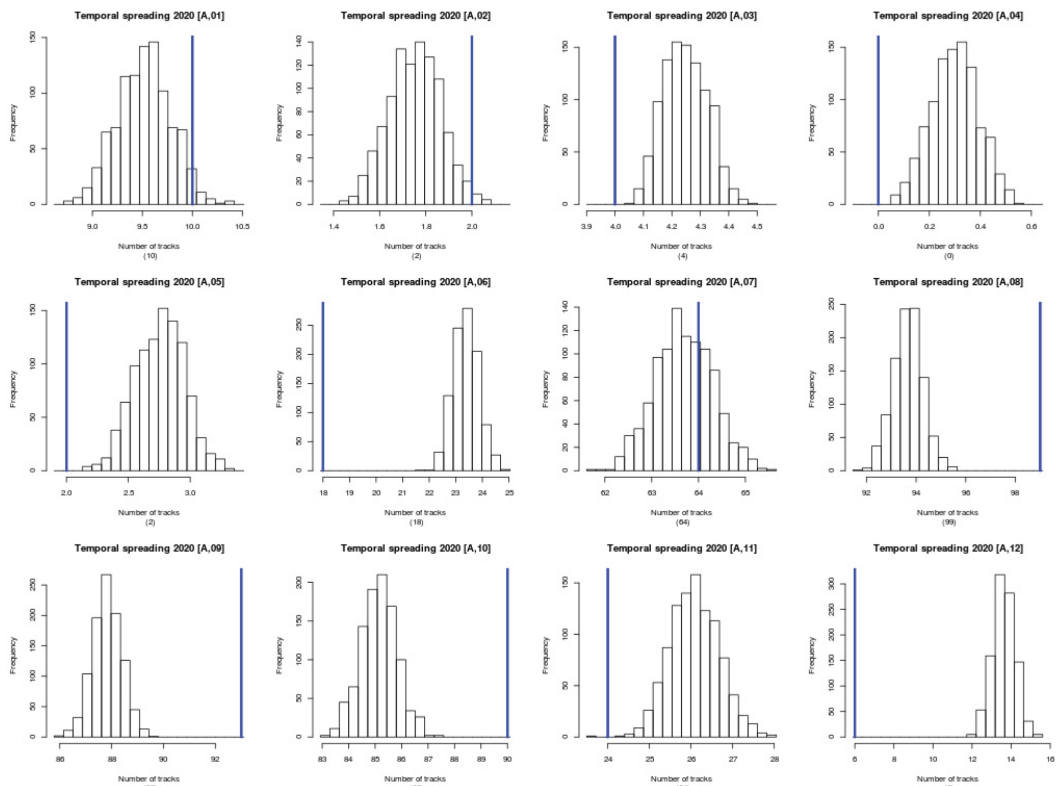


Figure 7-7: Monthly temporal spreading histograms (All ships)

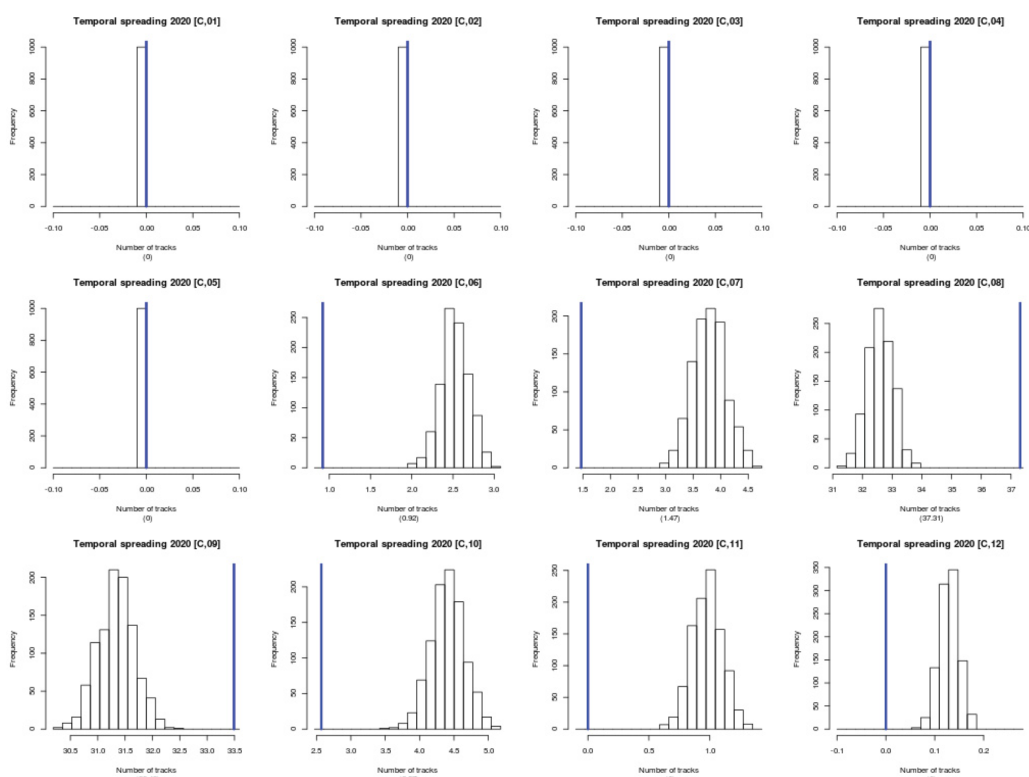


Figure 7-8: Monthly temporal spreading histograms (Cruise ships)

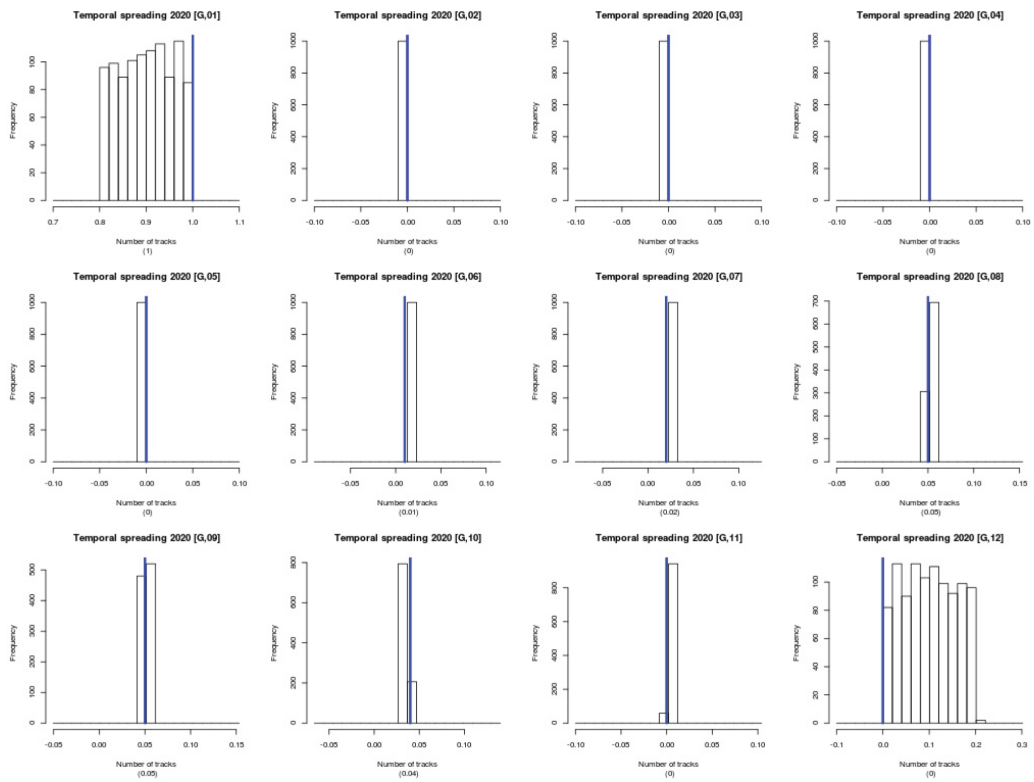


Figure 7-9: Monthly temporal spreading histograms (Government ships)

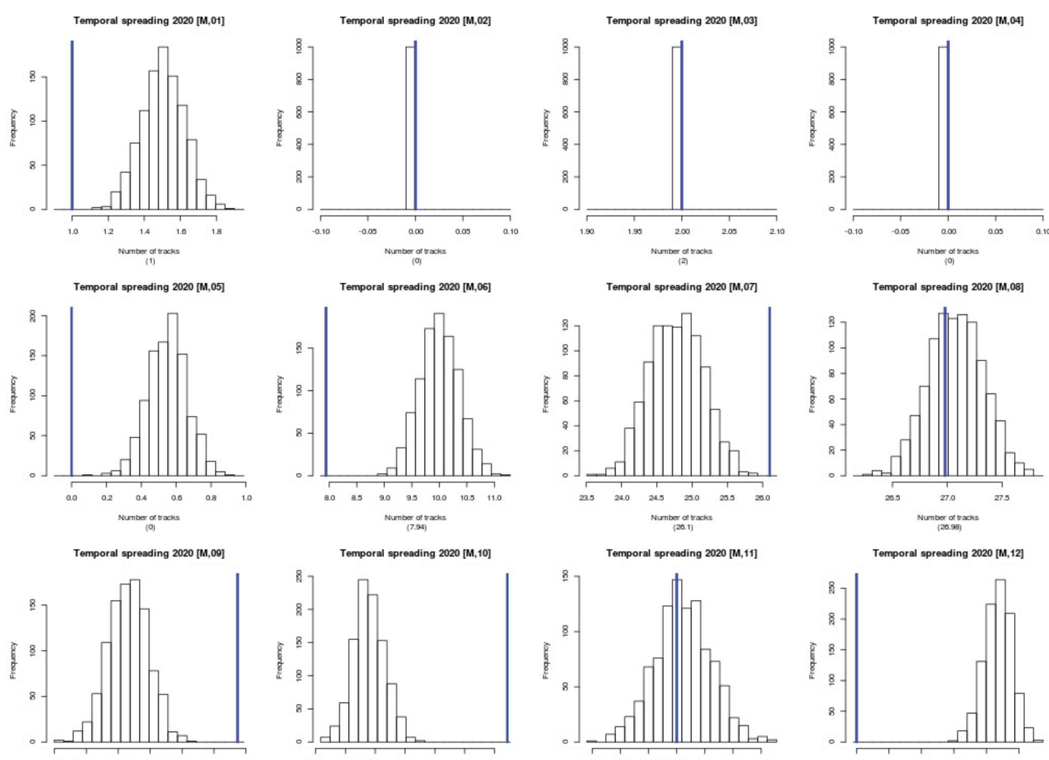


Figure 7-10: Monthly temporal spreading histograms (Merchant/Bulk/Cargo ships)

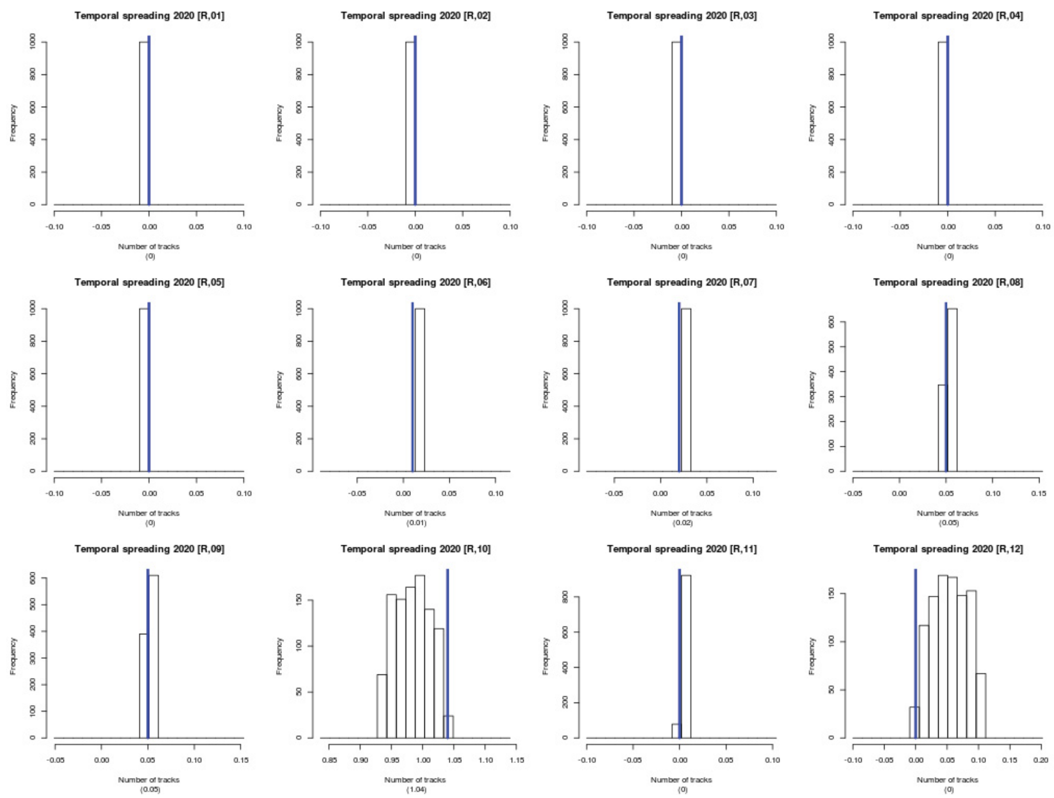


Figure 7-11: Monthly temporal spreading histograms (Research ships)

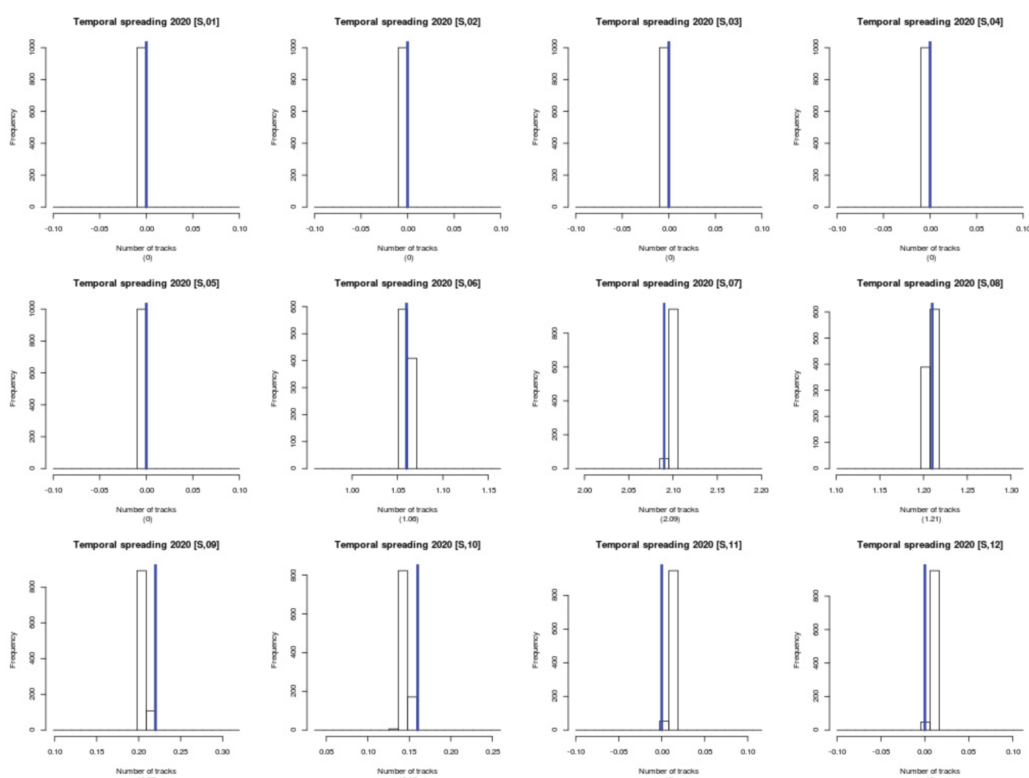


Figure 7-12: Monthly temporal spreading histograms (Tugs/Service ships)

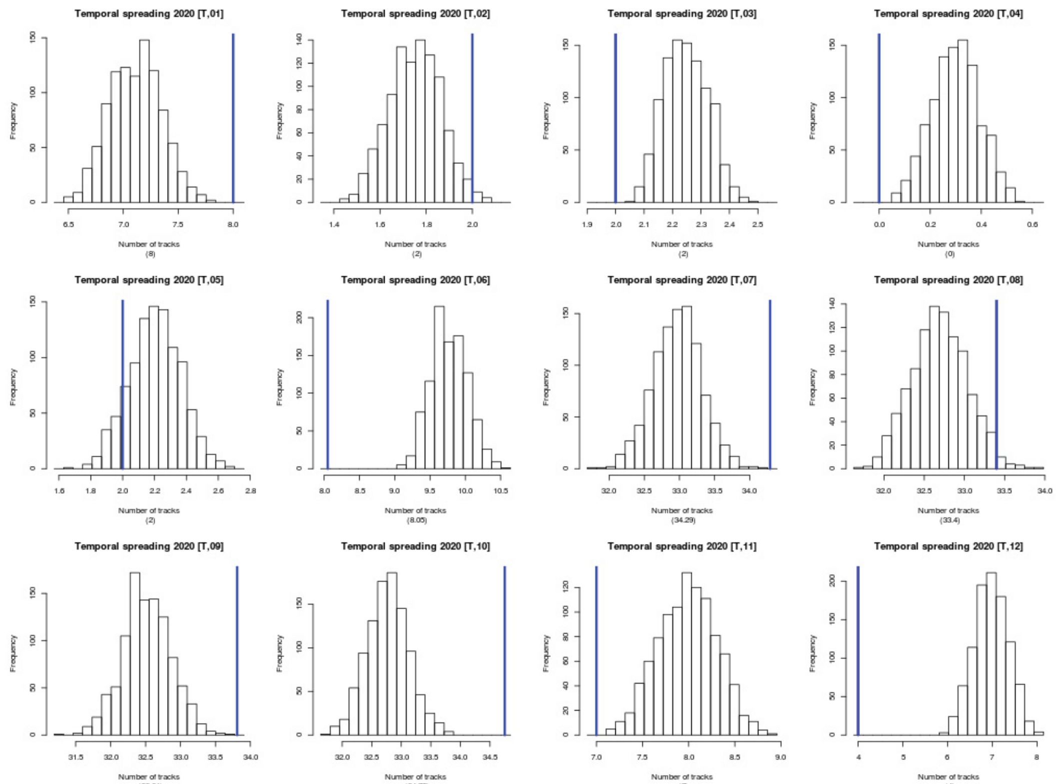


Figure 7-13: Monthly temporal spreading histograms (Tanker ships)

The results of this monthly spreading analysis provide a good perspective on possible effects of the traffic shifting in time relative to historical patterns as the sea ice recedes. The assumptions on the amount of shifting are reasonable, but arbitrary. However, the simulation model is constructed to easily handle changes in input parameters, and conduct more runs. The outputs from this particular set of parameters provide face validity to the approach, as the traffic shifts are consistent with expectations.

7.2. Spatio-Temporal Impact Factors

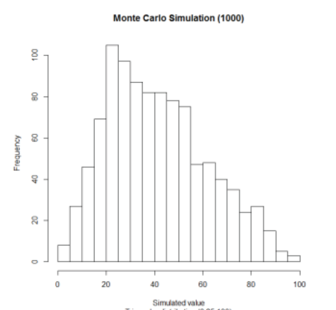
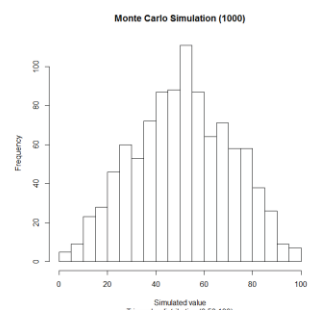
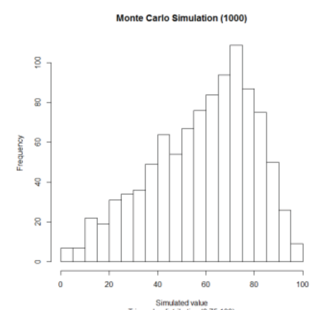
The multitude of drivers (factors) that underpin changes in Arctic maritime traffic were developed in detail in AMT-Ph2-Part1, with important updates provided in Appendices C and D. The search for, and extraction of, resources are major drivers of arctic traffic, encompassing oil and gas, mining and fishing. Increased cruise ship tourism is forecast for the North, and the sealift operation to supply communities is contingent on population changes and spending patterns (for which we use GDP growth as a surrogate measure). Pleasure boating levels are largely tied to community population as well.

A necessary assumption when making the prediction contingent on all of these factors is that the number of vessel trips is not restricted to whole numbers. For example, if one ship goes to a community once in the summer currently, and the population of that community is expected to grow by 25% by the year 2020, then we assume that the "number" of trips following that route for resupply is 1.25 trips.

The problem of determining when a second ship is needed, versus filling the first ship more, or using a larger ship, is intractable for this type of modelling. For most uses of arctic maritime traffic forecasts, the fractional number of trips serves the purpose of showing presence, and relative traffic density across different areas.

In order to take into account the uncertainty for each different factor, we used a probability distribution based on three different parameters. The minimum scenario, the maximum scenario and the most likely scenario (referred to as the 'mode'). The triangular distribution is well suited to simulate this behaviour. This distribution can be used to simulate random values ranging between the minimum and maximum scenario. Moreover, the mode of this distribution will match the most likely scenario for the given parameter. For example, Table 7-1 illustrates the histogram results for a Monte Carlo simulation (1000 values generated) using triangular distributions with the same minimum and maximum values but distinct mode parameters. As described earlier, Monte Carlo simulation is essential for our model as it can be used to simulate a multitude of different scenarios for each spatio-temporal factor individually, and then combine the different scenarios for each factor to generate the overall traffic distribution across the Arctic.

Table 7-1: Examples of Monte Carlo simulations using different triangular distribution parameters

Monte Carlo Simulation (1000) using a Triangle Distribution			
Minimum	**0**	**0**	**0**
Mode	**25**	**50**	**75**
Maximum	**100**	**100**	**100**

The methodology used to simulate the traffic change factors presented in this section of the report is detailed in Flowchart 2-3. First of all, a new criterion has to be created for each spatio-temporal factor (Flowchart 2-3, process 1). The criterion is given a name and a grouping category (population change, mining, oil and gas, tourism…). Then, the simulation parameters are set up for this factor (Flowchart 2-3, process 2). These parameters depict the range of potential scenarios envisaged for this spatio-temporal factor in 2020 (low, medium and high case scenario). These different scenarios are represented using a triangular distribution and an operator. The operator indicates whether the spatio-temporal factor has a multiplicative impact on currently existing maritime traffic (for example, shiploads of a particular commodity expected to increase by x%) or an additive impact (more traffic due to a new activity). Once the parameters are set up, the category of ship impacted by this criterion is defined (Flowchart 2-3, process 3). Note that if the scenarios values are different depending on the category of ship, then different criterion have to be set for each ship type.

In some particular case, a criterion might impact multiple ship categories. An exception to this process arises when projecting future changes to a current activity cannot be done adequately using a multiplicative factor. In this case, the required levels are set using an assign operator which, practically is identical to using a multiplicative impact of zero combined with an additive impact.

The next step of the methodology consists in defining the temporal influence of the factor (Flowchart 2-3, process 4). The analyses conducted in this study have a monthly precision. If a factor impacts the maritime traffic all year long, then 12 different monthly criteria will be created (one per month). These criteria might have constant distribution parameters, or they may differ depending on the month of the year. Once the temporal influence has been specified, the spatial influence has also to be defined (Flowchart 2-3, process 5). A Zone Of Interest graph is used to characterize the maritime traffic in the Arctic (see Section 3.3). Spatial queries can be applied in order to select ZOI that are spatially located in the area of influence of the criterion. The links impacted by the factor are defined at that step of the process. Most of the time, the literature review indicates names of ports or locations where the maritime traffic is expected to change. Using the Canadian Geonames database, these names can be geocoded and transformed into existing or new Zones Of Interest in the graph. In some particular case, a new Zone Of Interest and links might have to be added to the graph (Flowchart 2-3, process 6). The shortest maritime path, taking ice into account, has to be computed for these new links (Flowchart 2-2, process 8) which would be set up with a null initial traffic count.

In order to facilitate the reading of this report, the minimum, maximum and mode scenarios were summarized for each spatio-temporal factor in a consistent tabular format depicting the triangular distribution used, the operator applied to the traffic count (multiplicative, additive or assigned), the categories of ship impacted, the spatial links, and the monthly temporal impact (Table 7-2).

Table 7-2: Tabular format used to describe a spatio-temporal factor

Group:							**Name:**						
Links	**From:**						**To:**						
Categories:		*C*	*F*	*G*	*L*	*M*	*R*	*S*	*T*				
Operator:							**Note:**						
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min													
Mode													
Max													

The next steps of the methodology consist in generating the Monte Carlo simulation for all the criteria previously defined (Flowchart 2-3, process 7). The results of these simulations are then applied to the monthly spread traffic counts depending in the operator of the factor (multiplicative or additive). The multiplicative factors are computed first (Flowchart 2-3, process 8) then the additive factors are added to the results (Flowchart 2-3, process 9). Finally, the results are aggregated together in order to compute the minimum, average and maximum cumulative traffic count per link, ship category, and month (Flowchart 2-3, process 10). The new 2020 ZOI graph simulated traffic statistics are then aggregated by grid cell (Flowchart 2-3, process 11). The gridded base layers for other categories of traffic (Fishing vessels and Pleasure crafts) are ultimately added to the gridded traffic statistics (Flowchart 2-3, process 12).

The different spatio-temporal factors used to predict the maritime traffic in 2020 are detailed in the sections below. The parameters used to simulate the impact of these factors on maritime traffic were extracted from the literature review, as summarized in AMT-Ph2-Part1 Section 6, and the updates in Appendices C and D of this report. The following sub-sections use the same listing of maritime traffic impact factors.

7.2.1. Trans-Arctic Shipping

We define transarctic shipping as going across the Canadian Arctic without making any stops on the way into any ZOI. The links EAST-WEST and WEST-EAST are then considered to be the transarctic links. In 2011, there is no ship that navigates across the Canadian Arctic without making any stops in a ZOI. Moreover, most reports from the literature review concur that transarctic shipping is not expected to happen by 2020 (AMT-Ph2-Part1 Section 6.6 Trans-arctic shipping). Hence, there is no simulation of transarctic shipping in this study.

7.2.2. Community Resupply

As stated in a previous part of our study (AMT-Ph2-Part1 Section 6.8 Community Re-Supply), the community resupply factor is highly related to the populated areas located in the Canadian Arctic. The ZOI were cross-referenced with the Canadian Geonames database to identify links that terminate in habited areas, resulting in 65 of the 199 ZOI being so identified as shown in Table 7-3.

Table 7-3 Northern Communities selected from the Canadian Geonames database

Habitation category	No. of ZOI
"Hamlet"	26
"Locality"	8
"Municipalité de village nordique"	8
"Harbour"	6
"Town"	4
"Hamlet (1)"	2
"Landing"	2
"Village cri"	2
"Municipalité de village cri"	2
"Dock"	1
"City"	1
"Settlement"	1
"Community"	1
"Canadian Forces Station"	1

It is expected that the maritime traffic required to resupply these communities will be impacted by their population growth. The categories of ship impacted by these resupply activities are the Merchant, Tankers, Tug and Government vessels. Statistics Canada (2010) provides a yearly population growth prediction for each province and territory as summarized in Table 7-4.

Table 7-4: Population growth projections for Canadian provinces and territories (between 2011 and 2020)

Territory	Low-growth (%)	Medium-growth (%)	High-growth (%)
Canada	+8.28	+11.39	+14.50
Newfoundland/Labrador	-1.10	+0.57	+2.24
Prince Edward Island	+6.47	+9.21	+11.94
Nova Scotia	**+3.05**	**+5.10**	**+7.11**
New Brunswick	+2.33	+4.22	+6.16
Quebec	+5.14	+7.77	+10.46
Ontario	+9.77	+13.23	+16.67
Manitoba	+7.23	+10.72	+14.31
Saskatchewan	+3.80	+6.33	+8.92
Alberta	+10.35	+13.47	+16.60
British Columbia	+12.29	+15.79	+19.29
Yukon	+3.25	+5.33	+7.69
Northwest territories	+5.03	+7.76	+10.50
Nunavut	+7.08	+10.46	+14.11

The multiplicative factors used for the simulation are indicated for each territory and province in the following tables. Note that Alberta, British Columbia, Saskatchewan, New Brunswick, Nova Scotia and Prince Edward Island are completely outside of the Area Of Interest (AOI) of this study, thus they have no impact on the simulation of the maritime traffic (Figure 7-14). The links impacted by the population change are those having at least their starting or ending Zone Of Interest spatially located in the territory or the province. Thus, every ZOI has been assigned to a territory depending on its location as depicted in Figure 7-14. Manually-added ZOI are not impacted by these population change factors.

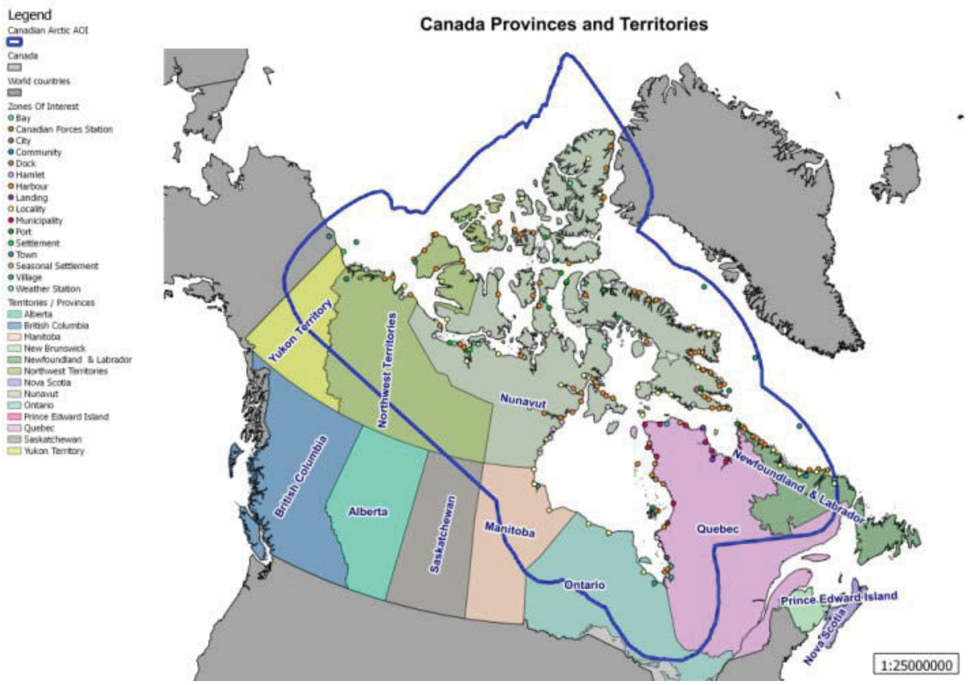


Figure 7-14: Intersection of provinces and territories with the AOI

The tables below summarize the spatio-temporal factors' parameters used to simulate the population growth between 2011 and 2020.

Group:		population					**Name:**	Manitoba					
Links	**From:**	All ZOI in this territory All ZOI					**To:**	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					**Note:**	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723	1.0723
Mode	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072	1.1072
Max	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431	1.1431

Group:		population					**Name:**	Newfoundland & Labrador					
Links	**From:**	All ZOI in this territory All ZOI					**To:**	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					**Note:**	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890	0.9890
Mode	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057	1.0057
Max	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224	1.0224

Group:		population					**Name:**	Northwest Territories					
Links	**From:**	All ZOI in this territory All ZOI					**To:**	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					**Note:**	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503	1.0503
Mode	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776	1.0776
Max	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050	1.1050

Group:		population					**Name:**	Nunavut					
Links	**From:**	All ZOI in this territory All ZOI					**To:**	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					**Note:**	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708	1.0708
Mode	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046
Max	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411	1.1411

Group:		population					**Name:**	Ontario					
Links	**From:**	All ZOI in this territory All ZOI					**To:**	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					**Note:**	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977	1.0977
Mode	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323	1.1323
Max	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667	1.1667

Group:		population				Name:	Quebec					
Links	From:	All ZOI in this territory All ZOI				To:	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**			
Operator:		Multiplicative				Note:	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514	1.0514
Mode	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777	1.0777
Max	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046	1.1046

Group:		population				Name:	Yukon						
Links	From:	All ZOI in this territory All ZOI					To:	All ZOI All ZOI in this territory					
Categories:		*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
Operator:		Multiplicative					Note:	Yearly multiplicative factor					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325	1.0325
Mode	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533	1.0533
Max	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769	1.0769

In order to check whether the sealift community resupply was captured in the LRIT dataset for 2011, we downloaded from the internet the 3 major companies' schedules doing the sealift for community resupply (Northern Transportation Company Limited, Nunavut Sealink & Supply Inc., Nunavut Eastern Arctic Shipping). Every community listed in the sealift schedules corresponds to a ZOI of the graph network. This geo-visual analysis validates our methodology regarding the use of Zones Of Interest to simulate the traffic in the arctic and confirms that the sealift community resupply is already captured by the LRIT system (a multiplicative factor is then an appropriate way to simulate the change in traffic for 2020).

Based on an Organisation for Economic Co-operation and Development report (OECD 2012), the following parameters were taken into account to simulate the impact of the Gross Domestic Product (GDP) growth Canada-wide on arctic communities resupply. As indicated in Table 7-5, the yearly GDP growth is expected to range from 2.2% to 2.3% over the coming decades. Thus, between 2011 and 2020, the cumulated GDP growth multiplicative factor would range between 1.216 and 1.227. The mode of the triangular distribution for the GDP for the simulation is set to a 2.25% yearly GDP growth rate, which corresponds to a cumulative GDP multiplicative factor of 1.222.

Table 7-5: Canadian yearly GDP growth rate forecast

Potential Real Growth in GDP				Real GDP Growth
2001-2007	**2012-2017**	**2018-2030**	**2031-2050**	**2012-2017**
2.6	**2.2**	**2.2**	**2.3**	**2.3**

The Gross Domestic Product growth is considered to have an impact on Merchant, Tankers, Tug and Government vessels (note that the Fishing and Pleasure craft traffic come from a different data source and thus are not simulated using the ZOI graph; they will have their own parameters as detailed in sections 0 and 7.2.6 respectively). The spatio-temporal factors' parameters used to simulate the GDP growth between 2011 and 2020 are summarized in the table below.

	Group:	**GDP**					**Name:**	**GDP growth Canada**					
Links	**From:**	All community ZOI All ZOI					**To:**	All ZOI All community ZOI					
	Categories:	*C*	*F*	**G**	*L*	**M**	*R*	**S**	**T**				
	Operator:	Multiplicative					**Note:**	Canada wide yearly					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216	1.216
Mode	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222
Max	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227	1.227

Arctic Bridge – Churchill port

The Port of Churchill on Hudson Bay is a key port of export for Canada's grain industry. Therefore, although it falls within the AOI, it cannot be modelled in the same way as other Northern Communities. LRIT shows a lot of traffic from Churchill to the EAST gate of the AOI (mostly between August and October). This link is also called Arctic bridge in the literature. There is a need for additional infrastructure investment for this Port. The Port of Churchill's competitiveness is related to the ice conditions which constrain the shipping season (only 14 weeks), requiring icebreakers at the beginning and end of the season, and leading to higher insurance costs. Change in the Ice Conditions forecasted for 2020 might have an impact on these parameters. Recent government decisions may also affect the potential shipping activity as 95% of the shipments through this port have been related to the Canadian Wheat Board (single-desk marketing system) using mostly Merchant/Cargo ships. This marketing system was slated to end in September 2012. However the federal government pledged financial support for five years as an incentive to encourage grain companies to use the port for their shipments and Transport Canada has also committed to provide help to maintain the port. The literature review from AMT-P2-1 Section 5.2.2 Arctic bridge indicates a range between 15 and 25 voyages and over 20 voyages in the 2000s.

	Group:	Arctic bridge				Name:	Arctic bridge				
Links	From:	Churchill EAST GATE				To:	EAST GATE Churchill				
	Categories:	*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*		
	Operator:	Assigned				Note:	Merchant				
Month	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	15								5	5	5		
Mode	20								6	8	6		
Max	25								8	9	8		

7.2.3. Resources

An important spatio-temporal factor taken into account in the simulation is the exploitation of resources in the Canadian Arctic. This factor is the one with the greatest impact on the simulation since there are a lot of new activities planned in this sector. Moreover, there are major uncertainties about the projects that may be operating in 2020. That is why the Monte Carlo Simulation, coupled with a triangular distribution, is a useful method to simulate the possible range of impacts of these scenarios on maritime traffic levels.

Oil and Gas

Oil and Gas is an important resource in the Canadian Arctic. As the annual sea ice extent progressively shrinks and Oil and Gas prices rise, exploiting Oil and Gas fields in the arctic will become increasingly attractive. The development of this sector based on a literature review was presented in AMT-Ph2-Part1 Section 6.9 Resources: Oil and Gas, with an update in Appendix C of this report.

First of all, we used the Oil and Gas Rights Digital Files from the Aboriginal Affairs and Northern Development Canada website (Aboriginal Affairs and Northern Development Canada, n.d.). This file contains the digital spatial boundaries of existing exploration licences, significant discovery licences, production licences, former permits, former leases and the Norman Wells Proven Area. The date of issuance and expiration date are included in this file. Figure 7-15 represents the maps of all the inactive and currently active licences, leases and permits in Canadian Arctic. Then the expiry date was used to filter out leases that expire before 2020. However, these leases could be renewed by the owners. Figure 7-16 illustrates the leases that will still be valid in 2020.

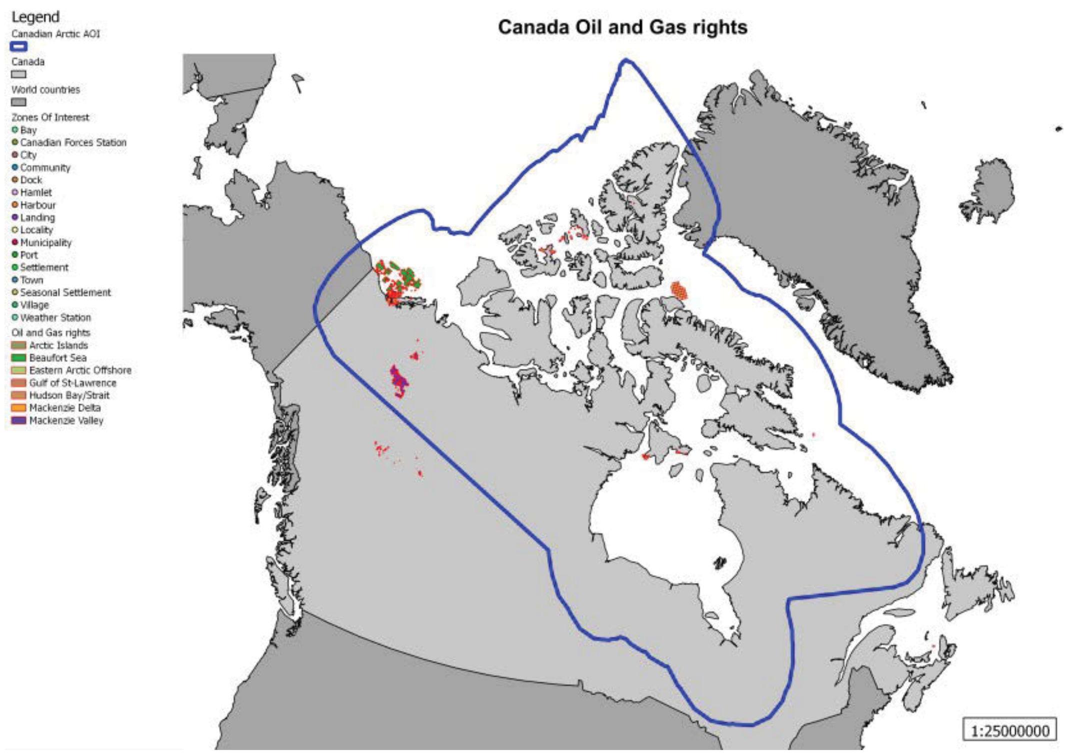


Figure 7-15: Canada Oil and Gas rights map

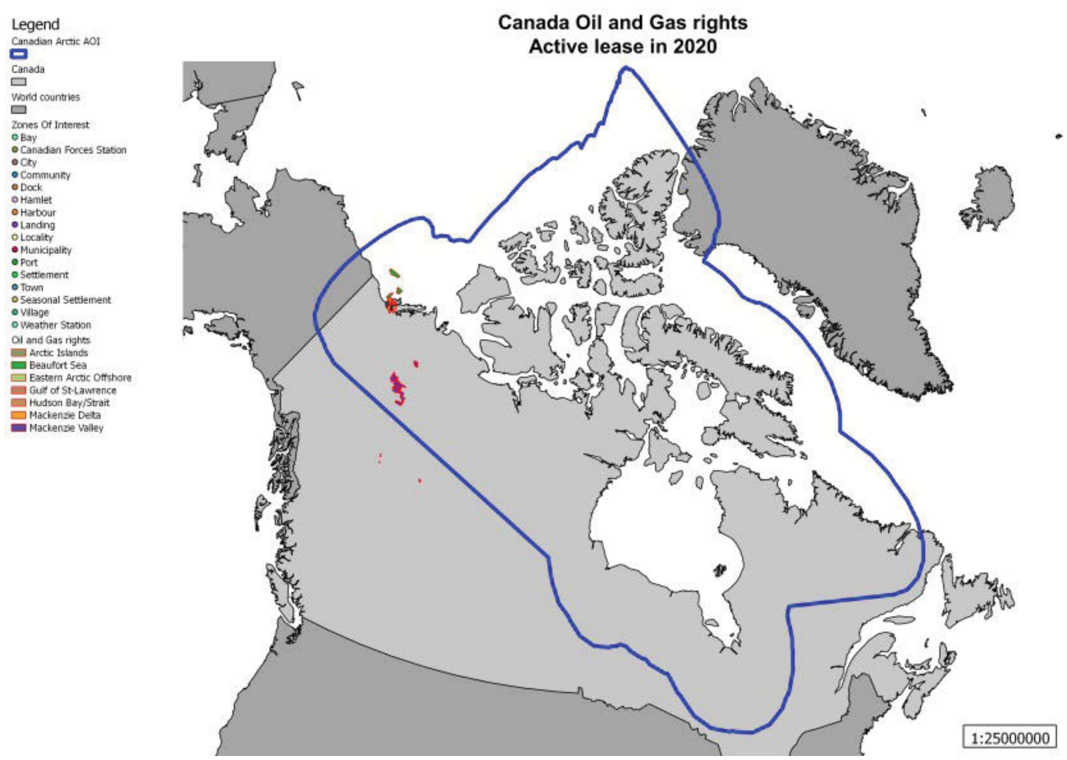


Figure 7-16: Canada Oil and Gas active lease in 2020

Once the location of the Oil and Gas fields and active leases were imported in the database, assumptions were made about the range of activity expected for 2020. To simulate the vessel traffic, we based the patterns on recent activity around an active oil rig in Greenland, for which we have the LRIT data. The results of our analysis are shown in Figure 7-17. The spatial spreading around the oil rig was measured (50 km) and a monthly count per ship category was conducted. One government vessel (Icebreaker) is used to keep the ice away from the oil rig all year long, one research vessel is conducting surveys of the area during one month only, and two Tugs/Service boats are operating during the summer season (July to October).

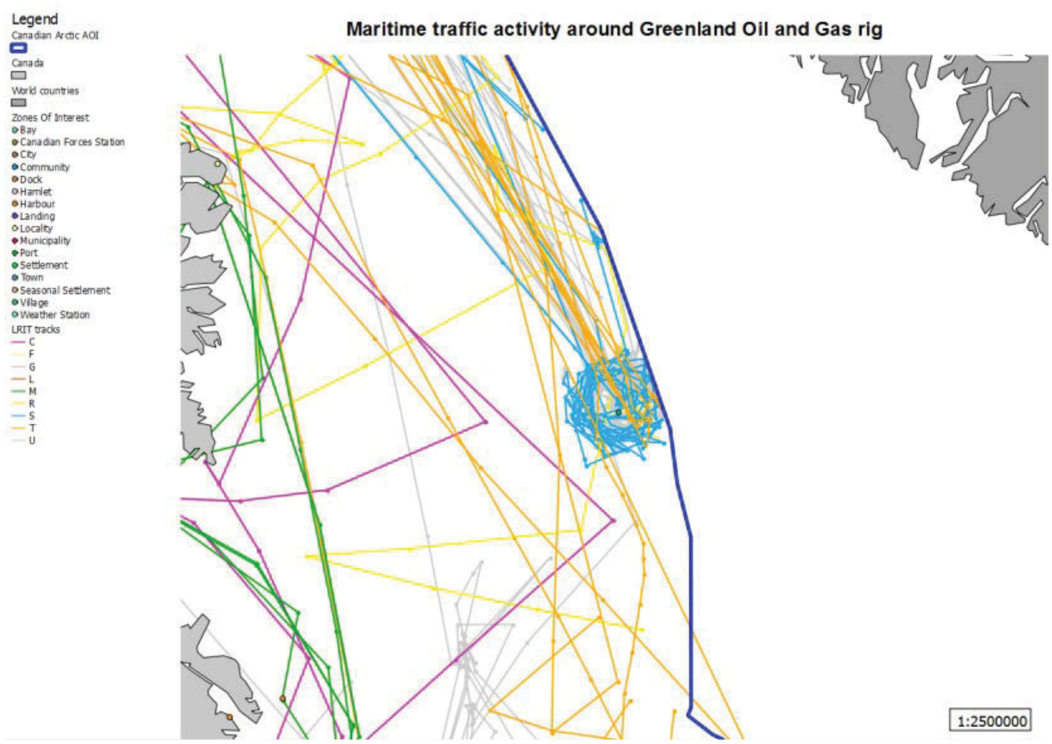


Figure 7-17: Maritime traffic around a Greenland Oil and Gas rig.

Using all this information, a new Zone Of Interest was manually created within the center of a large lease field in the Beaufort Sea which could be active in 2020, using a buffer size of 50 km spread based on the Greenland area measures. This new Zone Of Interest corresponds to the yellow point and circle in Figure 7-18.

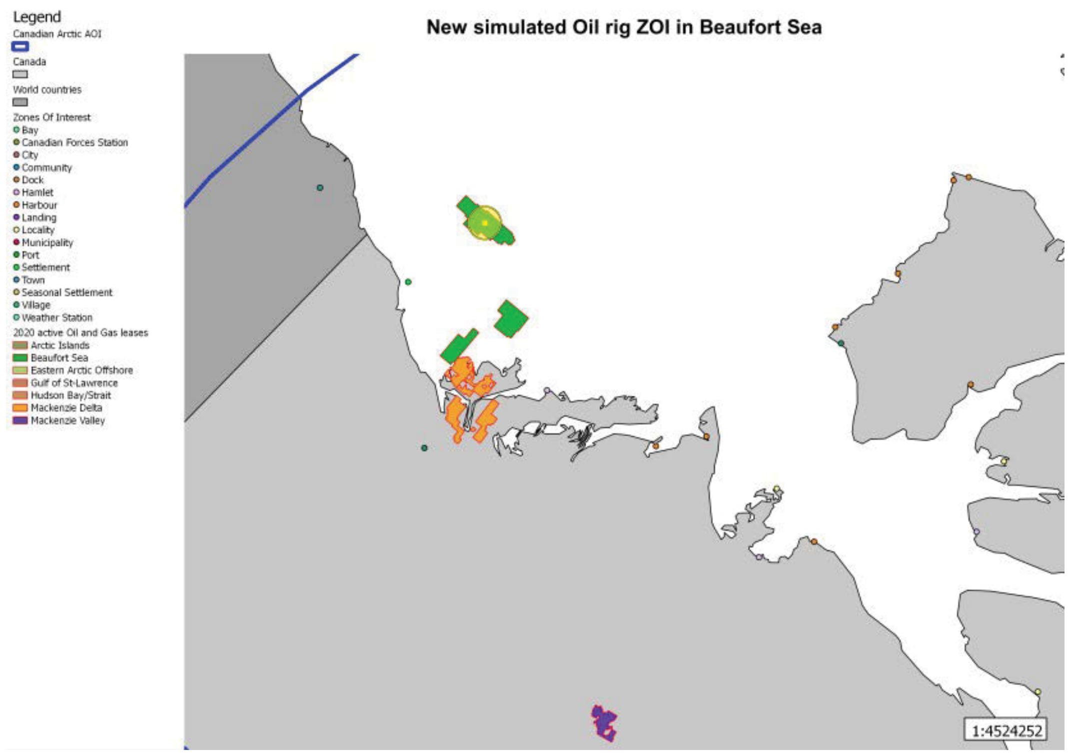


Figure 7-18: New simulated location of an Oil rig ZOI in Beaufort Sea.

Once the new ZOI is created, the new (additive) spatio-temporal factor is created using the traffic count and ship categories from the archetypical Greenland Oil & Gas activities. As stated in the literature review, the impacted links should be between the WEST GATE and the new Oil rig ZOI and also inside the ZOI itself. The spatio-temporal factor parameters used to simulate this new oil and gas activity are indicated in the tables below. Note that the spatial impact of this factor is different than other ones as it not only involves links between two ZOI, but also traffic over an area (OIL WEST AREA). It was simulated using a special link which has the same starting and ending ZOI (OIL WEST AREA).

	Group:	**Oil and Gas**					**Name:**	**Oil West G**					
Links	**From:**	***OIL WEST AREA*** OIL WEST AREA WEST GATE					**To:**	***OIL WEST AREA*** WEST GATE OIL WEST AREA					
	Categories:	*C*	*F*	**G**	*L*	*M*	*R*	*S*	*T*				
	Operator:	Additive (new activity simulated)					**Note:**	Government Ice Breakers					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	12	1	1	1	1	1	1	1	1	1	1	1	1

	Group:	**Oil and Gas**					**Name:**	**Oil West S**					
Links	**From:**	***OIL WEST AREA*** OIL WEST AREA WEST GATE					**To:**	***OIL WEST AREA*** WEST GATE OIL WEST AREA					
	Categories:	*C*	*F*	*G*	*L*	*M*	*R*	**S**	*T*				
	Operator:	Additive (new activity simulated)					**Note:**	Tugs					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0							0	0	0	0		
Mode	1.5							0.25	0.5	0.5	0.25		
Max	6							1	2	2	1		

	Group:	**Oil and Gas**					**Name:**	**Oil West R**					
Links	**From:**	***OIL WEST AREA*** OIL WEST AREA WEST GATE					**To:**	***OIL WEST AREA*** WEST GATE OIL WEST AREA					
	Categories:	*C*	*F*	*G*	*L*	*M*	**R**	*S*	*T*				
	Operator:	Additive (new activity simulated)					**Note:**	Research and survey					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0										0		
Mode	0.5										0.5		
Max	1										1		

Minerals

Another very important resource in the Canadian arctic are the Minerals. In this section, we indicate the spatio-temporal factors' parameters used to simulate the impact on maritime traffic related to changes to current mining activities, or to anticipated new ones, in the Canadian Arctic. These parameters derive from the literature review from AMT-Ph2-Part1 Section 6.10 Resources: Metals and Minerals, and the corresponding updates in Appendix D of this report. They are grouped by Territory and by Mining project name. In order to keep this section clear, we will present only the projects having an impact on arctic maritime traffic. New activities are modeled using an additive factor to the traffic count per links affected, while already existing activity changes are modeled using multiplicative factors.

Voisey's Bay (currently operating)

The Voisey's Bay project, operated by the Voisey's Bay Nickel Company (VBNC), is already operating in 2011. The shipping activities are conducted between Edward's cove and the EAST GATE. There are some temporal restrictions based on a shipping agreement with local residents (limitations in January, Apr, May, and December) although VBNC has stated that it would prefer year-long shipping. VBNC plans to ship up to nine cargos through landfast ice during the January to March period. During April and May, shipping would cease because of the potential whelping of ringed seals and travel for hunting by local people. However, closer inspection of the Vale Voisey's Bay development website shipping schedule[8], reveals that there are trips planned a few days before or after the months' restrictions deadlines. The literature review indicates that at least 20 voyages would be required to deliver annual fuel requirements during peak operation (Mode parameter). This fuel voyage would be back-hauled on the vessels carrying concentrates. Thus, the simulation of the traffic can vary during these restricted months from 0 to 2 trips. The ship category affected by this mining activity is the Merchant/Bulk Cargo. The table below depicts precisely the simulation parameters used. As it is an already existing activity, the actual LRIT traffic count (per link one way) is indicated in the first row. The values range from 1 to 2 trips per month as the vessels planned to do the shipping are either 25,000 DWT or 50,000 DWT CAC3 vessels. Moreover, the annual production is planned to be 50,000 tonnes of finished nickel product and other associated cobalt and copper products. The open-pit mine is forecast to be operating until at least 2019 and some estimates extends it to 2023. The production should be maintained at the same levels when they shift to underground mining as well.

	Group:	**Mining**					**Name:**	**Voisey**					
Links	**From:**	Edward's cove EAST GATE					**To:**	EAST GATE Edward's cove					
	Categories:	*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*				
	Operator:	Assigned (use simulated values)					**Note:**	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
LRIT	**15**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**3**	**5**	**2**
Min	8	0	1	1	0	0	1	1	1	1	1	1	0
Mode	20	1	2	2	1	1	2	2	2	2	2	2	1
Max	26	2	2	2	2	2	2	2	2	3	3	2	2

Raglan (currently operating)

The Raglan mine project is already operating in 2011. The shipping is conducted from the port of Deception to the EAST GATE. The literature review indicates that there is a minimum of 6 trips per year during 8 months and that the mining production is expected to grow from 27Kt/year to 40Kt/year (a 48% increase). Thus a maximum increase of 3 trips is expected to occur, concentrated during the summer months. The ship category affected by this factor is the Merchant/Bulk Cargo ships.

[8] http://www.vbnc.com/MarineTrafficSchedule.asp

Group:		Mining					Name:	Raglan					
Links	From:	Deception EAST GATE					To:	EAST GATE Deception					
Categories:		*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*				
Operator:		Additive (increase of activity)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0					+0	+0	+0	+0	+0	+0	+0	+0
Mode	2.45					+0.25	+0.25	+0.25	+0.4	+0.4	+0.4	+0.25	+0.25
Max	3					+0.3	+0.3	+0.3	+0.5	+0.5	+0.5	+0.3	+0.3

Nunavik Nickel (new project)

The Nunavik nickel project is a new project that is not already operating in 2011. This project is still uncertain, which is why the minimum simulation parameter is set up to be no traffic. The traffic scheme is not detailed for this project; shipping should be operating from the Deception port also. However, it is planned to produce 32Kt/year, relying on 25Kt DWT icebreakers. Compared to the Raglan mine production, we computed that the required number of ships should range from 2 to a maximum of 7 trips per year with an expected mode around 3. This number of trips is assumed to be shared across the different months, with a higher probability during the summer season. As icebreakers are planned to be used, we did not restrict the shipping during the winter months. The ship category impacted by this factor is Merchant/ Bulk Cargo as depicted in the table below.

Group:		Mining					Name:	Nunavik					
Links	From:	Deception EAST GATE					To:	EAST GATE Deception					
Categories:		*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*				
Operator:		Additive (new activity simulated)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	3	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.35	0.4	0.35	0.3	0.3
Max	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.9	0.8	0.5	0.5

Hopes Advance (new project)

Hopes Advance is a new project which may or may not be operating in 2020 (hence, the minimum traffic simulated is 0). The shipping for that project is planned to be operating from Aupaluk to the EAST GATE. There are two production scenarios for this project. The maximum scenario is expecting to produce 20Mt/year and will require 111 trips. The mode scenario is smaller and based on an expected production of 10Mt/year that will require 56 trips of Merchant/Bulk Cargo ships. The parameters for this spatio-temporal factor are detailed in the tables below.

Group:		Mining					Name:	Hopes Advance					
Links	From:	Aupaluk EAST GATE					To:	EAST GATE Aupaluk					
Categories:		C	F	G	L	**M**	R	S	T				
Operator:		Additive (new activity simulated)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	56	3	2	2	3	4	5	6	7	7	7	6	4
Max	111	6	4	4	6	8	10	12	14	14	14	12	7

Izok Lake Corridor (new project)

The Izok Lake Corridor is a new project which was not active in 2011. This project is still uncertain. The worst case scenario indicates that there will be no activity in 2020. The mode case scenario plans for 4 ships doing 3 trips each over a 3-month window (August to October). The maximum case scenario plans for up to 6 ships doing 3 trips over a 3-month window (August to October). The shipping port would be Grays Bay. There are two different paths planned to export the product (EAST or WEST GATE). The category of ship affected by this factor is the Merchant/Bulk Cargo as depicted in the tables below.

Group:		Mining					Name:	Izok Lake					
Links	From:	Grays Bay EAST GATE Grays Bay WEST GATE					To:	EAST GATE Grays Bay WEST GATE Grays Bay					
Categories:		C	F	G	L	**M**	R	S	T				
Operator:		Additive (new activity simulated)					Note:	Merchant (two possible path)					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	12	0	0	0	0	0	0	0	4	4	4	0	0
Max	18	0	0	0	0	0	0	0	6	6	6	0	0

Bathurst Inlet Port

The Bathurst Inlet port is expected to see its shipping activity increase depending on different mining projects. However, there is still some uncertainty regarding the activity of these projects in 2020. There is no LRIT traffic captured in this port in 2011. Between 6 and 8 trips are expected to deliver supplies and fuel to the Kitikmeot community using Tug/Services barges during the summer season. These parameters are detailed in the table below.

	Group:	**Mining**					**Name:**	**Bathurst Inlet**					
Links	**From:**	Bathurst Inlet EAST GATE Bathurst Inlet WEST GATE					**To:**	EAST GATE Bathurst Inlet WEST GATE Bathurst Inlet					
	Categories:	*C*	*F*	*G*	*L*	*M*	*R*	**S**	*T*				
	Operator:	Additive (new activity simulated)					**Note:**	Service Tug (two possible path)					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0							0	0	0	0		
Mode	6							1	2	2	1		
Max	8							2	2	2	2		

Sabina's Back River (new project)

The Sabina's Back River project is also planned to ship its production using the Bathurst Inlet port to the EAST or WEST GATE. The expected number of Tug/Services ships varies between two scenarios depending on whether the project is in the construction phase or already operating. During the construction phase, between 5 and 10 trips are expected. During the operating phase, between 3 and 5 trips are expected during the summer season. These parameters are listed in the table below.

	Group:	**Mining**					**Name:**	**Sabina**					
Links	**From:**	Bathurst Inlet EAST GATE Bathurst Inlet WEST GATE					**To:**	EAST GATE Bathurst Inlet WEST GATE Bathurst Inlet					
	Categories:	*C*	*F*	*G*	*L*	*M*	*R*	**S**	*T*				
	Operator:	Additive (new activity simulated)					**Note:**	Service Tug (two possible path)					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0							0	0	0	0		
Mode	5							1	1.5	1.5	1		
Max	10							2	3	3	2		

Hackett River (new project)

The Hackett River project is planning to ship its production using the Bathurst Inlet port to the EAST GATE. There is a possibility that this project will be operating in 2020. If so, 2 Merchant/Bulk ships will be doing 5 trips during the summer season ranging from August to October. These parameters are listed in the table below.

	Group:	**Mining**					**Name:**	**Hackett river**				
Links	**From:**	Bathurst Inlet EAST GATE					**To:**	EAST GATE Bathurst Inlet				
	Categories:	*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*			
	Operator:	Additive (new activity simulated)					**Note:**	Merchant/Bulk (Ice Breakers)				
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0								0	0	0		
Mode	5								2	2	1		
Max	10								4	4	2		

Meadowbank Mine (currently operating)

The Meadowbank mine project was started in 2010 and was already operating in 2011. This project's lifespan is expected to last until 2017. In 2020, this mine should not be operating anymore. The links impacted by this mining project are associated with Schooner Harbour and Baker Lake. A significant decrease (fractional multiplicative factor) is expected to apply to traffic to and from these links. We simulated it using a constant multiplicative factor keeping only 10% of the 2011 traffic on these links as depicted in the table below.

	Group:	**Mining**					**Name:**	**Meadowbank**					
Links	**From:**	Baker Lake All links Schooner Harbour All links					**To:**	All links Baker Lake All links Schooner Harbour					
	Categories:	*C*	*F*	*G*	*L*	**M**	*R*	*S*	**T**				
	Operator:	Multiplicative (less activity)					**Note:**	Service Tug (two possible path)					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mode	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Max	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Kiggavik project (new project)

The Kiggavik project is a new project that might be operating in 2020. The maritime shipping is expected to occur between August and September. A maximum of two Tugs/Service boats are planned between Baker Lake and Churchill, or Baker Lake and Chesterfield Inlet. Two Merchant and Tankers trips are also planned between Chesterfield Inlet and the EAST GATE. The two tables below indicate the simulation parameters, links and categories of ships impacted.

	Group:	**Mining**					**Name:**	**Kiggavik S**					
Links	**From:**	Baker Lake Churchill Baker Lake Chesterfield Inlet					**To:**	Churchill Baker Lake Chesterfield Inlet Baker Lake					
Categories:		*C*	*F*	*G*	*L*	*M*	*R*	**S**	*T*				
Operator:		Additive (new activity simulated)					**Note:**	Service Tugs					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0								0	0			
Mode	1								0.5	0.5			
Max	2								1	1			

	Group:	**Mining**					**Name:**	**Kiggavik M/T**					
Links	**From:**	Chesterfield Inlet EAST GATE					**To:**	EAST GATE Chesterfield Inlet					
Categories:		*C*	*F*	*G*	*L*	**M**	*R*	*S*	**T**				
Operator:		Additive (new activity simulated)					**Note:**	Merchant and Tankers					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0								0	0			
Mode	1								0.5	0.5			
Max	2								1	1			

Meliadine Project (new project)

The Meliadine project might be shipping its production from Rankin Inlet to the EAST GATE in 2020. During the open water season ranging from July to August, between 4 and 6 merchant and tankers vessels respectively are expected as shown in the following table.

	Group:	**Mining**	**Name:**	**Meliadine**
Links	**From:**	Rankin Inlet EAST GATE	**To:**	EAST GATE Rankin Inlet

Categories:		C	F	G	L	M	R	S	T			
Operator:		Additive (new activity simulated)					Note:	Merchant and Tankers				
Month	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	0								0	0			
Mode	4								2	2			
Max	6								3	3			

Mary River (new project)

Mary River production is expected to start in 2018. This project has two different scenarios for the shipping. The first scenario plans to use new facilities in Steensby Inlet to ship the production to the EAST GATE. The second scenario plans to ship from Milne port to the EAST GATE. The shipping is planned to occur between July and October for tankers and all year long for Merchant ships (Icebreakers). The high production scenario plans 102 round-trips for 18Mt/year production, using new facilities in Steensby port and 3 trips for supplies (Max Scenario). Between 3 and 6 tankers are expected to ship the fuel (6 is the maximum fuel scenario for tankers at Steensby). However, recent literature indicates that this project has been slowed down to only 3.5Mt/year, the Steensby port facilities might not be constructed (Minimum and Mode scenario for this port would be 0), and a lower shipping activity level will rely on the existing Milne port (between 2 and 3 tankers only, and only 18 cargos). As the project is still under review and is planning to start in 2018, it is more likely to be in the late construction phase rather than producing by 2020. That is why the Mode scenario for Milne port simulates only 2 tankers and 2-3 cargos during the summer season. The parameters used to simulate this highly uncertain new project's activity are detailed in the tables below.

Group:		Mining					Name:	Mary River Milne Tankers					
Links	From:	Milne port EAST GATE					To:	EAST GATE Milne port					
Categories:		C	F	G	L	M	R	S	T				
Operator:		Additive (new activity simulated)					Note:	Tankers					
Month	Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	2	0	0	0	0	0	0	0	1	1	0	0	0
Max	3	0	0	0	0	0	0	0.5	1	1	0.5	0	0

Group:		Mining					Name:	Mary River Milne Merchants					
Links	From:	Milne port EAST GATE					To:	EAST GATE Milne port					
Categories:		C	F	G	L	**M**	R	S	T				
Operator:		Additive (new activity simulated)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	2	0	0	0	0	0	0	0	1	1	0	0	0
Max	18	1	1	1	1	1	1	2	3	3	2	1	1
Group:		**Mining**					**Name:**	**Mary River Steensby Tankers**					
Links	**From:**	Steensby port EAST GATE					**To:**	EAST GATE Steensby port					
Categories:		C	F	G	L	M	R	S	**T**				
Operator:		Additive (new activity simulated)					**Note:**	Tankers					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	6	0	0	0	0	0	0	1	2	2	1	0	0

Group:		Mining					Name:	Mary River Steensby Merchant					
Links	From:	Steensby port EAST GATE					To:	EAST GATE Steensby port					
Categories:		C	F	G	L	**M**	R	S	T				
Operator:		Additive (new activity simulated)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	3+102	8	8	8	8	8	8	10	10	11	10	8	8

Roche Bay (new project)

The Roche Bay project is a new mining activity that might be operating in 2020. The expected production of this mine is 5.5Mt/year. We do not have detailed information about the number of trips required to ship this production. However, we used the information from another mining project which planned 56 trips for a 10Mt production and 102 trips for a 18Mt/year production. We simulated the required number of trips for a 5.5Mt production using a maximum number of 32 trips from Roche Bay to the EAST GATE. The mode for the expected production scenario was set at around half the number of trips (16) throughout the year. The category of ships impacted by this factor is the Merchant/Bulk Cargo ships.

Group:		Mining					Name:	Roche Bay					
Links	From:	Roche Bay EAST GATE					To:	EAST GATE Roche Bay					
Categories:		*C*	*F*	*G*	*L*	**M**	*R*	*S*	*T*				
Operator:		Additive (new activity simulated)					Note:	Merchant					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Mode	16	1	1	1	1	1	1	2	2	2	2	1	1
Max	32	2	2	2	2	2	2	4	4	4	4	2	2

7.2.4. Tourism

Tourism activity has a direct impact on maritime traffic for the category of Cruise/Passenger ships in the Arctic. In order to check whether this activity was captured by the LRIT dataset in 2011, we downloaded tourism companies' brochures (Adventure Canada, Great Canadian Travel). Every eco-tour boat trip stop and community listed in the brochure was compared to the ZOI of the graph network that have Cruise ship activity (Figure 7-19). This geo-visual analysis validates our analysis regarding the use of a Zone Of Interest to simulate the traffic in the Arctic and confirms that the eco-tour trip activity is already captured by the LRIT system (a multiplicative factor is then an appropriate way to simulate the change in traffic for 2020).

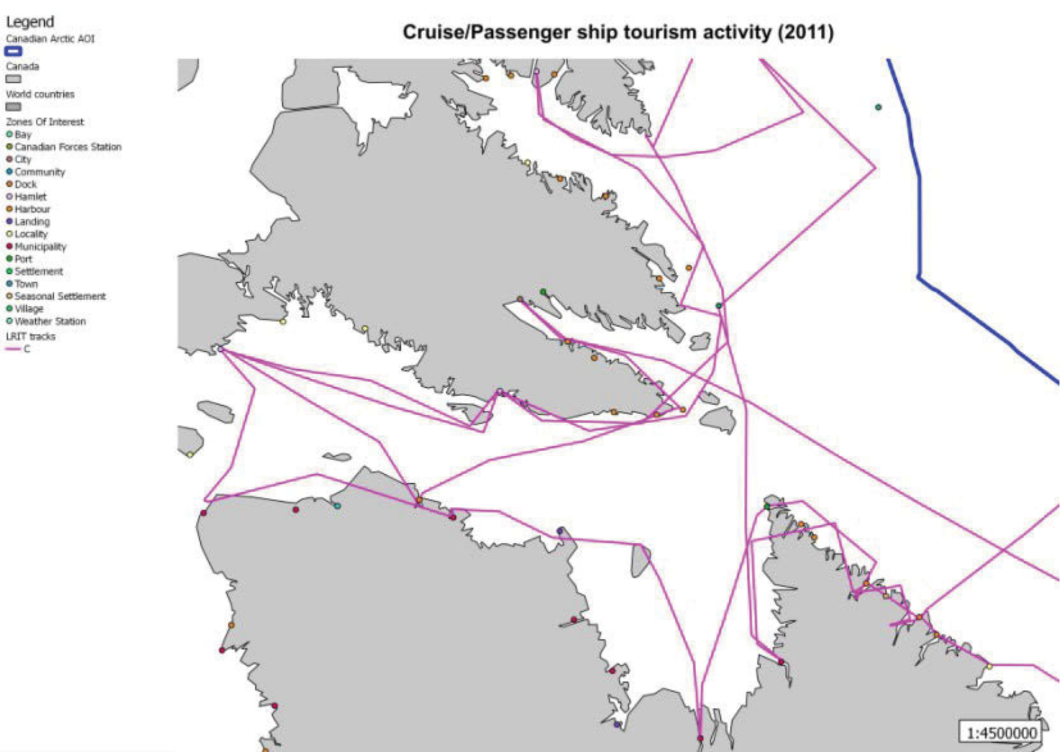


Figure 7-19: Cruise ship LRIT tracks and tourism activity (2011)

As stated in the literature review in section AMT-Ph2-Part1 Section 6.12 Tourism, there are no new Canadian Arctic tour routes expected to be created between 2011 and 2020. However, the tourism activity is expected to increase for the already existing tours. 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 expected change was simulated using a 25% increase. The category of ship impacted is the Cruise ships only.

	Group:	Tourism					Name:	Tourism					
Links	From:	All active links					To:	All active links					
	Categories:	C	*F*	*G*	*L*	*M*	*R*	*S*	*T*				
	Operator:	Multiplicative (already existing activity)					Note:	Cruise ships					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mode	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Max	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50

7.2.5. Fisheries

The LRIT dataset does not capture Fishing vessels. In order to integrate the Fisheries in this study, we imported the results from the previous AMT-Ph1 study. The results of that study were expressed in hourly temporal expected traffic density according to four seasons: Q1, Q2, Q3 and Q4. In this report, we are interested in simulating the monthly density of trip per ship category. First of all, the hourly density was applied to each month of the year using the correspondence shown in Table 7-6, and aggregated using the arctic 0.1° grid.

Table 7-6: Season to month matching

Instantaneous traffic density	Month affected
Q1	January, February, March
Q2	April, May, June
Q3	July, August, September
Q4	October, November, December

Then, the monthly traffic count was computed by multiplying the hourly density by the number of hours in the month using Table 7-7.

Table 7-7: Instantaneous density to monthly traffic count multiplicative factor

Months	Multiplicative factor
February	**24h*28d = 672**
April, June, September, November	**24h*30d = 720**
January, March, May, July, August, October, December	**24h*31d = 744**

As stated in the literature review report (AMT-Ph2-Part1 Section 6.11 Resources: Fisheries), fisheries are not expected to generate more traffic in the Canadian Arctic in 2020. Thus, no traffic increase has been modeled for this factor. The gridded average traffic density month overlay simulation for Fishing vessels is presented in Figure 7-20.

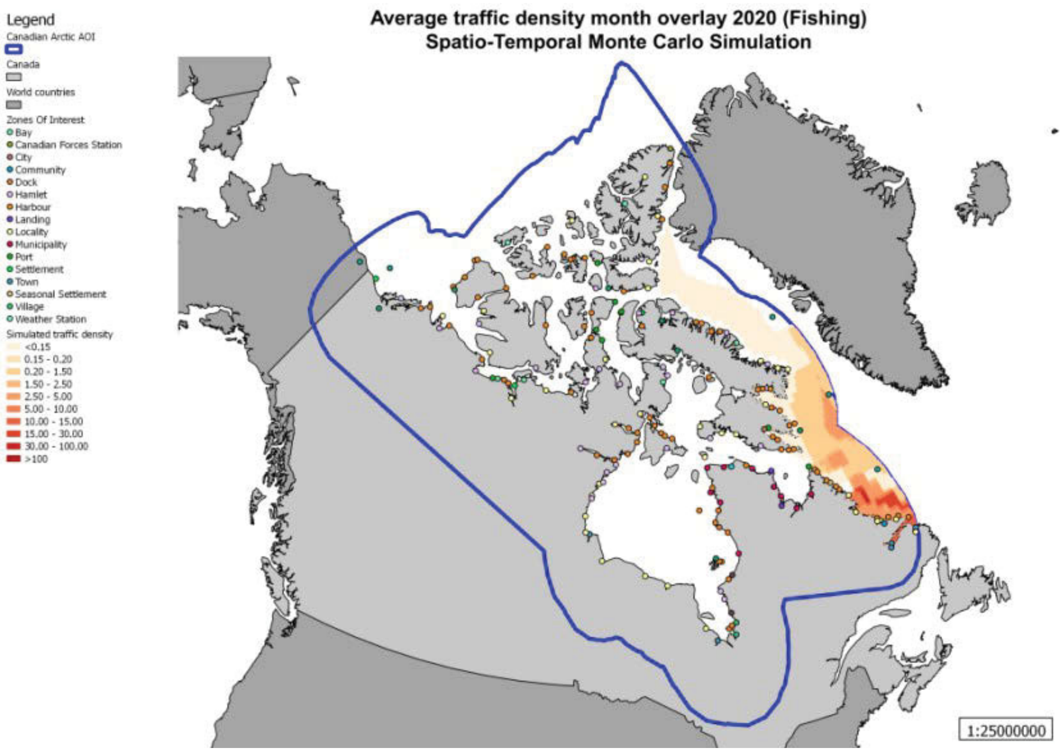


Figure 7-20: Gridded average traffic density month overlay (Fishing 2020)

7.2.6. Pleasure Boats

The pleasure boats are not captured by the LRIT system. As for the Fishing traffic simulation, the instantaneous traffic density from the AMT-Ph1 report was imported and processed the same way (Table 7-7, Table 7-7). However, as the population of communities in the arctic grows, the recreational boating is also expected to increase proportionally. We used the Canada wide population growth scenario to multiply the pleasure boat traffic density (Table 7-8).

Table 7-8: Canada population projection between 2011 and 2020

Territory	Low-growth (%)	Medium-growth (%)	High-growth (%)
Canada	+8.28	+11.39	+14.50

The spatio-temporal factor parameters used to simulate this change are summarized in the table below. Note that the base layer for Pleasure craft was already gridded in the previous study, and thus we cannot apply a link analysis. The factor is then a multiplicative factor applied to every grid cell already having pleasure craft traffic.

Group:		**Pleasure**					**Name:**	**Pleasure craft**					
Cells:		All grid cells											
Categories:		*C*	*F*	*G*	**L**	*M*	*R*	*S*	*T*				
Operator:		Multiplicative (already existing)					**Note:**	Pleasure craft					
Month	**Total**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828	1.0828
Mode	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139	1.1139
Max	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450	1.1450

The gridded average traffic density month overlay simulation for Pleasure craft is presented in Figure 7-21.

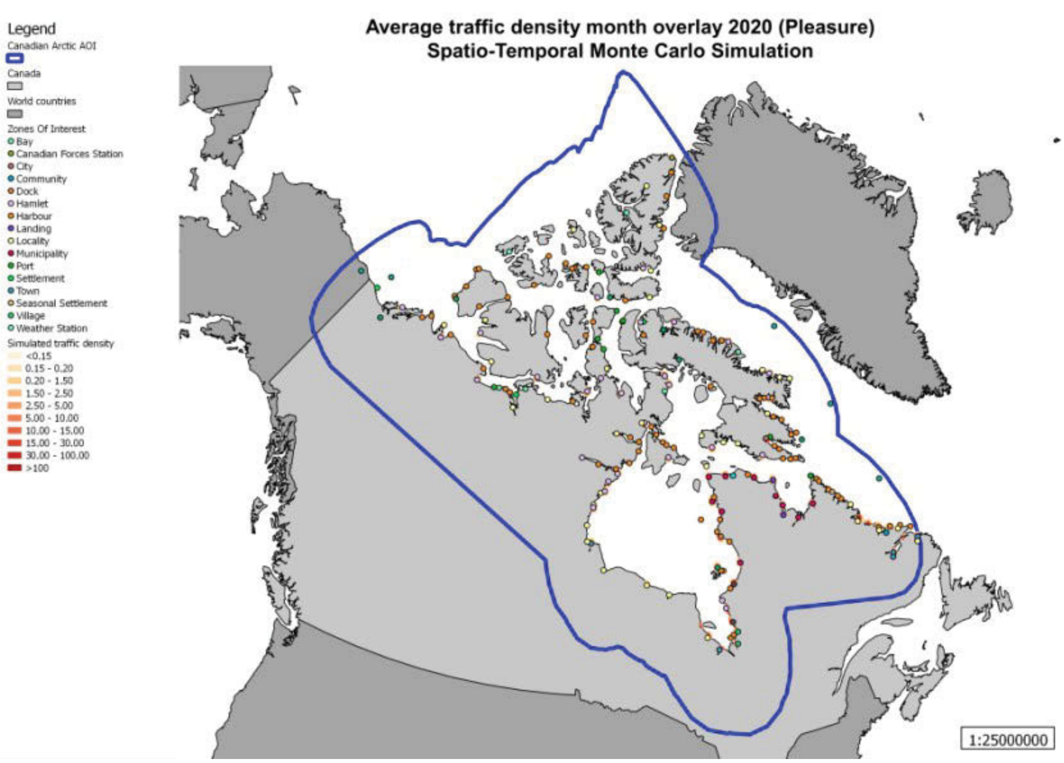


Figure 7-21: Gridded average traffic density month overlay (Pleasure crafts 2020)

7.3. Simulation Outputs

Once all the Monte Carlo simulations are generated, the results can be visualized using monthly histograms per ship category (Figure 7-22 to Figure 7-28). This visualisation is useful to understand the monthly traffic distribution per ship category. The results of these statistics (minimum, maximum and average) are then exported into different map files. In order to compare the results of the simulation between 2011 and 2020, the normalized traffic count values are overlaid on the histograms using a blue line. As most of the simulation's factors predict an increase in Canadian Arctic maritime traffic, all the histograms of simulated traffic are right-sided compared to this line (i.e. traffic increase).

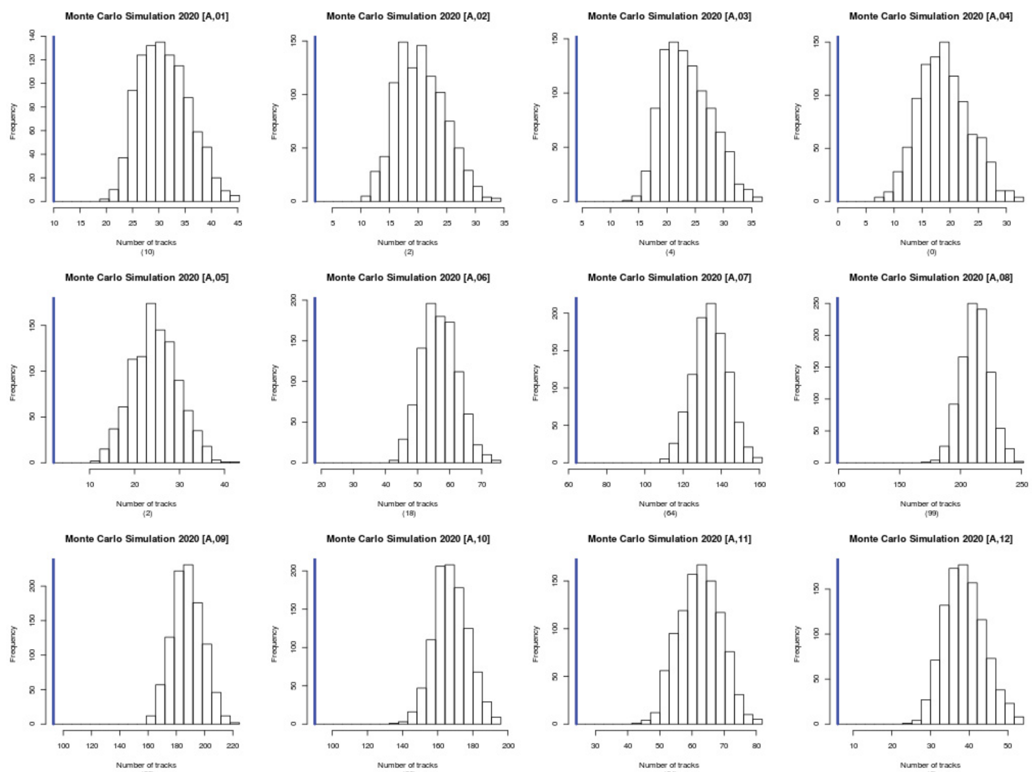


Figure 7-22: Monthly spatio-temporal Monte Carlo traffic simulation histograms (All ships)

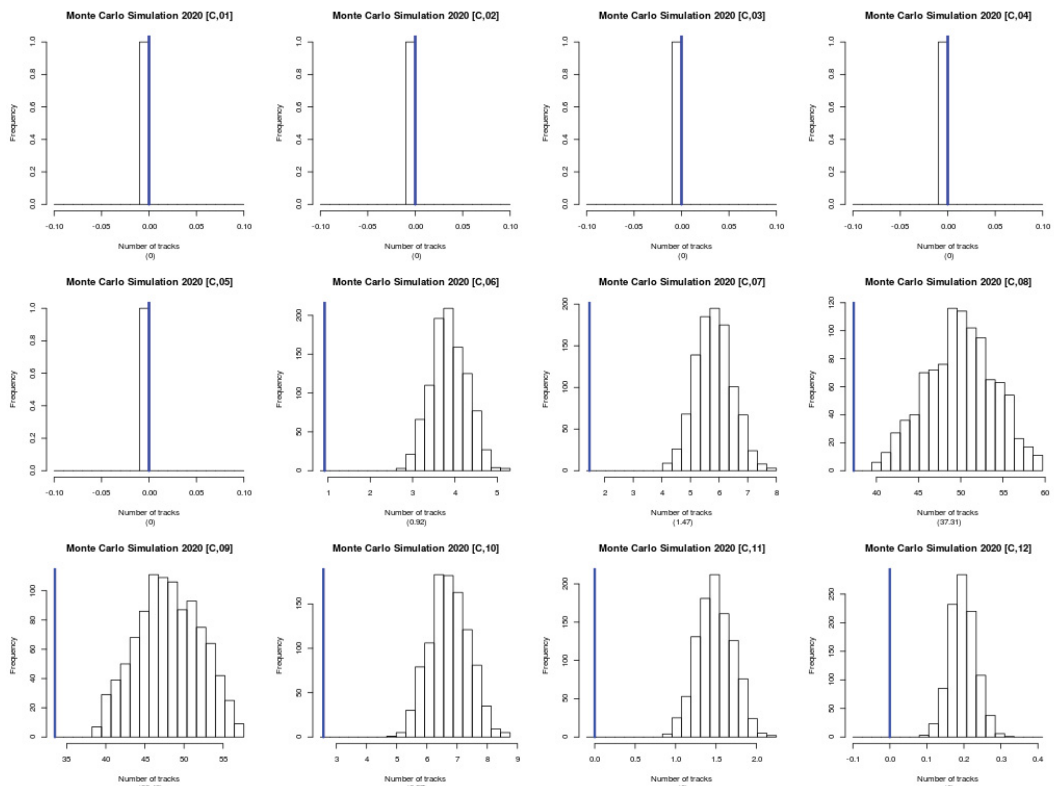


Figure 7-23: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Cruise ships)

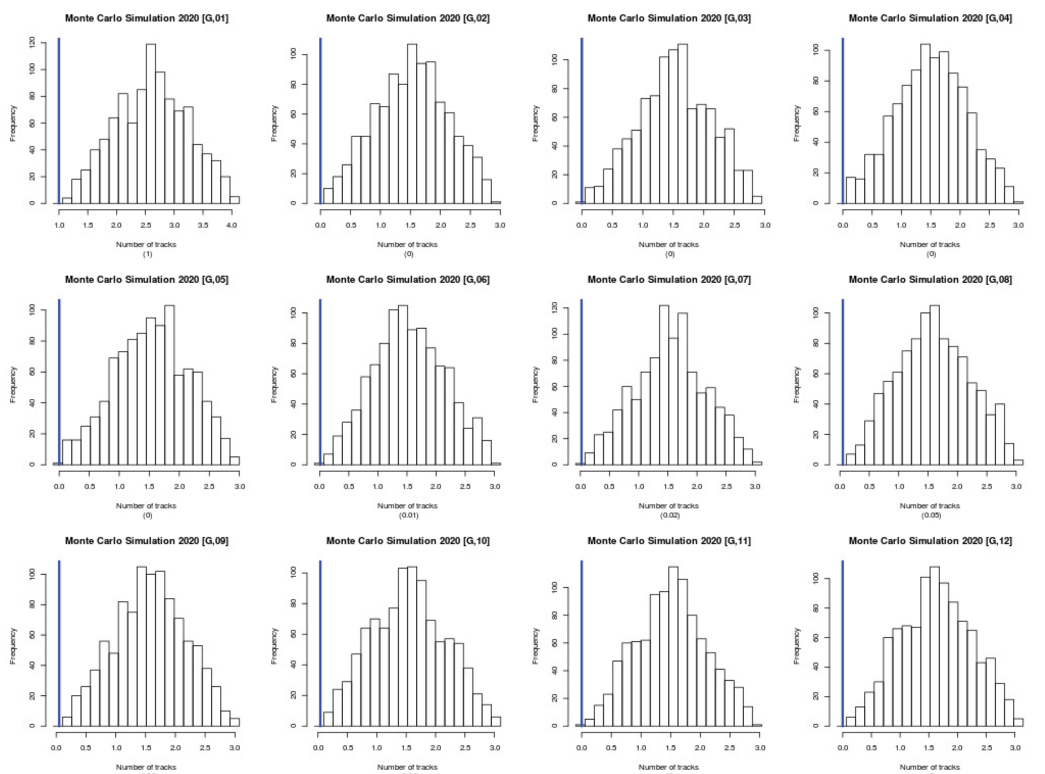


Figure 7-24: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Government ships)

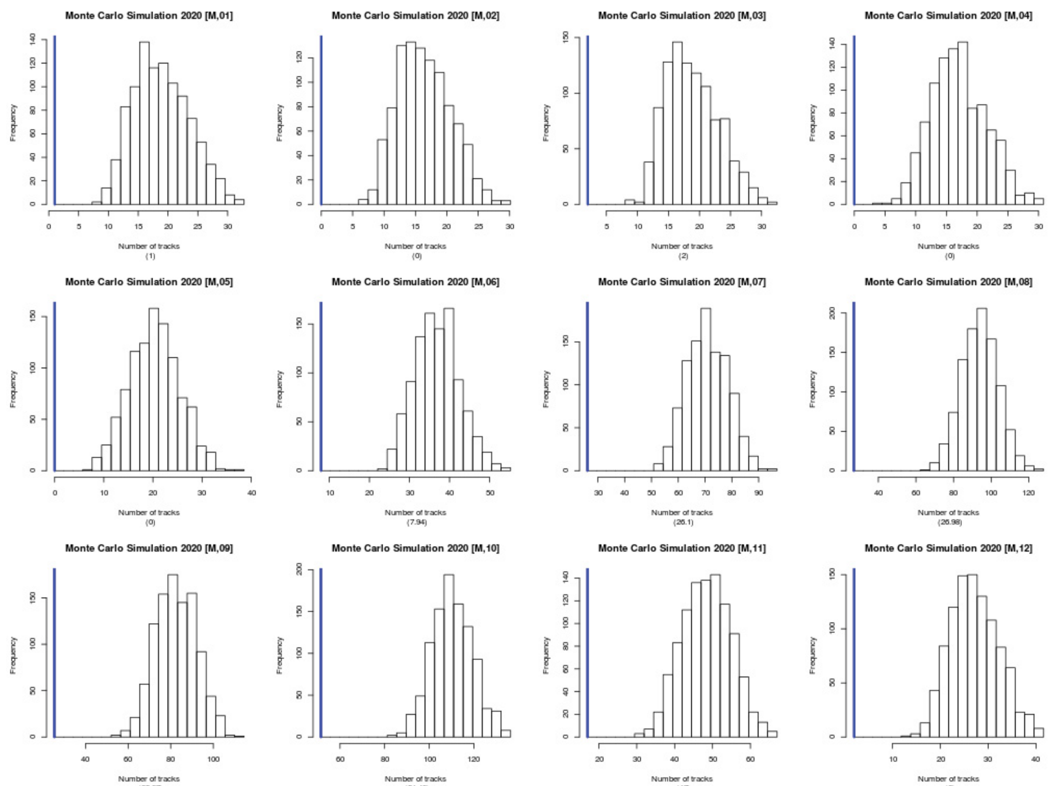


Figure 7-25: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Merchant/Bulk/Cargo ships)

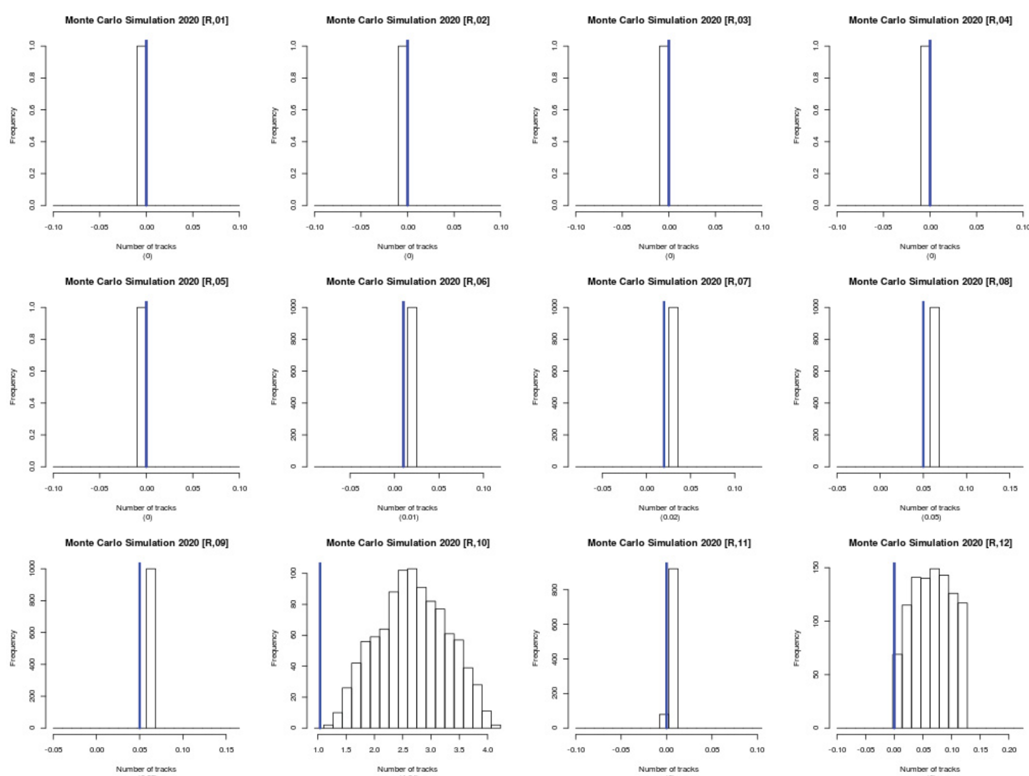


Figure 7-26: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Research ships)

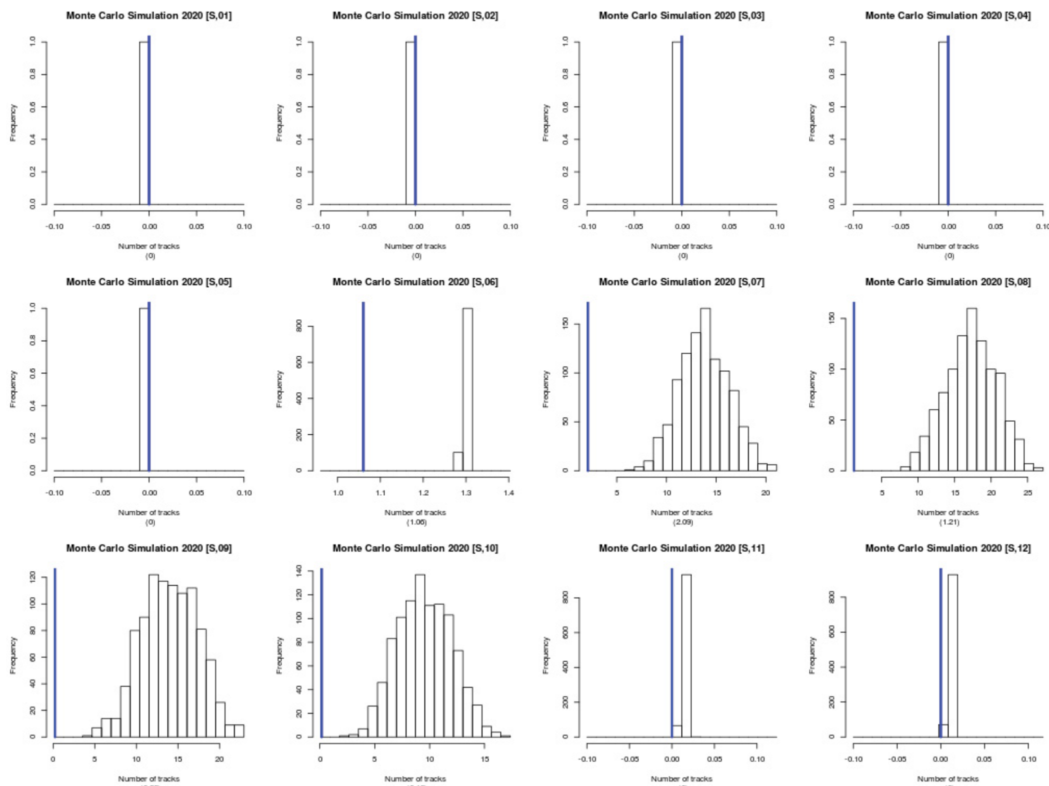


Figure 7-27: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Tugs/Service ships)

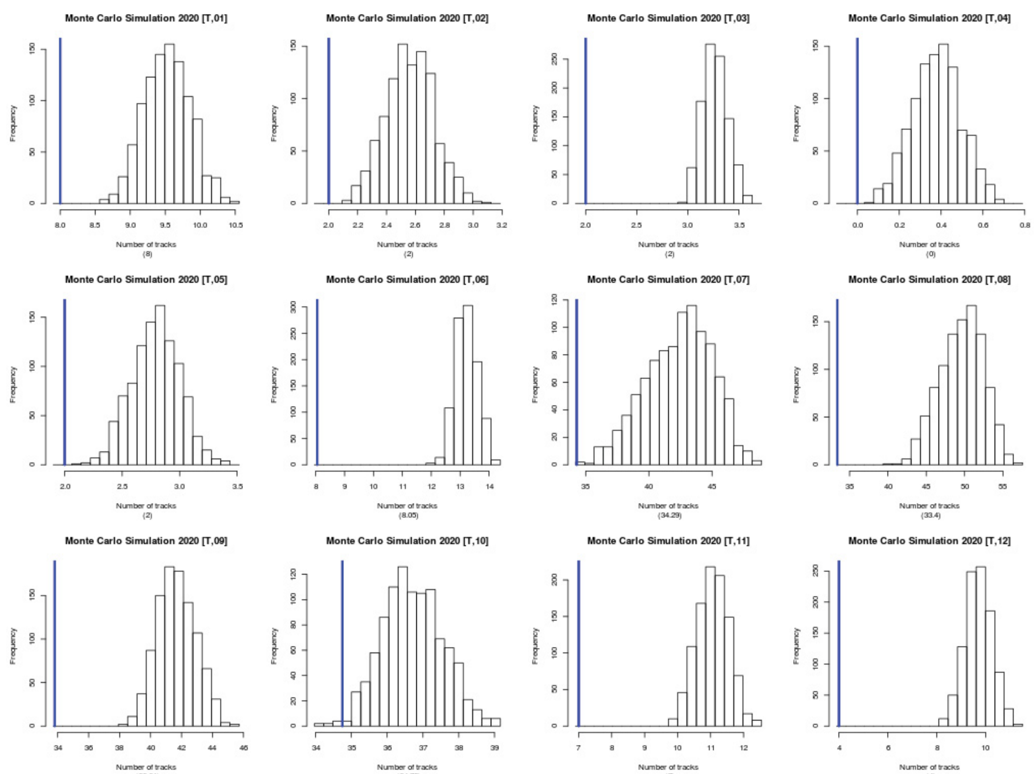


Figure 7-28: Monthly spatio-temporal Monte Carlo traffic simulation histograms (Tankers ships)

7.3.1. Traffic Density per Grid Cell and Graph Edge Analysis

The histograms are useful to understand the global distribution of the simulated traffic for a specific category of ship. However they do not give information about the specific locations of the maritime traffic. In order to visualize the traffic spatial density, intersections between the simulated links and grid cells were computed. Then, the statistical values of each link intersecting a grid cell were summed up in order to get monthly traffic statistics per grid cell and ship category. The maps produced can then be compared with the LRIT gridded traffic density presented in Section 3.3, Figure 3-16. Figure 7-29 illustrates the yearly gridded aggregated average of the simulated traffic in the Canadian Arctic for 2020.

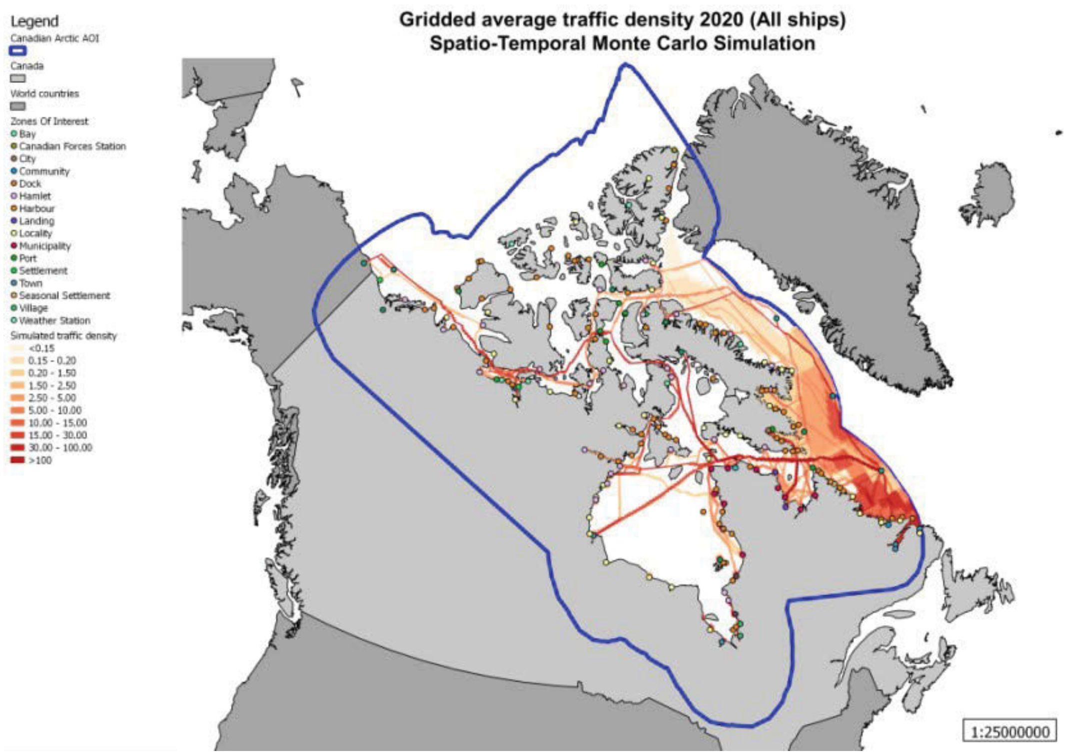


Figure 7-29: Average yearly gridded simulated traffic density for 2020

Table 7-9 presents the monthly temporal evolution of the gridded traffic density in the Arctic (all categories of ship summed together). Table 7-10 presents the results of the Merchant monthly simulation and the Tankers results are in Table 7-11.

Table 7-9: Monthly evolution of traffic count aggregated by grid cell (2020)

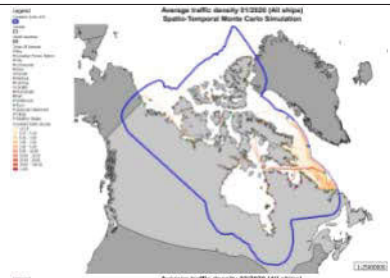
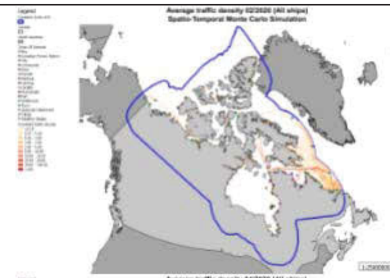
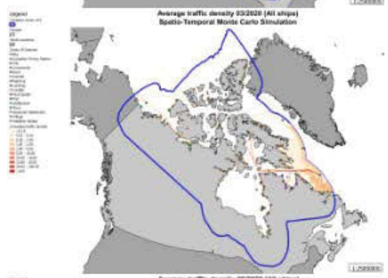
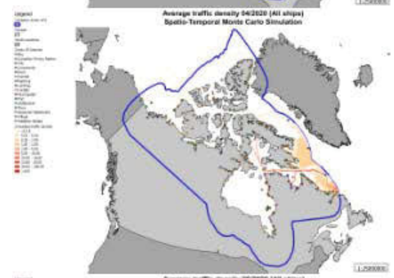
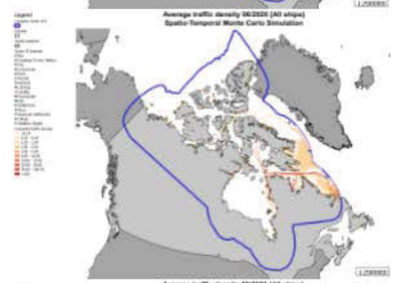
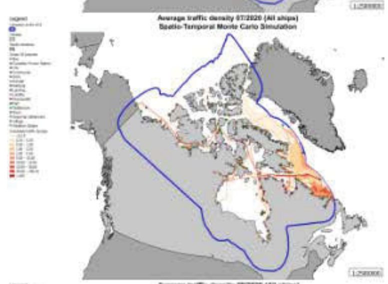
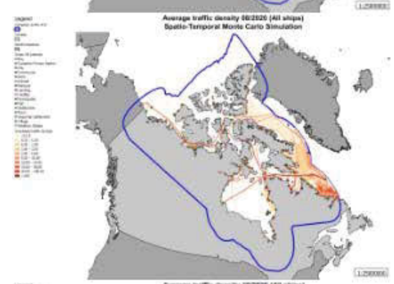
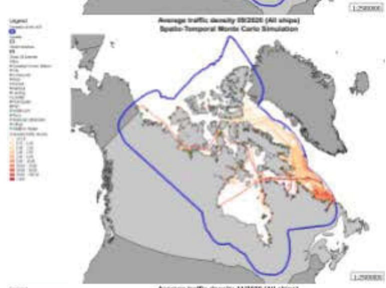
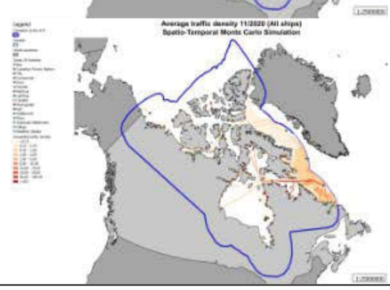
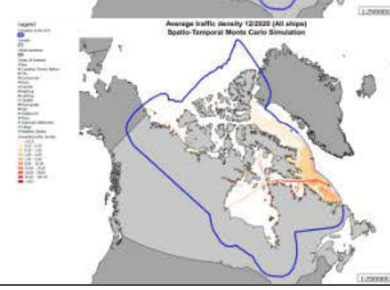
1		2	
3		4	
5		6	
7		8	
9		10	
11		12	

Table 7-10: Monthly evolution of traffic count aggregated by grid cell (Merchant 2020)

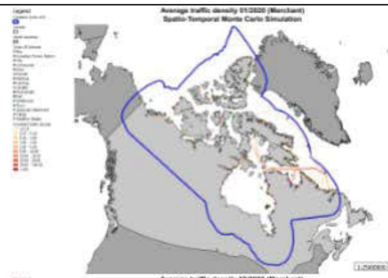
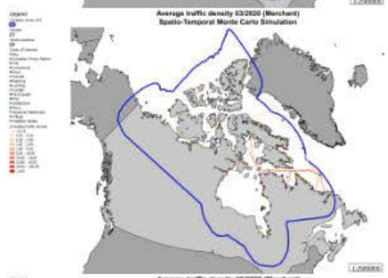
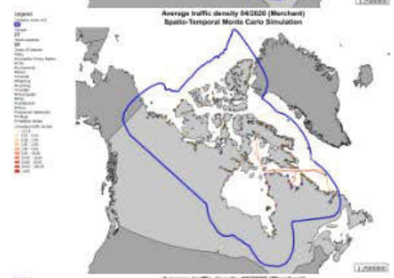
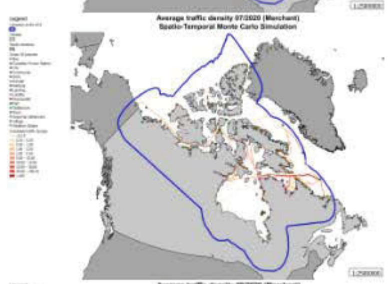
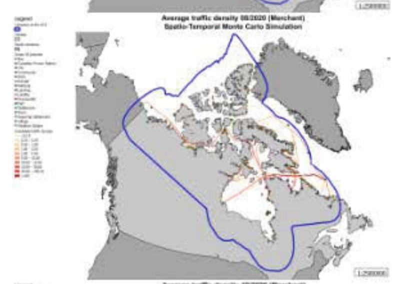
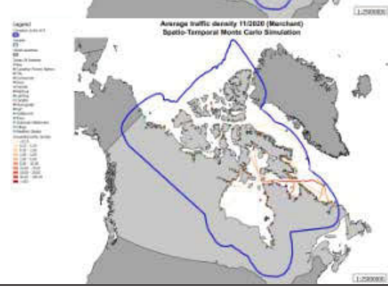
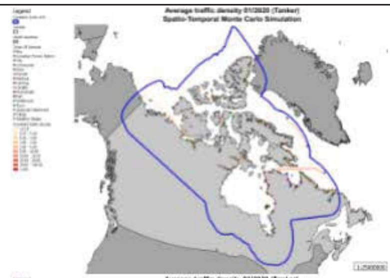
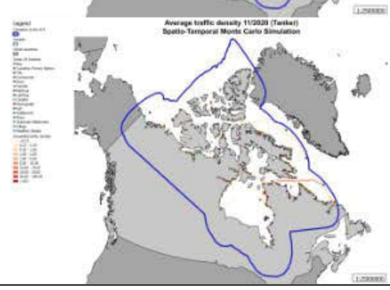
1		2	
3		4	
5		6	
7		8	
9		10	
11		12	

Table 7-11: Monthly evolution of traffic count aggregated by grid cell (Tankers 2020)

1		2	
3		4	
5		6	
7		8	
9		10	
11		12	

7.3.2. Analysis of the Variability between Minimum, Maximum and Average Scenarios

As presented in the previous sections, some spatio-temporal factors have high uncertainty, leading to very different traffic density scenarios ranging from the minimum case to the maximum case. The Monte Carlo simulation was used to combine all the scenarios together and the results of these simulations were aggregated by grid cells. For each grid cell, we computed the aggregated minimum, average and maximum traffic density. The range variation between these minimum and maximum scenario provides interesting information about the uncertainty of the traffic prediction simulation by grid cell. In order to visualize these variations, we exported the results into raster maps using the minimum, average and maximum traffic density in three different raster bands. Then we used these bands to visualize the results in pseudo-inverted RGB color. The **Red** band is assigned to the minimum simulated density, the **Green** band is assigned to the average simulated density, and the **Blue** band is assigned to the maximum simulated density.

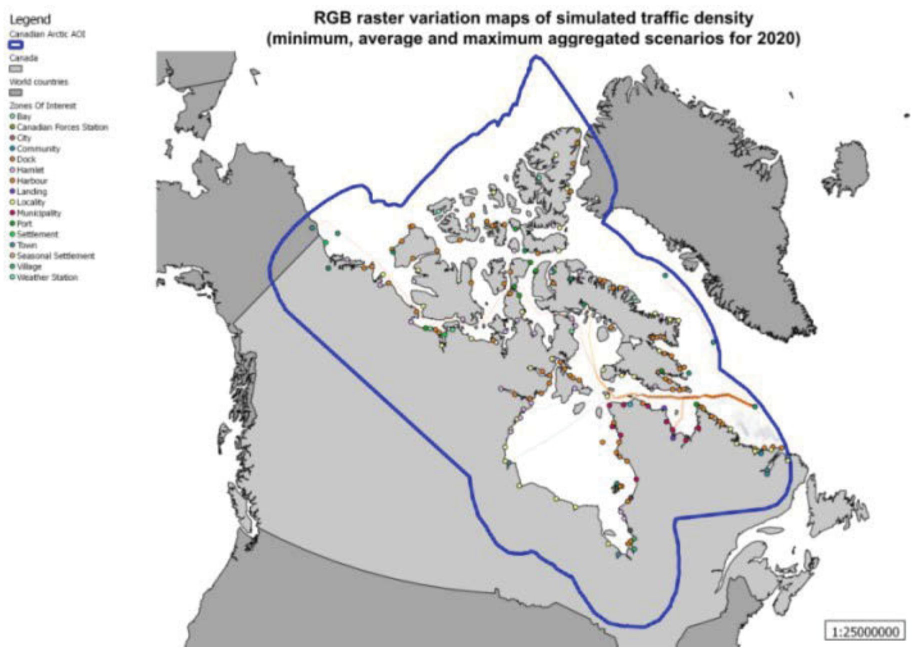


Figure 7-30: RGB raster aggregated traffic variation map (all categories of ship, year aggregated 2020)

Figure 7-30 illustrates this visualisation of the gridded traffic density simulation variation between minimum, average and maximum scenarios. Grid cells where no traffic (or very low traffic) is simulated for 2020 are plotted in **white** or light colors. Grid cells having a higher traffic scenario, but without significant uncertainty between the minimum and maximum scenarios, are plotted using a **grey/blue** colors. **Black** cells correspond to the highest traffic density near the community places due to the recreational boating simulation. Finally, **orange** cells correspond to traffic density having a high maximum traffic scenario but a low minimum traffic scenario (i.e. high variability between maximum and minimum scenarios). The raster RGB map of the Deception area is presented to illustrate this analysis in Figure 7-31. The same visualisation process can be applied to monthly maps per ship category. An example for Merchant ship traffic density analysis for June 2020 is presented in Figure 7-32.

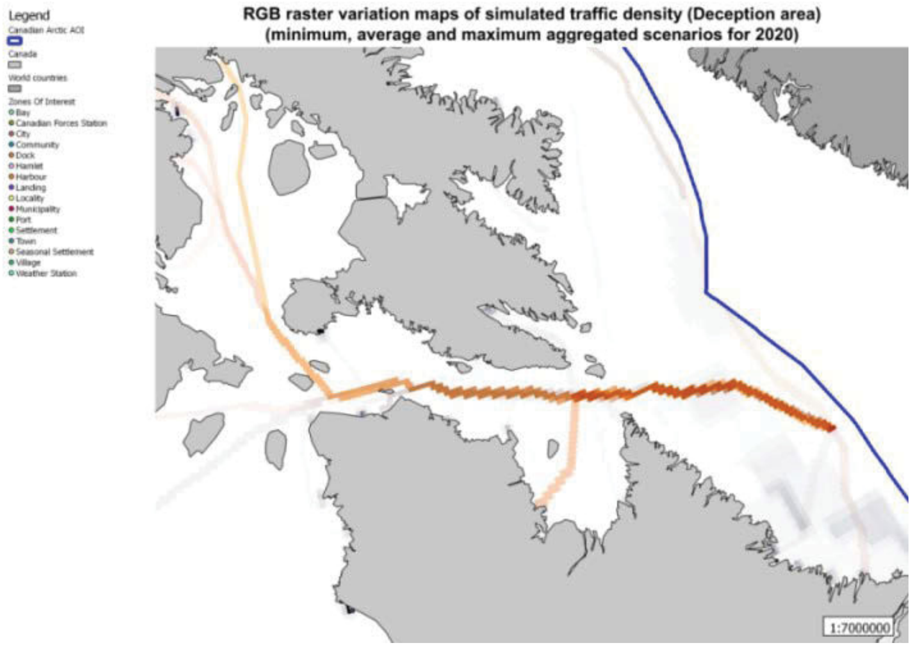


Figure 7-31: RGB raster aggregated traffic variation map (Deception area, All categories of ship, year aggregated 2020)

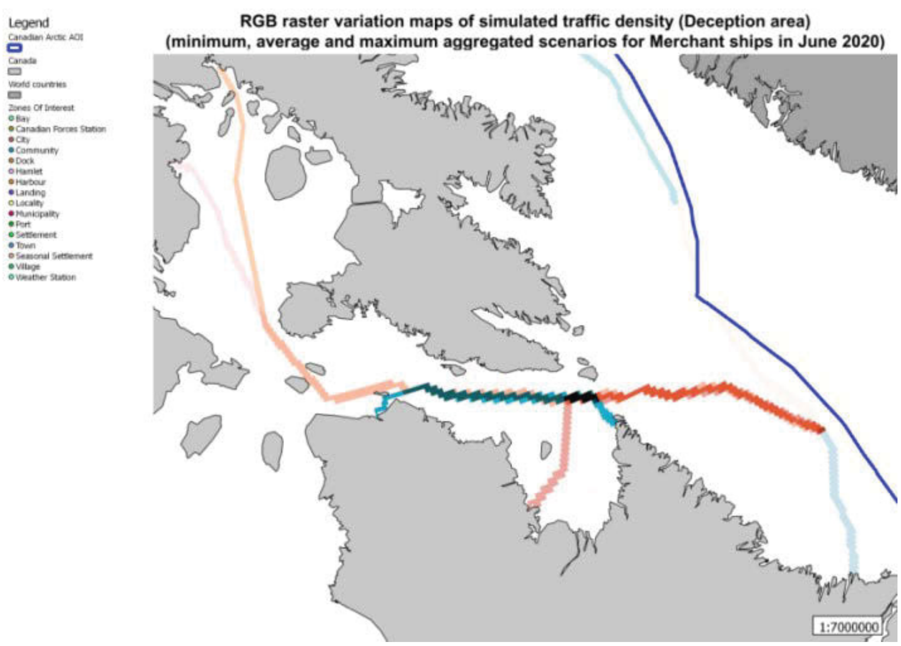


Figure 7-32: RGB raster aggregated traffic variation map (Deception area, Merchant ships, June 2020)

7.3.3. File Export Conventions

The outputs produced by this study are the minimum, average and maximum combined traffic scenarios, aggregated monthly by ship category and grid cells. As required, the results map produced were exported into different files using the ASCII raster format compatible with ESRI ArcGIS software. The results were also exported into GeoTIFF raster format files which are compatible with ESRI ArcGIS and other GIS software and can combine the minimum, average and maximum scenarios into a single 3-band raster file.

The output files listed in the table below are based on the following file naming conventions:

- The category ($CAT) is drawn from the following set {'A','M','T','C','G','R','S','F','L'} ('A' stand for All types of ship).
  There are 9 different combinations of this parameter.
- The month ($MONTH) range from '00' to '12' (00 stand for the full year).
  There are 13 different combinations of this parameter.
- The scenario ($LEVEL) comes from the following set {'rgb','min','max','avg'} ('rgb' will group the min, avg and max scenarios into a 3-band RGB raster file).
  There are 4 different combinations of this parameter.

The generated files, with names based on the above parameters, are:

GeoTIFF raster	amt_arctic_grid_simulation_stats_$CAT_$MONTH_$LEVEL.tif
ASCII grid raster	amt_arctic_grid_simulation_stats_$CAT_$MONTH_$LEVEL.asc
Projection file	amt_arctic_grid_simulation_stats_$CAT_$MONTH_$LEVEL.prj

Note that the 3-band RGB raster file is only available in the GeoTIFF raster format. The maximum number of files generated is equal to 9 * 13 * 4 = **468**. However, for some particular month and ship category there is no simulated traffic expected (mostly likely to occur in winter months). If no traffic is simulated for a parameters combination, then there is no raster file generated.

8. Summary

This Analysis of Maritime Traffic study (AMT Phase 2 – Parts 1 and 2) has produced several notable outcomes. First, a thorough literature review provides a synthesis of two fundamental aspects required for Arctic traffic projections: (a) previous work done on related topics concerning current or anticipated northern traffic, and descriptions of what drivers and conditions are associated with potential changes in ship activity; and (b) projections of ice conditions in 2020 and forecasts or anticipated trends in the major drivers of northern vessel traffic, including natural resource exploration and extraction, tourism activity, and population changes. This information was essential for framing the traffic model and estimating the input parameters.

Second, a network of feasible shipping routes had to be designed using a graphical node-network to allow traffic forecasted for the year 2020 to follow additional paths in addition to the currently used routes. The nodes on the network, current and potential future ones, are constructed on the basis of zones of interest (ZOI), an approach which 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 Arctic Area of Interest (AOI) through which traffic enters or leaves the vessel traffic network. To allow the maximum possible flexibility for traffic to move between the ZOI, graph edges (also called arcs) are created. 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 ice projections for the year 2020 into the model, which affects traffic in terms of where it can go and when it can go, as a function of the ice coverage, ice type, and ship 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 third major contribution from this study was developing a mechanism to include uncertainty about several factors simultaneously into the 2020 traffic forecast. The model allows for five categories of changes relative to current Arctic traffic patterns: new end points (ZOI), new paths, altered mix of vessel types, traffic volume increases or decreases (by type and location), and timing of trips. The node network is essential to enable the first two types of variations, and the temporal traffic-spreading algorithm supports the final adaptation. Using a Monte Carlo simulation method, probabilistic variations in diverse traffic drivers such as the minimum, maximum, and likely number of ships going to and from a resource extraction site, or variability in population growth or purchasing power of northern communities, can all be modeled using a standard form such as a triangular probability distribution. Running the model thousands of times by sampling from the distributions for each input factor generates overall estimated traffic patterns throughout the north, with the output itself represented as the most likely value (mode) by ship type, location and time (month), as well as the statistical range for each of these output values.

The fourth significant contribution is the output from the simulations. The spatio-temporal traffic projections, categorized by vessel type, location, and month provide a solid foundation for strategic planning for improved safety, such as Search & Rescue resource planning and enhanced vessel traffic monitoring. Incorporating the uncertainty into the model allows decision makers to assess the implications of low case traffic scenarios versus high case traffic scenarios. The fact that these output scenarios result from Monte Carlo simulation is valuable, because the alternative of assuming a low case scenario for all the factors simultaneously, or high case for all the factors simultaneously, is much more unrealistic.

Finally, the fifth, and perhaps most important contribution, is that all of the model elements have been organized into a user-friendly simulation tool for Arctic traffic spatio-temporal projections. While one can argue that having a simulation model available to rerun under a different set of input parameters is commonly required (i.e. versus using the model to just produce a specific one-time outcome), it is particularly valuable in this context because the complexity and volatility of many of the input factors are expected to compel more runs of the model as drivers evolve significantly in time and/or additional expertise is brought to bear to clarify the relationships between the factors and traffic patterns.

As with any model there are several limitations, some of which are unavoidable due to factors outside of our control such as data restrictions or the imprecision of input models such as future ice coverage. However, other aspects could be improved over time with additional modelling effort and refinements to the assumptions and the drivers. In particular, the forecast for the year 2020 was generated based on extensive references to recent literature, but could undoubtedly be improved by soliciting expert opinion on a wide variety of elements. This need is further amplified due to the ongoing volatility surrounding many of the arctic traffic drivers and conditions. Some notable aspects of the model that could be amended include the relatively coarse bathymetry information, the reasonable but arbitrary temporal traffic-spreading assumptions, and dependence between factors such as arctic offshore development and purchasing power in the local communities (which affects community resupply needs). However, the framework is in place to incorporate such refinements over time, thus improving the robustness of the predictions, particularly if the model is used to predict traffic over a longer time horizon.

Appendix A – List of Acronyms

AIRSS	Arctic Ice Regime Shipping System
AIS	Automatic Identification System
AMT	Analysis of Marine Traffic
AOI	Area of Interest (overall study area)
AOR	Area of Responsibility
CAC	Canadian Arctic Category
CF	Canadian Forces
CIS	Canadian Ice Service
DRDC	Defence Research and Development Canada
DWT	Deadweight tonnes
EIS	Environmental Impact Statement
GDP	Gross Domestic Product
GIS	Geographic Information System
GMDSS	Global Maritime Distress and Safety System
GT	Gross tonnage
IACS	International Association of Classification Societies
IHO	International Hydrographic Organization
IM	Ice multiplier
IMO	International Maritime Organization
IN	Ice Numeral
IOC	Intergovernmental Oceanographic Commission
kT	Kilotons
LRIT	Long-Range Identification and Tracking
MANICE	Manual of Ice (Canadian Ice Service)
MODU	Mobile Offshore Drilling Units
Mt	Megatons
nm	Nautical mile(s)
OECD	Organisation for Economic Co-Operation and Development
SIGRID	Sea Ice Grid
SOLAS	Safety of Life at Sea convention
SRTM	Shuttle Radar Topography Mission
TA	Technical Authority
tpd	Tonnes per day
tpy	Tonnes per year
UR	Unified Requirements (IACS)
ZOI	Zone of Interest (specific small zone representing a traffic origin or destination)

Appendix B – Simulation code for monthly traffic spreading

```
CREATE  FUNCTION  generate_link_cat_simulated_traffic_count_2020(arg_z1  integer,  arg_z2  integer,  arg_cat  text,  arg_nb  integer)
RETURNS SETOF link_cat_simulated_traffic_count_2020
    LANGUAGE plpgsql
    AS $_$
DECLARE
    -- local variables
    rN link_cat_traffic_count_normalized_2011; -- normalized traffic count for this ship category and link in 2011
    rI link_cat_ice_go_2020; -- ice go/no go for 2020
    rS link_cat_simulated_traffic_count_2020; -- used to store the data change per month

    N  numeric[];
    I  boolean[];
    S numeric[];

    M integer; -- the month loop index
    prev1 integer; -- prev/next month indexes
    prev2 integer; -- prev/next month indexes
    next1 integer; -- prev/next month indexes
    next2 integer; -- prev/next month indexes

    p1 numeric=0.2; -- maximum mult perc +1 month
    p2 numeric=0.1; -- maximum mult perc +2 months

    pprev1  numeric;
    pprev2  numeric;
    pnext1  numeric;
    pnext2 numeric;

    num integer;
BEGIN
    SELECT * INTO rN FROM link_cat_traffic_count_normalized_2011 WHERE zid1=$1 AND zid2=$2 AND cat=$3; -- the initial number of
trips
    SELECT * INTO rI FROM link_cat_ice_go_2020 WHERE zid1=$1 AND zid2=$2; -- the feasible paths ice prediction

    -- create the table data
    N[1]=rN.m1;N[2]=rN.m2;      N[3]=rN.m3;      N[4]=rN.m4;      N[5]=rN.m5;      N[6]=rN.m6;N[7]=rN.m7;      N[8]=rN.m8;N[9]=rN.m9;
N[10]=rN.m10;N[11]=rN.m11;N[12]=rN.m12;


I[1]=rI.m1;I[2]=rI.m2;I[3]=rI.m3;I[4]=rI.m4;I[5]=rI.m5;I[6]=rI.m6;I[7]=rI.m7;I[8]=rI.m8;I[9]=rI.m9;I[10]=rI.m10;I[11]=rI.m11;I[12
]=rI.m12;

-- LOOP TO GENERATE THE REQUESTED NUMBER OF SIMULATION
FOR num IN 1..$4 LOOP
    S[1]=0;S[2]=0;S[3]=0;S[4]=0;S[5]=0;S[6]=0;S[7]=0;S[8]=0;S[9]=0;S[10]=0;S[11]=0;S[12]=0;
    -- LOOP for every month
    FOR M IN 1..12 LOOP

-- initialise indexes for previous and next month to check for spreading
        prev1=M-1;
        prev2=M-2;
        next1=M+1;
        next2=M+2;

-- check for end of year circular month index
        If (prev1=0) THEN prev1=12; END IF;
        If (prev1=-1) THEN prev1=11; END IF;
        If (prev2=0) THEN prev2=12; END IF;
        If (prev2=-1) THEN prev2=11; END IF;
        If (next1=13) THEN next1=1; END IF;
        If (next1=14) THEN next1=2; END IF;
        If (next2=13) THEN next2=1; END IF;
        If (next2=14) THEN next2=2; END IF;
-- simulate the spreading percentage randomly
        If (I[prev1]) THEN pprev1=random()*p1; ELSE pprev1=0; END IF;
        If (I[prev2]) THEN pprev2=random()*p2; ELSE pprev2=0; END IF;
        If (I[next1]) THEN pnext1=random()*p1; ELSE pnext1=0; END IF;
        If (I[next2]) THEN pnext2=random()*p2; ELSE pnext2=0; END IF;
-- add the amount to the simulation
        S[prev1] = S[prev1] + N[M]*pprev1;
        S[prev2] = S[prev2] + N[M]*pprev2;
        S[next1] = S[next1] + N[M]*pnext1;
        S[next2] = S[next2] + N[M]*pnext2;
-- deduce the spreaded amount to the month value
        S[M]= S[M] - N[M]*(pprev1+pprev2+pnext1+pnext2);
    END LOOP;

-- spreading has been computed create the results to send
    rS.sid=num;

    rS.zid1=$1;
    rS.zid2=$2;
    rS.cat=$3;

    rS.m1=N[1]+S[1];rS.m2=N[2]+S[2];rS.m3=N[3]+S[3];rS.m4=N[4]+S[4];rS.m5=N[5]+S[5];rS.m6=N[6]+S[6];
    rS.m7=N[7]+S[7];rS.m8=N[8]+S[8];rS.m9=N[9]+S[9];rS.m10=N[10]+S[10];rS.m11=N[11]+S[11];rS.m12=N[12]+S[12];
    RETURN NEXT rS;
END LOOP;
RETURN;
END;
$_$;
```

Appendix C – Literature Review Update: Oil and Gas

This literature review update for the Oil and Gas sector is inextricably linked to the full literature review presented in the AMT-Ph2-Part1 report. This update has two objectives: a) to have the most up-to-date information on oil & gas development and forecasts; and b) to gather information on projected traffic volumes and shipping routes. The analysis focusses on two key Arctic developments: a) the Mackenzie Gas project; and b) the Beaufort Sea.

Canada's Arctic region holds the potential for vast oil and gas reserves, but its exploration and exploitation is surrounded by many uncertainties. The AMT-Ph2-Part1 Report analyzed three areas with potential Arctic shipping implications (Beaufort Sea and Mackenzie Delta, Sverdrup Basin, and Alberta Oil Sands) but concluded that only the Beaufort Sea and Mackenzie Delta had the potential for a modest impact on Arctic shipping by 2020. Nevertheless, the potential oil and gas exploration and exploitation developments in this area by 2020 were considered to be very uncertain. The most important sources of uncertainty include the fate of the Mackenzie Gas Project, and economic feasibility driven mostly by oil and natural gas prices.

A report released in April 2012 (Callow 2012) provided a general description of potential oil and gas activities in the Beaufort Sea in the short to medium term period (2012-2027). The report was prepared in support of the work of the Beaufort Regional Environmental Assessment, a multi-stakeholder regional research initiative.

The following update is based on Callow 2012 and recent news releases. It addresses four main issues: the Mackenzie Gas Pipeline; oil and gas prices forecast; the onshore and offshore activities in the Beaufort Sea; and other initiatives.

As pointed out in the AMT-Ph2-Part1 report and also by Callow 2012, another factor that is expected to influence oil and gas developments in the Arctic is the regulatory framework (for example, new stringent regulations adopted in response to the Deepwater Horizon incident). Consistent with the AMT-Ph2-Part1 report, this factor is not included in this report.

1. Mackenzie Gas Project

Potential natural gas developments rely on the transportation of the gas by the Mackenzie Gas Pipeline. In December 2010, the National Energy Board recommended that the project be allowed to proceed in the public interest, and the Federal Government approval via Cabinet Order-in-Council was received in March 2011. The approval contained 264 conditions, including the requirement to file an updated cost estimate and report on the decision to construct by the end of 2013 and, further, that construction must commence by December 31, 2015 (National Energy Board 2010, Appendix K clause 73 and 74).

However, the commercial viability of the project is dependent on many factors, including long-term natural gas markets and a positive fiscal agreement with the federal government (Imperial Oil, n.d.).

The major stakeholder, Imperial Oil, has signaled that they will proceed but must secure 'thousands of permits' and that it will be difficult to meet the 2013 deadline. The company asked for a three-year extension, which was denied (CBC 2012). If the project proponents obtain the necessary permits, the pipeline could be completed at the earliest in 2018 (NEB 2010, Chapter 4).

MACKENZIE PROJECT DESCRIPTION

The Mackenzie gas project is a 1,196 km network of pipelines starting in Mackenzie Delta in the Northwest Territories and connecting to existing pipelines in Alberta (see Figure B - 1). Three major onshore gas fields have been discovered that could feed into the Mackenzie pipeline (Taglu, Parsons Lake, and Niglintgak). These three 'anchor' fields will supply approximately 75% of the total capacity of the pipeline (800mcf/day of 1200mcf/day). Spare capacity is therefore available as other gas fields are discovered and brought online (Mackenzie Gas Project 2004a).

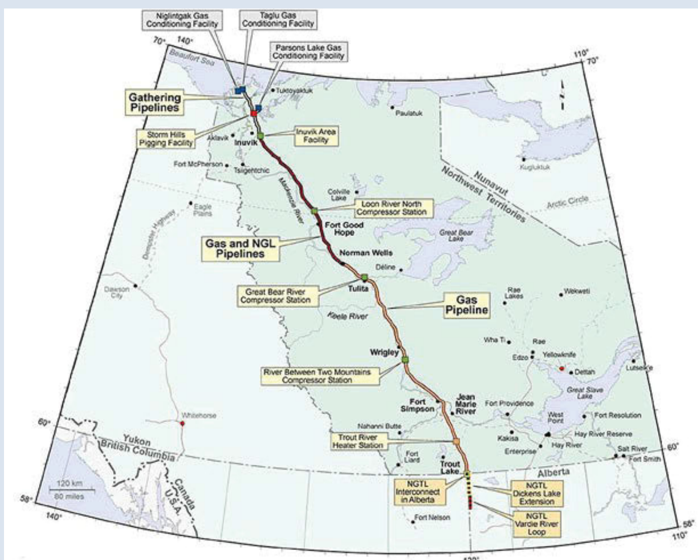


Figure B - 1: Map of the Mackenzie gas pipeline project (Mackenzie Gas Project, n.d.)

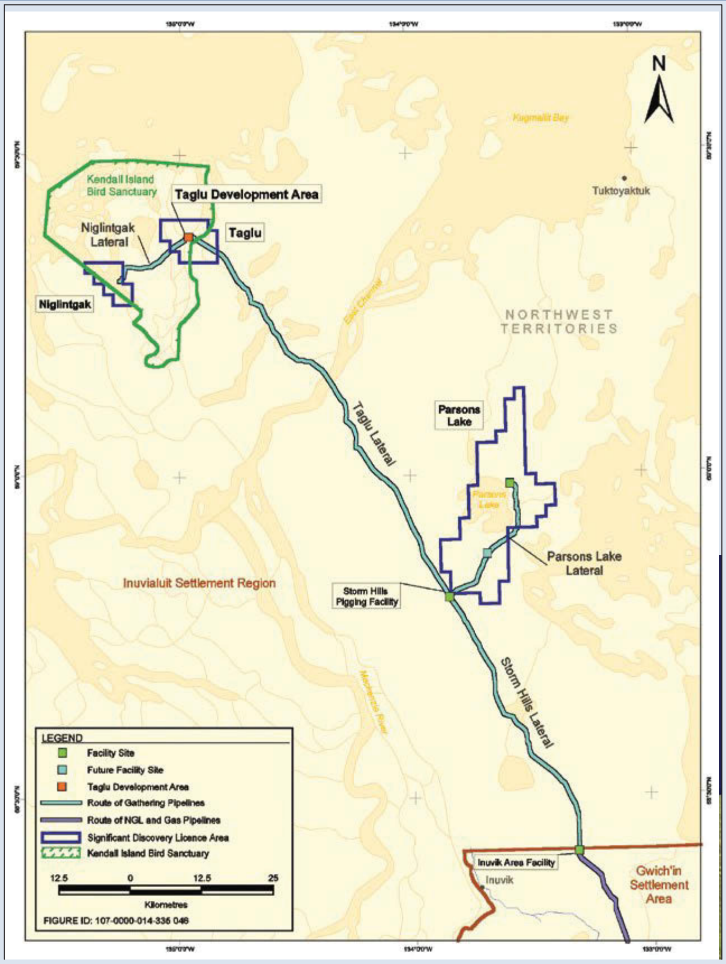


Figure B - 2: Pipeline gathering system from the natural gas fields to the Mackenzie gas pipeline.

The main pipeline starts at the Inuvik area facility (near Inuvik) where the natural gas is processed and liquids are removed (Mackenzie Gas Project, 2004a). A series of gathering systems (small pipelines) will connect the natural gas fields with the main Mackenzie gas pipeline (see Figure B - 2) (Mackenzie Gas Project 2004b). The expected lifespan of the fields is approximately 30 years (Mackenzie Gas Project 2005, 2006, 2007).

2. Oil and Gas Prices

The most recent forecast for gas prices was provided by the World Bank on January 2013 (See Table 2-1, World Bank 2013). Compared to the forecast included in the AMT-Ph2-Part1 Report, forecast oil prices appear to be consistent with medium price projections of the International Energy Agency while the natural gas forecast is slightly higher than the projections. It is unclear whether the expected price differences will have an impact on the investment in the Oil and Gas sector.

Table B - 1: Historical and Projected Natural Gas Prices (Nominal US$)

US$/ Mmbtu	1980	1990	2000	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2025
Natural Gas US US$Mmbtu	1.6	1.7	4.3	4.4	4.0	2.8	3.5	4.0	4.5	5.0	5.3	5.5	5.8	6.0	7.0
Crude oil, avg, spot, US$bbl	36.9	22.9	28.2	79.0	104.0	105.0	102.0	102.2	102.1	101.9	101.7	101.5	101.4	101.2	101.5

3. Beaufort Sea Offshore Oil and Gas Activities Projections

Callow 2012 provides a general description of potential oil and gas activities in the Beaufort Sea for 2012-2027, prepared in support of the Beaufort Sea Regional Environmental Assessment initiative. His work is based on previous reports describing potential activity scenarios, existing exploratory licenses and significant discoveries, past activities, and interviews with company representatives working on exploration and development projects in the area. Previous reports considered in his review include: the Beaufort Environmental Monitoring Project (1988); the Beaufort Region Environmental Assessment and Monitoring Program (1995); Gilbert, Laustsen, Jung Associated Ltd. (2004); Mackenzie Gas Project (2005); Breakwater Group (2006); and Beaufort Sea Strategic Regional Plan of Action (2008) (BSStRPA 2008 Report).

Callow 2012 predicts sporadic and limited activity in the Beaufort Sea for the years 2012-2027, with a ramping up of development after 2020. The projections are described in Table B - 2. Callow 2012 points out that the predicted short- to medium-term oil and gas exploration and development activities over the next 15 years in the Beaufort Sea have a large margin for error. In particular, the report notes that they are based on some assumptions and factors (see below) that currently provide a rather pessimistic outlook, but that can change dramatically over relatively short timeframes. A revision of the assumptions on a regular basis is required to ensure that the underlying assumptions remain valid.

Table B - 2: Summary of Offshore Oil and Gas Activity 2012-2027 (Callow, 2012)

Activity	Predicted timing or intensity
2D seismic surveys	Sporadic 1 or 2 per year
3D seismic surveys	On each EL a few years prior to drilling
Wellsite seismic surveys	Prior to spudding each well
Mackenzie Gas Project	Start-up in 2018
Discovered offshore gas tie-ins to Mackenzie Gas Project	First tie-in 2025, 1 or 2 per year after
Shallow shelf exploration wells	One or two per year starting in 2016
Deep shelf and slope exploration wells	First well 2018, next wells in 2021 and 2025
Shallow shelf oil production	First potential drilling/construction 2020

According to Callow 2012, although no operation applications have been submitted for drilling deep slope Beaufort Sea exploration wells, industry planning has advanced to the point where it expects that the following support vessels would likely be needed:

- 2-3 icebreakers to remain at the wellsite;
- 2-3 supply vessels to transport goods between the shore facility and wellsite;
- 1 wareship to stay at the wellsite which would replace the supply vessel; and
- 1 fuel tanker to stay at the wellsite during drilling operations.

The description of potential activities was based on a number of facts and assumptions, the most important of which should be made explicit. They also provide also valuable information for shipping activity projections.

a) The report assumes that the Mackenzie Gas Pipeline will be operating in 2018, a circumstance that is uncertain in light of the low prices of natural gas. Additionally, it assumes that the activity in the area will be driven by the Mackenzie Gas Pipeline and therefore, gas fields will be explored and developed first. However, the report notes that low prices of gas and an increase of price of oil to historical highs have the potential to shift the focus of offshore activity from MGP-induced gas exploration and development to oil exploration and development.

b) The existing offshore significant discoveries located in less than 100m water depths are believed to represent the best near term development opportunities in the Beaufort Sea. Previous reports consider that the shallow water Listric Fault play (see Fig. 2-3), including the Issungnak-Amauligak and Netserk-Kadluk-Minuk significant discovery areas, would be the focus of initial activity, with new exploration focused on expanding the discovered gas resources near these discoveries.

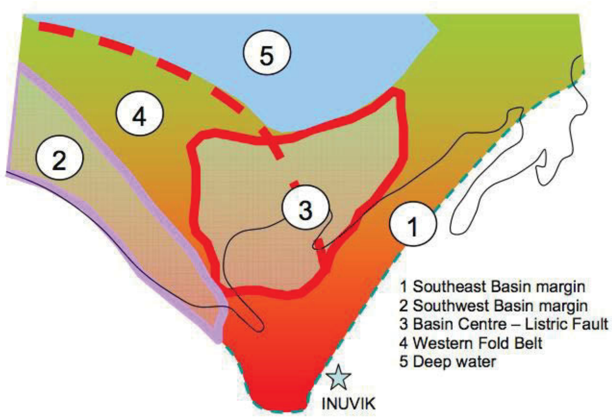


Figure B - 3: Mackenzie Delta and Beaufort Sea Basin Geology (Callow 2012, citing BSStRPA 2008)

c) Since 2006, one or two large 2D seismic surveys have been conducted each year in the Beaufort Sea. Without having access to industry confidential information, future seismic exploration is very difficult to predict. However, since large 2D have been conducted, the size and frequency of these surveys over the next 15 years is likely to decrease. In any specific year, one or two 2D seismic surveys of varying sizes are expected to be conducted. The number of 3D surveys can be expected to closely track the number of offshore wells drilled.

d) In the deep shelf and slope, 6 exploratory licences issued since 2007 call for 6 wells to be drilled in the deeper offshore Beaufort Sea between 2012 and 2016 (or 2014 and 2018, assuming that the NEB grants a 2 or 3 year extension). This is considered unlikely considering that the industry considers that only one or two built-for-purpose or retrofitted Arctic class drillships and support icebreakers will be acquired to drill deep slope wells in the next 15 years. One of those drillships is currently under construction for an estimated cost of $1,065 billion US$, the most expensive drillship ever built. The ship is scheduled for delivery in 2012. The report considers that a first drillship could be operating in 2018, drilling its first successful deep slope in 2021 at the earliest, and a second drillship would not be introduced until 2025 and assuming the first drill was successful.

e) In the shallow Beaufort Shelf Wells, four exploratory licenses are to be drilled between 2012 and 2016 (or 2014 to 2018, assuming a two year extension). Considering the lack of drilling platforms, it is predicted that the first shallow water drilling platform will commence operations by 2016, with a second commencing drilling in 2017 or 2018.

It is assumed that this drilling would tie in with the MGP, which is assumed to start operations in 2018. The Mackenzie Gas Project Environmental Impact Statement (Additional Information Report, March 2005, as cited by Callow 2012) show a possible sequence of tie-ins for Mackenzie Delta and Beaufort Sea existing significant discoveries and potential new discoveries. The first new offshore is expected to tie-in approximately 17 years after MGP start-up (Fig. 2-5). Allowing 3 years for drilling and tie-ins, the report concludes that there will be little incentive for MGP induced gas exploration to occur before 2032. Callow concludes that considering the combination of low natural gas prices and little MGP-induced natural gas exploration over the next 20 years, few if any, Listric Fault or Basin Margin exploration gas wells are likely to be drilled during the 2012-2027 timeframe. High oil prices may, however, provide the economic incentives to increase exploring and drilling activity during the next 15 years. Therefore, the report concludes that it is reasonable to assume that 1 or 2 shallow water drilling platforms will be in operation in the Beaufort Sea from 2016 on.

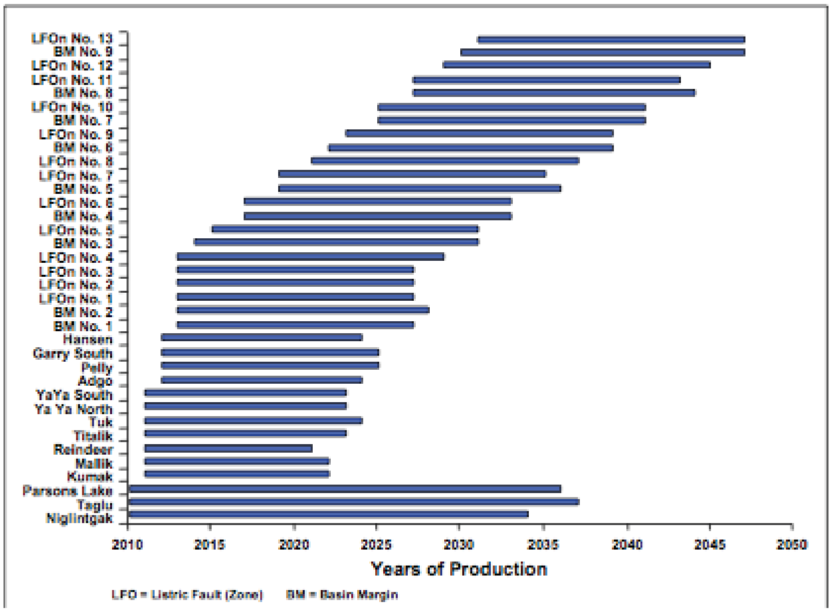


Figure B - 4: Estimated years of production for Mackenzie delta gas fields (Mackenzie Gas Project, 2005)

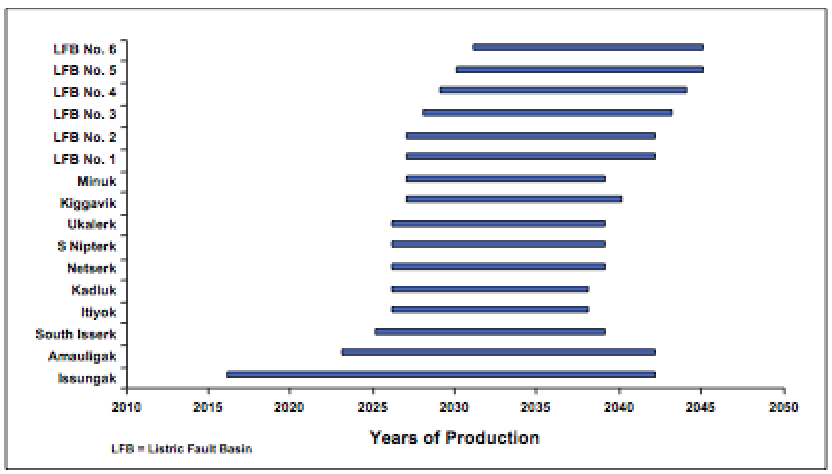


Figure B - 5: Estimated years of production for Beaufort Sea gas fields (Mackenzie Gas Project, 2005)

f) Callow 2012 considers an estimated timeframe for a Beaufort Sea Offshore Development Project of 14 years, reduced to 10 years due to concurrent work.

Table B - 3: Activities and Estimated Time Schedule for a Generalized Beaufort Sea Offshore Development Project

Activity	Estimated timing
Reserves Assessment Market Assessment Conceptual Engineering Economic Modeling Budgeting Assessment of Regulatory Environment Feasibility Study	0.5-1.5 years
Reservoir Engineering	0.5-1.5 years

Drilling and Completions Engineering Cost and Schedule Engineering Public and Regulatory Consultation	
Environmental Fieldwork Engineering Fieldwork	1-3 years
Construction Engineering Design Business and Economics Analysis Development Plan Environmental Impact Assessment Socio-economic Impact Assessment Decommissioning and Abandonment Plan	1-2 years
Public Regulatory Review Processes Regulatory Approvals Permitting	2-5 years
Detailed Design Procurement and Construction of Infrastructure Development Drilling Procurement and Construction of Facilities Facility Start-up/Commissioning	5-7 years
TOTAL Median Estimated Development Timeframe	14 years
TOTAL Estimated Development Timeframe Reduced 30% for Concurrent Work	10 years

Source: Callow, 2012, at p. 19.

g) The potential activity included in Callow 2012 is based on the following table developed by BSStRPA 2008, describing potential future oil and gas exploration and development activities.

Table B - 4: Potential Future Oil and Gas Exploration and Development Activities (Callow 2012, at p. 22, citing BSStRPA)

Activity	Details
2D and 3D Seismic – near shore	• Vibroseis vehicles on ice which must be frozen to the bottom • Airguns and geophones drilled through the ice in <20m water depth, one airgun or receiver per hole • Shot holes drilled through the ice in <20m water depth with charge size limited by Department of Fisheries and Oceans pressure restrictions • Ocean bottom cables with mini airguns used during open water season in <70m water depths
2D and 3D offshore seismic - deep water	• Seismic vessels using airgun arrays and streamers during the open water season in >20m water depths
Wellsite surveys	• High resolution seismic and geotechnical surveys
Exploration drilling - landfast ice zone	• Drilling from spray ice pads grounded in <15m water depths • Drilling from spray ice pads floating in >15m water depth within the land fast ice zone • Construction of ice roads to shore
Offshore exploration drilling - shallow water zone (including land fast ice zone)	• Drilling from gravel or sand islands in <20m water depth with a surface blowout preventer (BOP) and up to 12 month season • Drilling from gravity based structures (GBS) like the Caisson Retained Island (CRI), or the Concrete Island Drilling System (CIDS) in <20m water depth with a surface BOP and a 12 month season
Offshore exploration drilling - deep water zone	• Drilling from GBS like the Steel Drilling Caisson (SDC) or the Molikpaq in >10m to <40m water depths, with a surface BOP and up to 12 month season • Drilling from floating drill ships like the Kulluk in >15m water depths with a subsea BOP and a 3-6 month season
Offshore drilling support	• Small and heavy lift helicopters • Supply vessels and barges • Ice breakers for towing, anchor handling, and ice management • Spill response vessels and equipment • Marine maintenance facilities (i.e. floating drydocks)
Offshore development - shallow water zone	• Gravel islands in <20m water depths • Causeways or subsea pipelines to shore
Offshore development - shallow water zone	• A GBS in <60m water depths • The GBS may need an ocean bottom excavation and sand or gravel foundation • Directionally drilled production wells from GBS • Subsea pipelines to shore

Activity	Details
Offshore development - deep water zone	• floating development drilling • subsea wells and satellite well clusters in >60m water depths with subsea gathering lines • subsea pipelines to onshore processing facilities
Offshore development - deep water zone	• floating development drilling • subsea wells and satellite well clusters in >60m water depths with subsea gathering pipelines to the GBS which is located in <60m water depths **and** • subsea pipelines to shore **or** • crude oil storage on the GBS, with ice breaking crude oil tanker off take
Offshore development - deep water zone	• floating development drilling • subsea wells and satellite well clusters in >60m water depths with subsea gathering pipelines to the GBS which is located in <60m water depths and • subsea pipelines to shore with; • Liquified Natural Gas (LNG) facility onshore, and ice breaking LNG tanker off take
Subsea oil, gas and Natural Gas Liquids gathering and transportation pipelines	• Dredging, pipe laying, hydro testing, backfilling of trenches • Pipeline landfalls either trenched onto shore or directionally drilled from shore
Offshore production support	• Small and heavy lift helicopters • Icebreakers for ice management • Supply vessels, with oil spill response capability and barges • Marine Maintenance Facilities (i.e. floating dry docks) and other repair shops • Floating well workover, wireline and other well servicing equipment • Marine and logistics bases, including diesel storage and storage for oil spill equipment • Helicopter support bases • Camps with offices, control room and medical facilities • Multiple storage and warehousing facilities for companies providing drilling and production support services
Inspections	• Subsea Remote Operated Vehicle (ROV) inspections of pipelines, the GBS and subsea satellites • Subsea multi-beam and side scanning sonar inspections of pipelines, the GBS and subsea satellites • Diver inspections of pipelines, GBS and subsea satellites
Abandonment activities	• This area is uncertain at this time. Abandonment and reclamation are regulated and industry will work with regulators to develop appropriate plans

4. Other Initiatives

The Alberta oil and gas industry is also assessing alternatives for transportation, considering the difficulties and delays of the Northern Gateway Pipeline, including one that considers shipping in the area of interest. According to news releases, the alternatives under consideration are: to connect to an underutilized pipeline across the Yukon into Valdez, where there is spare storage capacity, a refinery and a deepwater port; to build a pipeline to the port of Churchill, Manitoba; and to build a pipeline connecting to the deepwater port of St. John, New Brunswick, for refining and shipping (Calgary Herald, 2013). It was informed that conversations are in progress, but in very initial stages and there is no sufficient information to consider these variables in the 2020 assumptions.

5. Conclusion

- There is considerable potential in Canada's Arctic for oil and gas, especially in the Beaufort Sea. Currently there is limited exploration and no production in the region, despite the large reserves. There are significant uncertainties, mostly related to infrastructure required for transportation, more stringent regulation, and low natural gas prices. These factors are slowing its development. Overall outlook at this time is somewhat pessimistic. However, it could change dramatically over relatively short timeframes.
- The industry does appear to be preparing for significant ramping up of development in response to the Mackenzie Gas Pipeline, which is expected to start construction in 2015 and begin operations in 2018 (with onshore fields).
- It is assumed that initial offshore activity will be induced by the Mackenzie Gas Pipeline, but increased oil prices may shift the focus of the industry to oil exploration and development.
- The industry has commissioned the construction of one purpose built Class 4 drillship for deep shelf and slope wells. The ship is scheduled for delivery in 2012. It is expected that the ship will initiate drilling in 2018 and complete drilling the first successful deep slope well in 2021. A second deep-water drilling and its icebreakers may be commissioned for 2025, depending on the results of the first drilling.
- The existing offshore significant discoveries located in less than 100m water depths are believed to represent the best near term development opportunities in the Beaufort Sea. It is reasonable to assume that 1 or 2 shallow water drilling platforms will be in operation in the Beaufort Sea from 2016 on.
- Callow 2012 summarizes the potential oil and gas exploration and development activity in the Beaufort Sea between 2012-2027 in the following table (noting that any prediction of oil and gas exploration and development activities in the Beaufort sea over a 15 year period will necessarily have a large margin of error) (see Table B - 2):

Activity	Predicted timing or intensity
2D seismic surveys	Sporadic 1 or 2 per year
3D seismic surveys	On each EL a few years prior to drilling
Wellsite seismic surveys	Prior to spudding each well
Mackenzie Gas Project	Start-up in 2018
Discovered offshore gas tie-ins to Mackenzie Gas Project	First tie-in 2025, 1 or 2 per year after
Shallow shelf exploration wells	One or two per year starting in 2016
Deep shelf and slope exploration wells	First well 2018, next wells in 2021 and 2025
Shallow shelf oil production	First potential drilling/construction 2020

- Industry planning has advanced to the point where it expects that the following support vessels would likely be needed:
    - 2-3 icebreakers to remain at the wellsite;
    - 2-3 supply vessels to transport goods between the shore facility and wellsite;
    - 1 wareship to stay at the wellsite which would replace the supply vessel; and
    - 1 fuel tanker to stay at the wellsite during drilling operations.

- Other oil and gas initiatives that may impact Arctic shipping are too uncertain to be considered in the assumptions at this point.

Appendix D – Literature Review Update: Mining

This literature review update for the mining industry is inextricably linked to the full literature review presented in the AMT-Ph2-Part1 report. This update has two objectives: a) to have the most up-to-date information on mining development and forecasts; and b) to gather information on projected traffic volumes and shipping routes. The analysis was undertaken for five Arctic regions: a) Labrador (Nunatsiavut); b) Northern Québec; c) Nunavut; d) Northwest Territories; and e) Yukon.

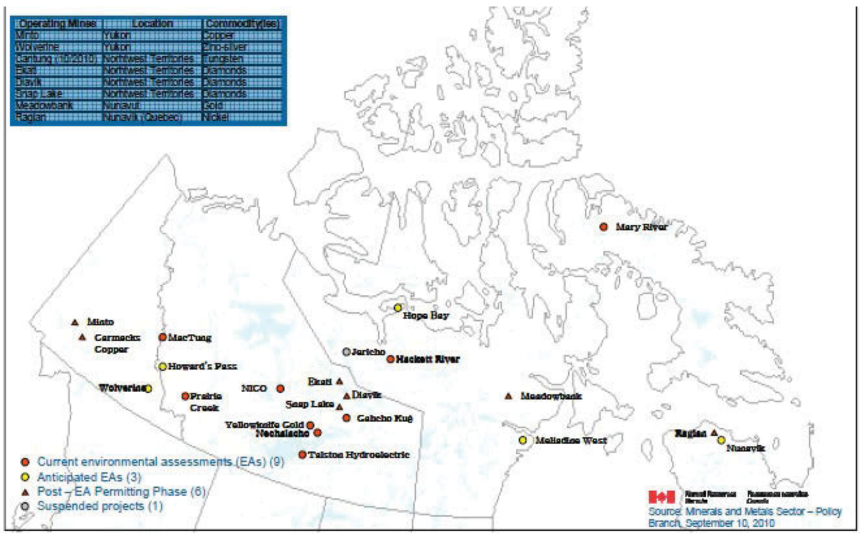


Figure C - 1: Mining projects in Northern Canada

The literature update is based on a number of main documents and public databases, as well as particular sources consulted for individual projects. The following main reports were considered:

- Conference Board of Canada, The Future of Mining in Canada's North (January 2013);
- Department of Natural Resources, Newfoundland and Labrador (Mines Branch), Mining in Newfoundland and Labrador (October 2012);
- Keith Storey, *An Overview of Mining Activity in Labrador* (Paper prepared for the Action Canada Working Conference, Labrador 21-25 September 2011);
- Northwest Territories News and Nunavut News, NWT/Nunavut Report on Mining (November 2012);
- AANDC 2012. Major Mineral Projects North of 60th Parallel in Canada (March 2012);
- Canadian Environmental Assessment Registry;
- Nunavut Impact Review Board (NIRB); and
- Mackenzie Valley Review Board.

Figure C - 2: Major Mineral Projects North of 60th Parallel in Canada (AANDC 2012).

1. Labrador

A map of the region can be found at Nunatsiavut Government Canadian Constituency n.d. (Figure C - 3). The Newfoundland and Labrador Government has released a recent publication that provides an overview of the mining activities and projects in the region (Figure C - 4). Figure C - 5 provides another overview of Labrador Mine Sites and Transportation Infrastructure according to the information available by September 2011.

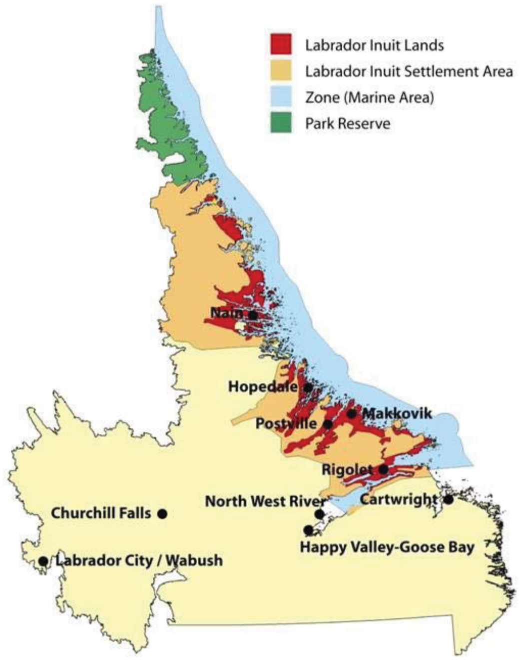


Figure C - 3: Labrador Map (Nunatsiavut Government Canadian Constituency n.d.)

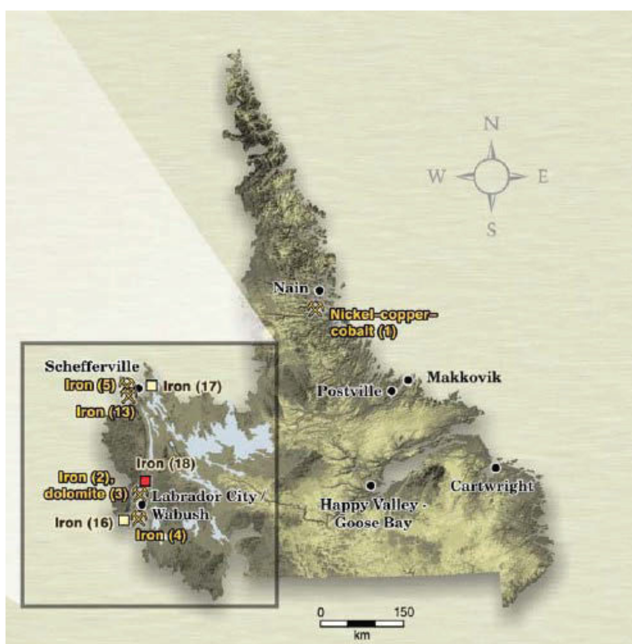


Figure C - 4: Mining Projects in Labrador (Department of Natural Resources (NFL) 2012)

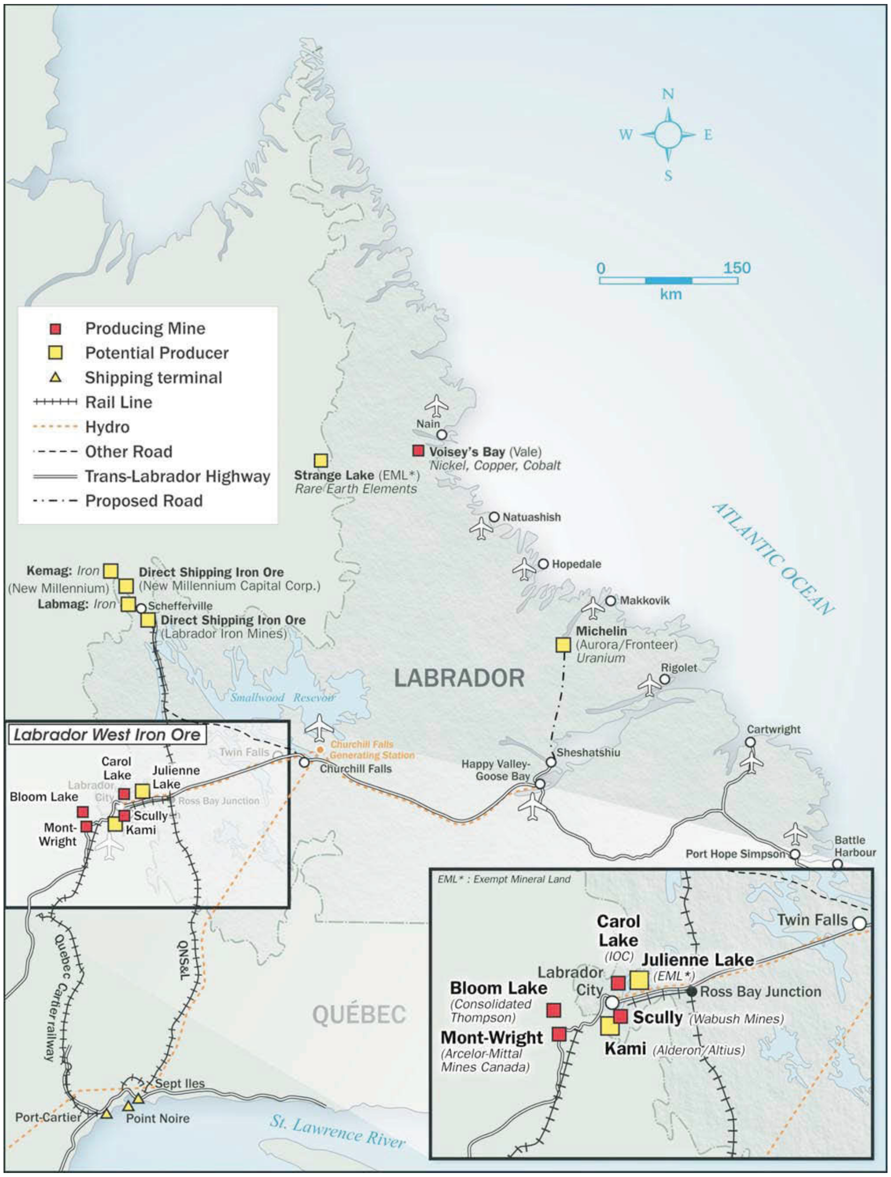


Figure C - 5: Labrador Map with Mine Sites and Transportation Infrastructure (Storey 2011, at 18).

According to the Canadian Environmental Assessment Registry, several mining projects included in the figures above are currently under review under to the *Canadian Environmental Impact Assessment Act*.

The information provided in the Canadian Environmental Assessment Registry, Department of Natural Resources, Newfoundland and Labrador 2012 (Figure C - 4) and Storey 2011 (Figure C - 5), was further analyzed to provide an updated summary of the mines in operation or projects in development in Labrador. The analysis is provided for each of the two main areas with mining developments in Labrador: Labrador Southwest; and North Nunatsiavut.

a) Area: Labrador Southwest

a.1. Mines in operation in Labrador Southwest (numbers follow Figure C - 4)

- Labrador City (Iron Ore Company of Canada) (Nr. 2)
- Labrador City (Iron Ore Company of Canada) (Nr. 3)
- Wabush (Wabush Mines) (Nr. 4)
- Menihek Area (Labrador Iron Mines Limited) (nr. 5)
- Menihek Area (Tata Steel Limited) (Nr. 6)

a.2. Mines in development (near term)

- Labrador City and Wabush Area (Alderon Iron Ore Corporation) (Nr. 16)
  Environmental Assessment commenced on 13 January 2012. Alderon announced on 14 February 2013 that it has moved into the final stages of the Environmental Assessment (EA) process with the submission of the official response to information requests received from the Provincial and Federal Governments, Aboriginal groups and the public. The company anticipates that the remaining steps of the EA process will be completed on schedule to allow for the construction of the mine to commence in the fourth quarter of 2013.
  The projected mine has a nominal capacity of 16 million metric tonnes of iron ore concentrate each year that will be transported by existing rail lines to the Pointe-Noire Terminal at the Port of Sept-Îles, Québec.
  Sources:
  Canadian Environmental Assessment Registry n.d.a.
  Alderon Iron Ore Corp. 2013.
  Alderon Iron Ore Corp. 2012.

- Menihek Area (Labec Century Iron Ore) (Nr. 17)
  Environmental Assessment commenced on 4 January 2013. The Joyce Lake property is part of the larger Attikamagen project that straddles the Newfoundland and Labrador / Québec provincial border about 20 km northeast of Schefferville. The Joyce Lake part of the property is wholly located in Newfoundland and Labrador. The project could produce up to 4 million tonnes of direct shipping iron ore over a mine life of about 7 years with production beginning in 2015.
  Ore will be transported through a conveyor over iron arm (750m) and an overland conveyor (2km) to the beneficiation plant. Final product will be hauled by truck from the beneficiation plant to the rail yard (new rail loop connecting with Tschiuetin Rail). The product will be taken to Sept-Îles, Québec, for shipping.
  Sources:
  Labec Century 2012.

a.3. Expression of interest

- Labrador City- Wabush Area (Julienne Lake) (Nr. 18) *a.4. Transportation*

Transport from the mines producing or projected in Southwest Labrador include rail to ports in Québec, particularly Port of Sept-Îles (50°13′N 66°23′W), outside the area of interest.

b) Area: North Nunatsiavut

b.1. Mine in operation

- **Voisey's Bay (Vale NFL Limited)**

  The Voisey's Bay nickel-copper-cobalt mine is located in northern Labrador, about 35 kilometres southwest of Nain. The project encompasses: an open-mine pit (Ovoide), two underground bodies (Eastern Deeps and the Western Extension), and a concentrator (mill plant), all at Voisey's Bay; port facilities in nearby Edward's Cove, Anaktalâk Bay; and a processing plant in Long Harbour, Newfoundland, currently under construction. Proven reserves in the open-pit mine Ovoide are 32 million tonnes of ore; reserves in the underground mine were unknown at the moment of the environmental assessment and estimated in 118 million tonnes by the Company.

  The open-pit mine started production in the fall of 2005, some eight months ahead of schedule. Currently, concentrate from Vale Newfoundland and Labrador is shipped to Vale's Ontario Operations in Sudbury for processing. However, the company plans to start processing the concentrate in a plant under construction in Long Harbour, Newfoundland in 2013. Vale registered the processing plant for environmental assessment in March 2006, submitted an Environmental Impact Statement in April 2008 and was released from environmental assessment by the federal government (July 2008) and by the provincial government (August 2008). Initial construction of the processing plant began in April 2009 with construction wrapping up in February 2013. VNL announced in October that a test-run operation at the Long Harbour nickel processing plant will start by the fourth quarter of 2013. This will be the beginning of a three year ramp-up to full production.

  According to the Project's Environmental Impact Statement (EIS), the concentrator would be designed with a production capacity of 20,000 tonnes per day of ore. The company's plan was to mine and mill nickel at an annual rate equivalent to 15,000 tpd but using a 20,000 tpd mill to accomplish it in nine months. The larger mill capacity would permit more flexibility in dealing with the severe winter weather; a delay of several years for winter shipping; and a gradual increase in throughput as underground material becomes available.

  However, the Panel assessing the project was concerned that this mining rate would reduce the life of the mine (which could be mined in just 6.5 years). The Panel recommended that the Province and VBNC negotiate a mining lease that promotes the attainment of durable and equitable social and economic benefits to the people of Labrador and of the Province through resource stewardship. The Panel recommended that the following conditions should be attached to that lease:

- VBNC must proceed as soon as possible with an underground exploration program and, if reserves are proven, commit to early development to blend underground output with the late stages of open pit production; and
- If initial underground exploration does not confirm current reserve projections, VBNC must extend the life of the open pit by reducing the annual production rate to ensure that the Project can continue to operate for at least 20 to 25 years.

The Agreement ultimately signed between the Government and the company included: a mill/concentrator plant capable of processing 6,000 tonnes of ore per day; the expansion of the concentrator if the underground exploration program identifies sufficient reserves; and a processing plant in Long Harbour with a design capacity to produce annually approximately 50,000 tonnes of finished nickel product, together with associated cobalt and copper products.

Estimated life of the open-pit mine is 14 years (2019 or 2023, according to some reports). The expansion to underground mining would sustain operations until 2049. According to the Conference Board of Canada, the mine would move underground in 2018. Given the impact that this production shift has had on other mines in similar circumstances, the Conference Board of Canada suggests a significant drop in the mine's production is expected over 2018-2020.

In 2011, the mine produced in 69,000 tonnes of nickel, 51,000 tonnes of copper, and 1,585 tonnes of cobalt. In 2012, production was 62,000 tonnes of nickel, 42,000 tonnes of copper and 1,221 tonnes of cobalt. Nickel production is 10% lower than in 2011 however this is more a function of the exceptional production during that year.

The port facility at Edward's Cove in Kakiak, Anaktalâk Bay, includes a dock, a concentrate storage building and equipment for loading the concentrate onto arriving ships. Most supplies for the project arrive at Edward's Cove by ship. According to the company's EIS, three shipping routes (northern, eastern and southern) were assessed for the passage of bulk carriers containing the concentrate between the mine's port and the processing plant, with the northern route following a portion of "Strathcona Run" (the existing shipping route to Nain) being the proponent's preferred.

The company's EIS planned to use 25,000 DWT vessels. They would be Canadian registered vessels with Canadian crews because the final destination would be a Canadian port. These vessels would be designed to CAC3 ice class standards or equivalent. VBNC proposes to ship the copper concentrates to undetermined locations in vessels acquired on the spot market, which might be somewhat larger (the 1997 EIS stated that vessels up to 50,000 DWT could be used, but that the EIS was based on 25,000 DWT vessels). According to the project's website, the

Fednav Group's polar-class ship MV Umiak 1 is generally used to support Vale/Inco's shipping requirements.

VBNC also plans to back-haul most required bulk supplies on the concentrate vessels. Fuel would be transported in special tanks in the transport vessels, with a maximum return cargo of 5,000 tonnes. VBNC has committed not to transport fuel during shipping in landfast ice. At least 20 voyages would be required to deliver annual fuel requirements during peak operations. It is possible that, with the exception of winter shipping, every return voyage would include fuel delivery. Other bulk supplies would be back-hauled in specially designed containers to allow for rapid and safe unloading at Edward's Cove.

Although the proponent would have preferred year-long shipping, the negotiation with the Inuit precluded that option and instead, an "extended shipping season" was agreed upon. The shipping agreement negotiated and signed with the Nunatsiavut Government reportedly includes the following provisions:

- A description of the required capabilities for ships transiting the ice;
- Closure periods when shipping cannot take place (winter shipping would be limited to four trips each season (January 22-April 6), and no shipping would take place between April 7 and May 21 and December 7 to January 21);
- The obligation to have shipping observers on board of the ship to ensure that the ship's captain is aware of Inuit who may be harvesting in the area of the ships route. In addition they monitor that the Shipping Agreement is implemented as intended;
- Provisions for communications between VINL and the Inuit community; and
- Description of standards to which vessels and shipping activity must conform.
- The obligation to conduct further research into the ecosystem through which the ship's route traverses.

The Shipping Agreement is not publicly available.

VBNC has proposed to ship up to nine cargoes through landfast ice in the January to March period. During April and May, shipping would again cease because of the potential whelping of ringed seals and because usage peaks during this time as days become longer, weather moderates, and travel for hunting and other purposes increases.

Sources:

Review Panel. n.d. Voisey's Bay Mine and Mill Environmental Assessment Panel Report.

Newfoundland and Labrador Government and Inco Limited. 2002. Voisey's Bay Development Agreement.

Vale n.d.a., Voisye's Bay Development

Vale n.d.b., Voisye's Bay Development: Overview

Vale 1997, Voisey's Bay Mine/Mill Project, Environmental Impact Statement (December 1997) (in particular Chapter 3 for project description).

Davies 2007. Inuit Observations of Environmental Change and Effects of Change in Anaktalâk Bay, Labrador [unpublished].
Conference Board of Canada 2013
Department of Natural Resources (NFL) 2012
Department of Natural Resources (NFL) 2013
Infomine. n.d. Voisey's Bay.

b.2. Mining Projects

- **Aurora Michelin Project** (see Figure C - 5).
  Aurora identified a significant uranium deposit in 2006. The company halted exploration work in Labrador after a moratorium on uranium mining on Labrador Inuit lands was put into effect in 2008. On 2 December 2011, the Nunatsiavut Assembly lifted the moratorium (subject to the entry into force of the *Nunatsiavut Environmental Protection Act*, which occurred in March 2012).
  The project has not formally commenced the regulatory approval process. Therefore, it is unlikely that this project would be in operation by 2020.
  Sources:
  Aurora n.d. Michelin Project.
  CBC 2011a. Labrador Uranium Mining Moratorium Lifted (14 December 2011).

c) Conclusions for Labrador Region

1. Mining developments in Labrador are concentrated in North Nunatsiavut and Southwest Labrador.
2. Labrador Southwest (Labrador City, Wabush, Menihek) is the most active region. However, transportation takes place mostly using the rail road to the port of Sept- Îles, Québec, for shipping. No Arctic shipping is considered for the construction or operation of the mines in this area.
3. The Nunatsiavut area has one mine in operation (Voisey's Bay) and one potential project (Aurora Michelin project).
4. The Voisey's Bay operation started in 2005 with the mining of the open-pit Ovoide body. The open-pit mine has an estimated life of 14 years (2019 or 2023 according to some reports), but the development agreement signed with the Newfoundland and Labrador Government sought to secure operation for at least 25 years with the underground operations.

   The mine ships through Edward Cove in Anaktalâk Bay. Most supplies arrive there as well. Currently, the mine is shipping the product to Ontario but it is expected to ship to Long Harbour, Newfoundland starting in 2013. The mill has currently a production capacity of 6,000 tpd; an expansion of this capacity is planned if sufficient reserves are found in the underground bodies. The plant in Newfoundland is designed to produce 50,000 tpy of finished nickel product. In 2011, the mine produced in 69,000 tonnes of nickel, 51,000 tonnes of copper, and 1,585 tonnes of cobalt. In 2012, production was 62,000 tonnes of nickel, 42,000 tonnes of copper and 1,221 tonnes of cobalt.

The underground mine is expected to start operations around 2018. Conference Board of Canada expects a drop in the mine's production over 2018-2020. However, this drop has not been quantified. Additionally, at least some reports consider that the open-pit mine will be producing until 2023.

The company signed a Shipping Agreement which establishes restrictions to protect the Arctic ecosystem. The Shipping Agreement includes no-shipping seasons and restricted shipping during the winter season. Actual shipping traffic schedule is available on the company's website.

5. The Aurora Michelin Project is a uranium project. A moratorium for uranium exploitation has been lifted by the Nunatsiavut Assembly on December 2011, effective in March 2012. The project has not started the authorization process. Therefore, it is unlikely that it will be in operation by 2020.

6. The only (other) port in the Nunatsiavut area (Happy Valley - Goose Bay) appears to be used for community re-supply only. However, an increase mining activity may imply more activity in the region that impacts shipping levels in this port as well.

7. There is a ferry service between Happy Valley - Goose Bay and Nain, stopping in different communities.

2. Nunavik (Northern Québec)

Figure C - 6: Map of Nunavik and Nunavik Communities (Nunavik n.d.)

The following sources were consulted to update the mining information of Northern Québec (Nunavik) in the area of interest:

- Nunavik n.d. Nunavik communities
- Resources Naturelles Québec 2012a, Producing Mines (October 2012)
- Resources Naturelles Québec 2012b, Major mining projects in advanced phase (October 2012)
- Gouvernement du Québec 2011, Report on Mineral Activities in Québec 2010*,*
- According to the Canadian Environmental Assessment Registry, the following mining projects are under review:
  - Arnaud Mining Project – 63926 (James Bay)
  - BlackRock Mining Project – 62105 (James Bay)
  - Dumont Nickel Mine Project – 66976 (James Bay)
  - Fire Lake North Iron Ore Project – 80014 (south of Labrador city)
  - Hopes Advance Iron Mining Project – 80008 (Nunavik)
  - Kami Iron Ore Project – 64575 (south of Labrador city)
  - Niobec Mine Expansion Project – 80011 (James Bay)
  - Québec Lithium Spodumene Mine Project – 59158 (James Bay)
  - Renard Diamond Mine Project – 55169 (James Bay)
  - Rose Mining Project – 80005 (James Bay)
  - Whabouchi Mining Project – 80021 (James Bay)

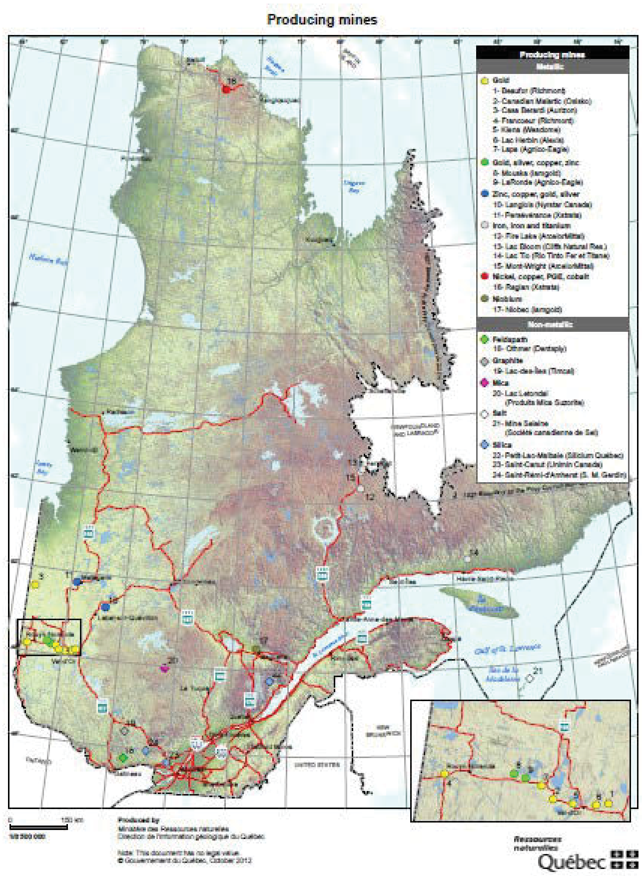


Figure C - 7: Producing Mines (Resources Naturelles Québec 2012a)

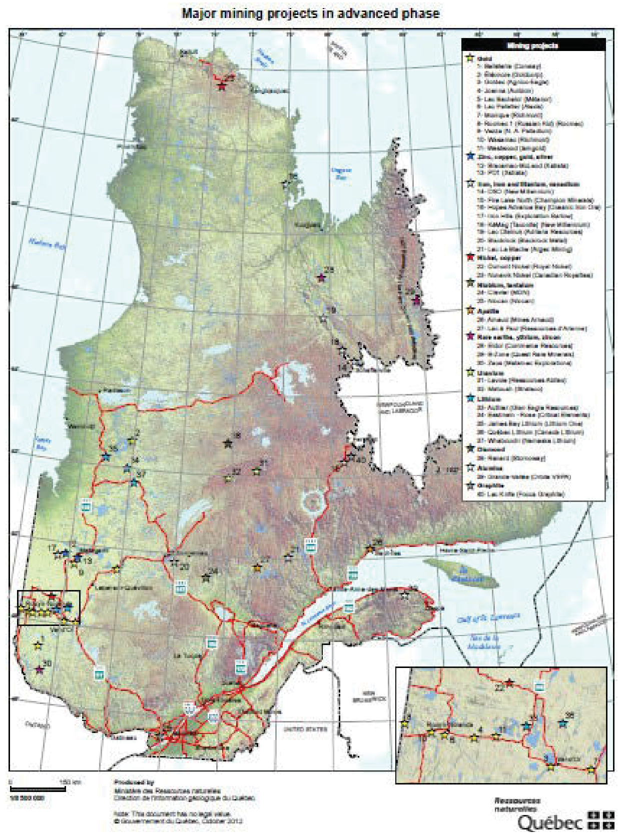


Figure C - 8: Major Mining Projects in Advanced Phase (Resources Naturelles Québec, 2010b)

Current mining projects concentrate in three areas: a) James Bay Area; b) Shefferville Area; and c) Northern Area. The mining developments in James Bay and Shefferville do not consider Arctic shipping. For this reason, they will not be included in this update report.

a) Development Projects in Nunavik – Some General Factors

- About 1.2 million square kilometers, or 72%, of the area covered above the 49th parallel holds gold, diamonds, platinum, copper, uranium, nickel, tin, as well as newly economic commodities such as lithium and rare earths metals.
- Chinese companies have invested in the development of mines in Northern Québec by buying Canadian companies or shares in Canadian companies.
- The provincial Government launched Québec's *Plan Nord* on 9 May 2011. The initiative, which general objective is to promote economic development in Northern Québec, is expected to continue over a 25-year period. It considers investments of more than $80 billion for renewable energy, mining and public infrastructure including roads, ports and airports in the northern part of the province. *Plan Nord* has six major public infrastructure priorities, namely:
  - the extension of highway 167 to the Otish mountains;
  - the extension of highway 138 between Kegaska and Blanc-Sablon;

- the rebuilding of highway 389 between Baie-Comeau and Fermont;
  - studies of possible land connections between Kuujjuaq and southern Québec;
  - studies on a deep-water port in Whapmagoostui-Kuujjuarapik and a road connection to Radisson; and
  - improvements to airports.
- Besides the priorities identified by the province, several mining projects currently in the exploration phase will include the construction and relocation of railway and port infrastructures within the *Plan Nord* territory. For example, the exploration of an iron deposit at Otelnuk Lake between Kuujjuaq and Schefferville could lead to the construction of an approximately 800-km railway between the deposit and port of Sept-Îles. A second iron ore deposit exploration project close to the Inuit community of Aupaluk includes the construction of a port in Hopes Advance Bay.
- The Government is considering environmental protection of the area covered by *Plan Nord*. The plan is to complete a network of protected areas on at least 12% of the area covered by the *Plan Nord* and dedicate 12% of the area of the boreal forest blanket to the creation of protected areas by 2015. By 2020, the Government is planning to set aside at least 5% of the *Plan Nord* territory (i.e. approximately 60,000 square kilometers) for the purpose of conserving biodiversity, protecting the environment and for non-industrial activities.

Sources:

Resources Naturelles Québec 2011. Québec Mines: Mining Information Bulletin (November 2011).

Government of Canada 2012. Transportation in Canada 2011: Comprehensive Review.

Québec Government 2011. Plan Nord: Building Northern Québec Together: The Project of a Generation.

Québec Government 2012. Plan Nord: Transportation and communication.

b) Mine in Operation in Northern Are: Raglan (Xstrata Nickel)

The Raglan property is situated near Salluit. The nearest Inuit villages of Salluit and Kangiqsujuaq are accessible only by air from the mine site. The nickel and copper-producing facility operates three underground mines and one open-pit mine. Once crushed and treated, ore is trucked 100 km (all weather road) to the port of Deception Bay (the company is re-using a wharf built in the 1970s for an asbestos mine near Salluit) where it is transported by sea to Québec city and then by rail to the smelter in Sudbury, Ontario. It then returns by rail to Québec City to be shipped to the refinery in Nikkelverk, Norway.

Since beginning of production in 1997, the total yearly production has increased gradually to today's 1.3 million tonnes of ore. The current mine life is estimated at more than 30 years. The company is accessing new deposits and upgrading infrastructure to increase annual nickel concentrate production to 40,000 tonnes per year by 2016 (2011 production was 27kt Ni concentrate, 7kt copper in concentrate, and 567t cobalt in concentrate).

The navigation season lasts eight months and at least six maritime trips are planned each year. In 1998, the annual production of the Raglan mine, once refined, was 21,000 tonnes of nickel, 5,000 tonnes of copper, 200 tonnes of cobalt, as well as a small quantity of platinum and palladium.

Figure C - 9: Raglan Property Mine (Lewis and Brocklehurst 2009, at 21)

Sources:
Duhaime *et al*. 2003. The Mining Industry and the Social Stakes of Development in the Arctic.
Xstrata n.d. Annual Report 2011: Creating Value through Difference. Performance Review.

c) Mining Development Projects in Northern Area

In the Northern Area, the mining activity includes several explorations near Raglan mine (Azimut Explorations), as well as two projects in advanced stages of development (Nunavik Nickel and Hopes Advance Bay).

- **Azimut Explorations**

  Properties include: Rex, Rex South, NCG, Diana, Kativik, Nantais. On 17 January 2013, 3 new properties were added to the exploration: the Qassituq, Kovik and Tasinga properties. All the properties appear to be in early stages of exploration (although results of the explorations appear to be encouraging).

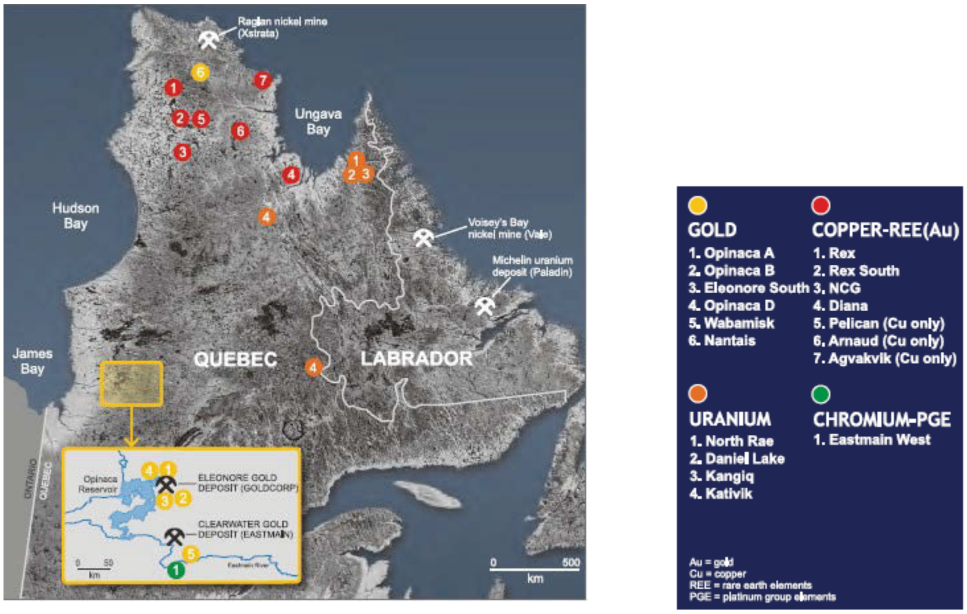


Figure C - 10: Azimut Explorations

Source:

Azimut Exploration Inc., n.d., Nunavik Overview, http://www.azimut-exploration.com/en-prop-nunavik.html.

- **Nunavik Nickel (Canadian Royalties, owned by Jilien Jien Nickel Industry Co.)**

  The mine was first owned by Canadian Royalties, but the Chinese company Jillien Jien Nickel Industry Co. acquired the property. The project is in advanced stages of the authorization process. Makivik Corp., Canadian Royalties Inc., and representatives of three affected First Nations communities first signed an impact and benefit deal in 2008. The deal was renewed with senior staff from Jilin Jien Nickel Industry Co. Ltd. in Kuujjuaq in 2009.

  The project is located near the Raglan mine. It considers transportation through sealift (heavy equipment, large quantity supplies) from Montreal to Deception Bay or Salluit. The construction of a deep water marine facility along the shoreline of Deception Bay hit a layer of clay and they had to relocate. They secured another building site roughly 800 metres downstream south of the original site, and planned to begin construction of a new port in June 2012. Since in July 2012, the new *Canadian Environmental Assessment Act*, *2012* came into force, a requirement to complete the environmental assessment for the new port site was not required. Furthermore, Canadian Royalties has found what it calls an environmentally safer and cheaper solution: a giant barge that can serve as a docking facility at Deception Bay. The docking facility is awaiting final permitting approval.

  On 31 October 2012, the company and Canadian ocean-freight shipper Fednav Group announced that they have signed a long-term deal to ship nickel and copper concentrates from the mine to customers in Europe and bring equipment into the project. The terms of the agreement were not disclosed, but Fednav stated that it has placed an order for a new 25,000-tonne ice-breaking bulk carrier to ship the concentrate. The ship, a Polar Class 4 vessel, will be built at Universal Shipbuilding's Tsu shipyard in Japan, is scheduled for delivery in December 2013. When it arrives, it will be added to Fednav's existing fleet of ice-breaking freighters, which consists of the MV Arctic and the MV Umiak I.

According news released at the end of 2012, Nunavik Nickel mine was planning to ramp up production in early 2013 and reach full production by 2014. When it reaches full production, Canadian Royalties expects the mine to produce 4,500 metric tons (MT) of ore a day, or about 1.6 million MT a year. Information about shipping traffic and shipping routes was not found in the documentation reviewed.

Sources:
Nunatsiaq Online 2012a. Canadian Royalties aims to start shipments from Nunavik Nickel in 2013 (28 November 2012).
Nunatsiaq Online 2011. Nunavik Nickel mine sticks to 2012 start-up (2 December 2011).
Canadian Environmental Assessment Registry n.d. Construction of port infrastructures for the Nunavik Nickel Project, Deception Bay, Nunavik, Project Nr. 12-01-66172 (last modified 5 December 2012).
Nickel Investing News 2012. Nunavik Nickel Project Nearing Production (8 November 2012).

- **Hopes Advance Project (Oceanic Iron Corp.)**

The project is located near Aupalak. The Environmental Assessment process commenced on 11 October 2012. Construction is scheduled for 2014, with operation beginning in 2016.

The project includes several open pit mines, with an expected production of 10 to 20 million tonnes per year of iron concentrate product over a planned period of up to 48 years. The ore will be treated in a concentrator located near the mine, and will be pumped to the port area via a 26 kilometres long concentrate pipeline for shipping.

The project will require a new deep water marine facility consisting of an iron ore wharf and a causeway (coordinates of Hopes Bay: 68°09' North and 106°47' West). Marine facilities are design for 365 days/year operation. Shipment of ore requires navigation through Ungava Bay and the entrance to Hudson Strait and Labrador Sea. Ice class vessels with capacity of 180,000 deadweight tons (DWT) will be used for shipping, while vessels with 240,000 DWT may be used during ice-free season. Smaller vessels will be used for other shipping requirements (10,000 DWT). Fuel will be shipped in 25,000 DWT ice-class tankers.

The number of required shipments, considering the use of 180,000 DWT vessels, is 56 for the 10Mt production scenario and 111 for the 20Mt production scenario (departing every week for the 10Mt scenario and every 3.3 days for the 20Mt scenario, with seasonal variations to increase summer shipments and reduce winter shipments).

Sources of information:
Oceanic Iron Ore Corp. 2012. Hope Advance Project: Description of a Designated Project under the *Canadian Environmental Assessment Act, 2012.*
Canadian Environmental Assessment Registry n.d. Hopes Advance Iron Mining Project.
Oceanic Iron Ore Corp. n.d. Ungava Bay Iron Deposits: Overview.
Oceanic Iron Ore Corp., n.d., Hopes Advanced Project Map.

d) Conclusions for Nunavik (Northern Québec)

1. There is significant investment in the development of Nunavik mining industry, both by the government and industry (including new Chinese investments).
2. One mine is in operation and shipping through Deception Bay: Raglan (Xstrata). Company expects to increase production to 40,000kt by 2016 (from 27kt in 2011). According to one source, the current mine operation considers 6 shipments within an 8 month shipping season.
3. New mining projects are under various stages of development in three areas: Shefferville, James Bay, and Northern Area.
4. Projects in James Bay and Shefferville consider transport with train or track to ports in the St. Lawrence River (i.e. Sept- Îles). They do not consider Arctic shipping.
5. In the Northern Area, one mining project is in advance stage of the authorization process (Nunavik Nickel), while one other started the EIA process (Hopes Advance Bay). Azimut has several explorations but none appear to be in project development stage.
6. Nunavik Nickel project is expected to start in 2013 (including shipping). Port is under construction in Deception Bay (and apparently down-sized to a giant barge serving as a docking facility). It considers at least the operation of one ice-class vessel currently commissioned for construction in Japan and expected in December 2013.
7. Hope Bay is currently under EIA and may be operative by 2020. It considers the construction of one deep water marine facility (Hopes Advance Bay, near Pointe Breakwater). Projections consider between 56 and 110 shipments a year depending on yearly production (10Mt and 20Mt scenarios). That represents one ship every week or every 3.3 days, depending on annual production, with seasonal variations to adjust for winter conditions. Additional vessels for supply and oil supply are expected to use the port. Operation is expected to start in 2016.

3. Nunavut

The analysis of mining activities in Nunavut is described for each of the three Nunavut regions: **Kitikmeot**, **Kivalliq** and **Qikiqtaaluk (Baffin).**

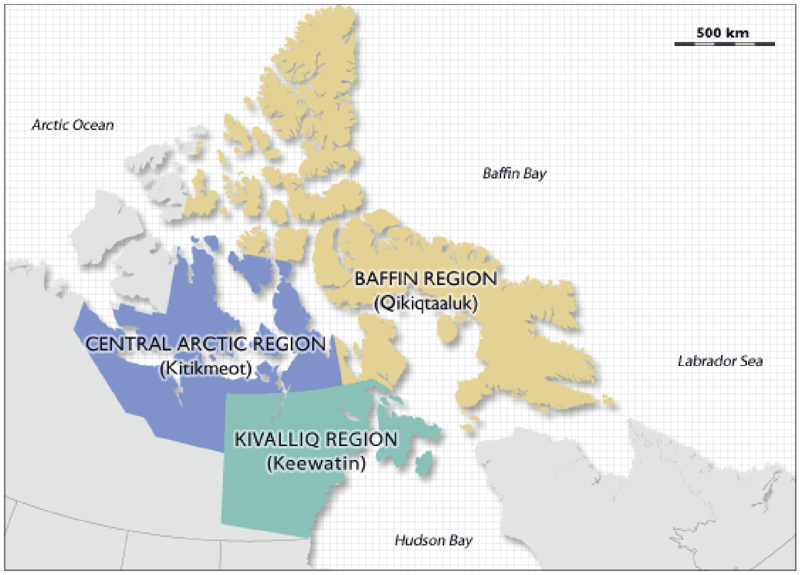


Figure C - 11: Map of Nunavut
(Library and Archives Canada 2005)

General souces of information consulted for this section include:

- Conference Board of Canada, 2013, The Future of Mining in Canada's North (January 2013).
- Northwest Territories News and Nunavut News, 2012, NWT Report on Mining (November 2012).
- Canadian Environmental Assessment Registry
  Search did not show results.
- Nunavut Impact Review Board
  Reviews Completed: Jericho Diamond mine; Doris North gold mine 2004; Doris North Gold mine 2006; MMG High Lake; Meadowbank Gold Mine; Resolution Island Clean up.
  Active Reviews: BIPR; Uravan Garry Lake; Xstrata's Hackett River; Sabina Back River; AEM Meliadine; Baffinland Mary River; Areva Kiggavik; HBML Phase 2 Hope Bay Belt.

a) General Projections

According to the Conference Board of Canada, Nunavut had no metal or non-metallic mineral mining output in 2009, but its mining real GDP increased to $163 million in 2010 thanks to the opening of the Meadowbank gold mine. For the remainder of the decade, mining output will more than double to reach $352 million in 2020—a compound annual growth rate of 8.8 per cent (See

Figure C - 12).

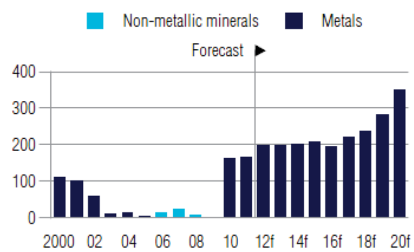


Figure C - 12: Nunavut's Mining GDP (Conference Board of Canada 2013, p. 15).

b) Mines in Operation, Projects in Review Process and Mining Properties in Exploration

Table C - 1 contains a summary of the mines in operation, in review process and in exploration stage in each of the three Nunavut regions, according to the information provided in the sources indicated above.

Table C - 1: Summary of Mines in Operation, Review Process and Exploration in Nunavut

Region	End of life, Remediation	Production	Approved	In review process	Exploration
Kitikmeot	Lupin	(Jericho Diamond mine)	Hope Bay (Phase I: Doris North)	Hope Bay (Phase II: Boston and Madrid/Patch) BIPR Sabina, Back River Project Xstrata, Hackett River Project Izok Lake corridor	Lupin and Ulu properties
Kivalliq		Meadowbank Gold Mine		Areva, Kiggavik Meliadine Gold Uravan Garry Lake	Peregrine Diamonds Inc. Nanuq and Nanuq North
Qikiqtaaluk	Nanisivik		Baffinland Mary		Roche Bay

(Baffin)	Polaris		River		Chidliak Quilak Cumberland Tuku II Committee Bay

c) Kitikmeot region

This region had one mine that was productive in the past but that has suspended operations (Jericho Diamond Mine). It also has four development complexes: Hope Bay complex; Izok Lake Corridor; Bathurst Inlet Port and Road (BIPR); Sabina's Back River and Xstrata's Hackett River properties. Finally, two properties are under exploration (Ulu and Lupin).

- **Jericho Diamond Mine**

The mine was sold to Shear Diamonds in 2010. Shear Diamonds suspends stockpile production due to low diamond prices on September 4, 2012. On November 15, 2012, Shear revealed it was facing new challenges, including the loss of executives and a debt of about $3 million to the Belgian diamond firm Taché. In the news release, Shear hinted it was looking for a buyer and said it wanted to enter into "a transaction, whether financing, joint venture, sale or otherwise that will either allow Shear to advance its Jericho project or to otherwise realize value for Shear's stakeholders." On February 4, 2013, it was announced that the owner of the mine had disappeared, disconnecting phones and website

Sources:
CBC 2013a. Owners of Nunavut's first diamond mine deserted site (4 February 2013).

- **Hope Bay complex** (including approved Phase I (Doris North) and Phase II (Boston and Madrid/Patch) under active review)

The previous owner, Newmont, had postponed the work indefinitely while the project was under review. The project was then sold to TMAC Resources on 28 January 2013 (the agreement has a number of conditions, and the transaction is to be completed in the first quarter of 2013). When the new owner raises $50 million in share offerings, the company will use the money to pay for:

- opening Hope Bay's mothballed camps;
- building ice landing strips;
- flying in underground and surface drills;
- beginning underground and surface drill exploration work;
- transporting a mill and other equipment that is now located in Pennsylvania, Lachine, Québec and Durban, South Africa to the Hope Bay site;
- finishing a pre-feasibility study that will look at putting the Doris gold deposit at Hope Bay into production.

Newmont had developed an underground shaft at the small Doris North section of Hope Bay, in Phase I of the project (EIA completed). An application to the NIRB for an environmental review on Phase II of Hope Bay (Madrid/Patch and Boston districts, in addition to Doris district) is frozen at the moment

Sources:

Nunatsiaq Online 2013a. New firm signs deal to buy Nunavut's Hope Bay gold.

- **Izok Lake Corridor**

The Izok Lake Corridor consists of two properties (High Lake and Izok Lake), a mill at Izok property, and a dock in Grays Bay. On 4 September 2012, the Chinese-controlled Mineral and Metals Group (MMG) submitted the project to NIRB to trigger the official environmental assessment process. The screening report issued by the Board on 14 December 2012 recommended to the federal Ministers that the proposal requires review pursuant the Nunavut Land Claim Agreement.

The two properties are required for the economic feasibility of the project. The company expects that, "in a perfect world", it could start construction in the third quarter of 2015 and production in 2018, with a first shipment in August 2018.

The first property considered in the complex is **Izok Lake.** The Izok Lake property has an open pit mine that is expected to be mined in 3 phases. Expected production is 13Mt ore mined over 10 years, along with zinc, copper and lead. It also has an underground mine that is expected to produce 1Mt ore mined over 4 years. The underground mine is lower grade than the open pit mine, and also contains moderate amounts of zinc and copper and only negligible lead. The total expected life of the property is 12 years.

The second property is **High Lake**. High lake has two open-pits and one underground mine. The two open-pit mines are expected to produce 3 Mt ore mined over 6 years, along with zinc, copper, and negligible lead. The underground mine is expected to produce 4 Mt ore mined over 9 years, with zinc, copper and negligible lead.

If pursued as presented, the complex would install a dock in **Grays Bay in Coronation Gulf** for marine traffic to the mines. Coordinates are: 67°49′N 111°03′W (www.geodata.us). The dock and ship loader facility would accommodate 50,000 DWT bulk carrier ships.

The concentrate will be trucked year round from Izok Mine to Port through a new all-weather road. The project considers a three-month shipping window (early to mid August to October), and the operation of 4 to 6 ships, with 3 trips each. An alternative container supply route with barges via Mackenzie River is also considered.

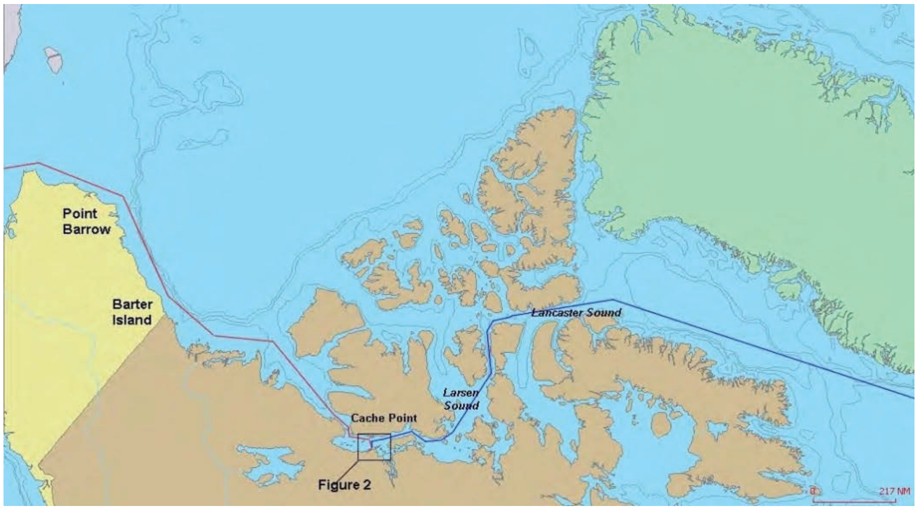


Figure C - 13: High Lake Complex Proposed Shipping Routes (MMG 2012)

News had also suggested that the MMG will put the project in operation considering Bathurst Inlet port and road (BIPR) as a shipping point. However, apparently the studies revealed that this alternative was too expensive and is not going to be pursued.

Sources:
MMG 2012. Overview of the Izok Corridor Project, presentation at the Nunavut Mining Symposium, Iqaluit, 19 April 2012.
MMG n.d. Izok Corridor Project.
MMG 2012. Izok Corridor Project: Project Proposal (August 2012).
CBC 2011b. Bathurst Inlet port idea nixed by mining firm (8 February 2011).

- **Bathurst Inlet Port and Road (BIPR) Project**

The BIPAR project consists of the development of a marine port on Bathurst Inlet, a 211 km all-weather road from Bathurst Inlet to Contwoyto Lake connecting to the existing Tibbitt to Contwoyto Winter Road.

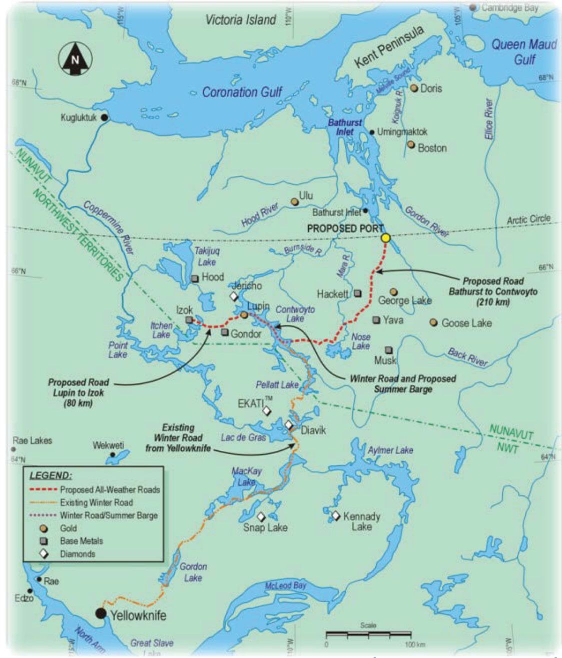


Figure C - 14: Bathurst Inlet Port and Road Map (Nunalogistics n.d.)

An environmental review initiated in 2004 was suspended after the proponents decided the project was not feasible. Now its new proponents — Sabina Gold & Silver and Xstrata Zinc Canada — want the review to continue. The project environmental evaluation was reactivated in the NIRB in 2012. On February 2013, the Board recommended the steps required to reactivate the assessment, which include the submission of an updated Project Description prior the submission of the Draft Environmental Impact Statement.

According to the 2004 Draft Environmental Impact Statement, it was predicted that proposed and potential future developments including Gahcho Kué, Hackett River, and Hope Bay deposits will use the Project facilities to import supplies and export products. In addition, the road and port would supply Nunavut northern communities. The development of these projects was predicted to cause a three-fold increase in shipping and truck traffic (Izok Lake was also mentioned to potentially use this facility, but according to the information of this project this transportation mode was assessed and found economically unviable).

According to the project description presented to the environmental assessment process, the project's annual operating schedule would reflect the seasons of the Arctic environment. Marine shipping will occur between mid-July and October 15; vessels up to 50,000 tonnes will deliver approximately 300,000 tonnes of fuel and supplies for the communities and operating mines served by the Project. As with other Arctic projects, icebreaker support may be required; however, icebreaking to extend the normal shipping season will not be required to keep this shipping schedule. Marine barge operations will also supply fuel and general cargo to the Kitikmeot communities, with up to seven round trips by tug and barge from the port during the summer shipping season.

Marine access to the port will use the existing shipping lanes that currently serve Resolute (and in the past served Polaris Mine, Bent Horn, and Rea Point). The shipping route, Barrow Strait and Queen Maud Gulf, has seen intermittent use by cruise ships. The Queen Maud Gulf to Coronation Gulf portion is part of the annual Northern Transportation Company Limited sealift resupply route for the Kitikmeot communities from Hay River in the Northwest Territories.

Road operations will follow the Arctic shipping season. The road, although designed for all-weather operations, will operate from January to April and connect with the existing Tibbitt to Contwoyto Winter Road (TCWR) from Yellowknife to haul 265,000 tonnes of fuel and cargo to the operating mines in Northwest Territory and Nunavut (i.e., Diavik, EKATI, Snap Lake, and Jericho). Approximately 73 trucks (58 fuel trucks and 15 cargo trucks) will operate on the road on an annual basis. Accommodation and meals for drivers will be provided by the camp at the port. There will be some road maintenance work from mid-July to early September. This work is essential to carry out maintenance on the roadbed and stream crossings. Sand and gravel required for winter operations will be stockpiled during this summer maintenance period.

Sources:

Bathurst Inlet Port and Road Project: Draft Environmental Impact Statement, Volume I (2008).

Nunatsiaq Online. 2012b. Mining companies revive Nunavut's Bathurst road and port project (March 31, 2012).

- **Back River Project (Sabina Gold & Silver Corp.)**

Sabina submitted the project description to NIRB in July 2012 to trigger an environmental assessment. The screening phase finished in December 2012. The draft EIS has not yet been submitted to the Board.

The project is located 150 kilometres south of the community of Bathurst Inlet. It includes the development of mineral deposits in areas referred to as the Goose and George Properties, with associated infrastructure including all-weather and winter access roads connecting the properties and the Marine Laydown Area in southern Bathurst Inlet.

Ore will be mined and trucked to a central processing plant at the Goose Property. Its projected production is 7,000 tonnes of ore per day for an approximate 10-15 year operation period (for an approximate total of 20-28 million tonnes) and annual production of 300,000-400,000 ounces of gold. Sabina's proposal projects that the development would take approximately two (2) years construction work, followed by a ten to fifteen (10-15) year mine operation phase and a five (5) year closure period.

Marine access, activities, and associated infrastructure include:

- Annual resupply and seasonal transport during the open-water season to transport equipment, supplies and fuel using 5-10 ships per year during construction and 3-5 ships per year during operations (ship equivalent in size to those currently used in community resupply);
- Routing via marine shipping routes north of Bathurst Inlet to the Coronation Gulf and into existing shipping corridors to the East or West;
- Construction of laydown area situated in the southern portion of Bathurst Inlet;
- Loading and unloading facilities to include in-water infrastructure such as a dock, jetty, moorings and buoys.

Sources:

Sabina Gold & Silver Corp. 2012. The Back River Project: Project Description (June 2012).

- **Hackett River Project (Xstrata Zinc Canada, formerly Sabina Gold & Silver Corp.)**

The Hackett River Project is located 75 km south of the southern portion of Bathurst Inlet. The project finished the screening phase of the environmental assessment in 2010. In 2012, the project was bought by Xstrata Zinc Canada. The company has announced its intention to submit a Draft Environmental Impact Statement by the second quarter of 2013. In 2012, a pre-feasibility study team was assembled. A camp was opened on 20 February 2012.

Sabina announced in March 2007 a preliminary economic assessment of the Hackett River Project which indicated a mine plan with average annual production of 324.7 million pounds zinc, 12.4 million ounces silver, 20.7 million pounds copper, 37.0 million pounds lead, and 17.2 thousand ounces of gold over a mine life of 13.6 years.

The concentrate produced at the Project would be trucked to a port located at Bathurst Inlet using the proposed Bathurst Inlet Port and Road (BIPR). Concentrate will be shipped out by two ice-class bulk carriers with a DWT of about 50,000 t. Each vessel will make call at the proposed BIPR port about five times each season. The first ship will make its first call on or about the first part of August; the last vessel will depart around mid-October. The ice-class bulk carriers will transfer their cargoes to other vessels at a transfer terminal in Greenland for the onward journey to the final destination, smelters in Europe or North America.

Inbound cargoes, such as fuel (58,000 t/a) and mining and process supplies and consumables (100,000 t/a), will be delivered by the ice-breaking vessels as a back-haul cargo or by barge. Ships will follow the eastern shipping route proposed by BIPR.

Sources:
Sabina Silver Corporation 2008. Hackett River Project, Nunavut: Project Proposal Report (January 2008).
Xstrata Zinc Canada 2013. Letter to NIRB File No. 08MN006-Hackett River Project.

- **Ulu and Lupin properties**

Both properties were acquired by Elgin Mining Inc. in 2011 and there appears to be prospects for further explorations (Lupin was in production in the past). Neither has initiated the environmental assessment process. They also have road access.

Sources:
Elgin Mining Inc. n.d. Properties Overview.

d) Kivalliq

This region has one mine in operation (Meadowbank mine), and three projects under review (Kiggavik, Meliadine and Garry Lake). Projects in exploration include Peregrine Diamonds Inc. Nanuk and Nanuk North properties.

- **Meadowbank Mine (Agnico Eagle)**

The mine started production in 2010. Its estimated life time is 2010-2017.

Source:
AEM n.d. Meadowbank.

- **Kiggavik Project**

Kiggavik is an uranium mine project. A revised draft Environmental Impact Statement was submitted to the NIRB in April 2012. The owner, Areva anticipates submitting responses to its Draft Environmental Impact Statement to the NIRB by 31 January 2013.

Mineral resources are estimated at approximately 51,000 tonnes uranium (133 million lbs U3O8) at an average grade of 0.46% uranium. Based on existing resources mine life is estimated at 14 years of operation after three to four years pre-operational construction.

All extracted ore from the mine sites will be processed through a mill located at the Kiggavik site using hydrometallurgical processes. Mined out pits at the Kiggavik site will be used as tailings management facilities. The uranium product will then be packaged and transported using aircraft to southern transportation networks.

The majority of goods required for the Project will be shipped via marine transportation during the open water season. The Marine Shipping Plan has been based on a conservative operating season estimate of 60 days. No ice breaking activity is planned.

Dry cargo and fuel will be off-loaded at a dock facility along the north shore of Baker Lake (64°19′05″N 096°01′03″W). Transportation then continues by winter road, and/or all-season road if necessary, to the site. The preferred marine transport strategy is the strategy currently in use by Agnico-Eagle and the Hamlet of **Baker Lake**. Given the rate of development of the mineral industry in the north, the desire of communities and governments for infrastructure development and seasonal variations, it is anticipated that the following options may be used in combination within a single shipping season or over the life of the Project:

- Marine shipment of fuel and dry cargo via ocean going vessels through Hudson Strait to Chesterfield Inlet. The cargo would then be lightered into barges or smaller self propelled vessels in Chesterfield Inlet and delivered to the final destination in Baker Lake.
- Marine shipment via ocean going tug/barges from southern ports direct to Baker Lake.
- Marine shipment via ocean-going vessels through Hudson Strait and Hudson Bay to Churchill. The cargo would be transshipped from Churchill to Baker Lake via tug and barge. A rail link connecting to major southern railways is also available for shipping fuel and dry cargo to Churchill.

Ocean-going vessels that are considered for shipment of fuel vary in size from 18300 DWT to 30000 DWT. Ocean-going vessels that are considered for shipment of dry goods vary in size from 660 TEU geared cargo ships to 1000 TEU container ships. The tug-barge arrangements that are considered vary in size from 5000 DWT to 7500 DWT. All vessels used for carrying fuel will be of double hull construction.

The Baker Lake dock site will receive barges, offload goods, and store goods prior to transport by road to the Kiggavik site. Since the preferred transportation option includes a winter road only, the current design considers storage of all goods required for one year of operation.

The dock will consist of a spud barge placed from the shore out to sufficient depth to permit barge-docking. No dredging of the lake bottom is anticipated. This design is anticipated to be relatively unaffected by changing water levels, ice shifting, and spring thaw.

Sources:
Areva 2011. Kiggavik Project Environmental Impact Statement: Tier 1 Volume 1. Main Document. (December 2011).

Nunavummiut Makitagunarningit n.d. AREVA's Kiggavik Proposal and the Nunavut Impact Review Board.

- **Meliadine Gold Project (Agnico Eagle Mines Limited)**

The company submitted a draft EIS for the project in January 2013. It hopes to start production in 2017. The construction phase will take about 3 years to be completed. Operation is projected to start about 2 years after construction begins and continue for about 13 years. The Conference of Canada Board (2013) includes this project in the prospects for Nunavut mining sector on the assumption that it will be operating by 2017.

The Meliadine Gold Project is a gold mine located north of the Hamlet of Rankin Inlet. Project-related shipping will make use of the relatively shallow Melvin Bay near Rankin Inlet. It will use Rankin Inlet's airport and sea port. A 24-kilometre, all-weather access road from Rankin Inlet to the Meliadine site was approved this year by the NIRB. The road will provide a year round link from the hamlet into the gold exploration project.

Throughout the project life, a total of 27 million tonnes of ore, 373 million tonns of waste rock, and 57 million tonnes of overburden will come from open pit mining of all 5 deposits. The UG mining will produce a total of 11 million ones of ore and 5.3 million tonnes of waste rock throughout the project life. The mining rate will be at around 40.1 million tonnes per year of moved material.

Applying the experience gained in the operation of the Meadowbank mine since 2008, the company plans to carry out all shipping during the open water summer season. No ice breaking or winter shipping is proposed. The company will not operate its own ships. It intends to contract shipping of both dry cargo and fuel to one of the recognized shipping companies that currently supply annual sea lift services to the Kivalliq region of Nunavut. Approximately 40,000 tonnes of dry cargo and 122 million litres of diesel fuel will be required annually. All shipping will follow established shipping lanes that are presently in use for the annual sea lift to Ranking Inlet. The company believes that the majority of its shipping will be between Eastern Canada through the Hudson Strait. Annually, a total of 4 to 6 vessels will deliver dry goods, and 4 to 6 tankers will deliver diesel fuel.

Dry cargo will be loaded on ocean-going barges and container ships in eastern ports (almost exclusively Bécancour, Québec) and delivered directly to Rankin Inlet. The first vessels of the year will arrive in Rankin Inlet in the latter part of July or early August. These first ships will include 2 loaded barges having dry cargo and 2 tugs. Once they arrive in Rankin Inlet, the tugs and barges will remain in the Rankin Inlet area until the last of the dry cargo has been received. This will be followed by up to 6 freighters delivering dry cargo. These ships are too large to navigate the access passage to Itivia and will anchor approximately 3 km from Itivia. Sea cans, large equipment machinery, and vehicles will be lightered onto the barges that arrived earlier for transport through the access passage using the tugs before being docked alongside the AEM floating dock located in Itivia. The lightering of the dry cargo will occur in advance of high tide, with the barges moved next to the floating dock at high tide.

Sources:
Agnico Eagle 2013. Draft Environmental Impact Statement: Meliadine Gold Project, Nunavut (2013).

- **Garry Lake (Uravan Minerals Inc.)**

Garry Lake is a uranium ore mining project. In 2008, the NIRB ordered a review. The process appears to be delayed by disagreement on the guidelines for the assessment. The project is not considered in the report of the Conference Board of Canada outlook. According to the information provided in the screening process, the project does not consider Arctic shipping.

Sources:
NIRB. n.d. Uravan Garry Lake Project.

- **Nanuq and Nanuq North (Peregrine Diamonds Inc.)**

These properties are under exploration.

Source:
Peregrine Diamonds Inc. n.d. Projects Overview.

e) Qikiqtaaluk (Baffin)

The Baffin region has one project already approved by the NIRB (Mary River Project), and several properties under exploration, including: Chidliak, Quilak, Cumberland , Tuktu 2, Committee Bay Greenstone Belt.

- **Mary River Project**

The project was approved by the NIRB on September 2012 (with 184 conditions). The final hearing report was sent to Northern and Aboriginal Affairs Canada for approval of the project. Construction is scheduled to start in 2013, and production is expected to start in 2018.

On January 10, 2013, the company announced that it was planning to slash scope of the project, postponing the construction of a railway, Steensby Inlet port and year-round shipping on Foxe Basin or Hudson Strait. Planned iron ore production would be slashed from 18 million tonnes a year to 3.5 million tonnes a year, and would be shipped only from Milne Inlet, in the summer (July 15 to Oct. 15), to Rotterdam and other European markets. The company now seeks amendments to that project certificate, which now includes 182 terms and conditions (some of which must now have to be altered). No information is provided as to when the company is expecting to resume the original production and infrastructure.

The description of the project, as contained in the final Environmental Impact Statement, is summarized below. Please not that it does not take into consideration the content of the more than 180 recommendations included in the final authorization, nor the recently announced reduced production and infrastructure.

Description

The Project involves the production and shipment of an estimated 18 million tonnes-per-annum (Mt/a) of high grade iron ore from Deposit No. 1. Deposit No. 1 is estimated to be sufficient to meet the production design for an operating period of 21 years.

After crushing and screening, the iron ore would be transported via a new 150 kilometre railway to an all season deep water port to be located at Steensby Inlet. Upon reaching Steensby Port, the iron ore would be loaded from the rail cars into purpose-built ore carrying vessels with ice-breaking capabilities for shipment to European customers.

During the construction period, material, equipment and supplies required for the construction at the mine site and the northern portion of the Railway would be received via a port site at Milne Inlet. A freight dock would be constructed at Milne Port. At the onset of the Project, much of the construction material and supplies, fuel and mining equipment would be received at Milne Port during the open water season. Milne Port and the existing Milne Inlet Tote Road linking the mine site to Milne Port would be upgraded to improve access from the Milne Port to the mine site. It is proposed that Milne Port would operate during the open water season while Steensby Port would operate year round. Once Steensby Port is operational, Milne Port would only be used occasionally for the delivery of oversized equipment to the mine site.

Subject to safety considerations and the potential for conditions as determined by the crew of transiting vessels, to result in route deviations, the Proponent shall require project vessels to maintain a route to the south of Mill Island to prevent disturbance to walrus and walrus habitat on the northern shore of Mill Island.

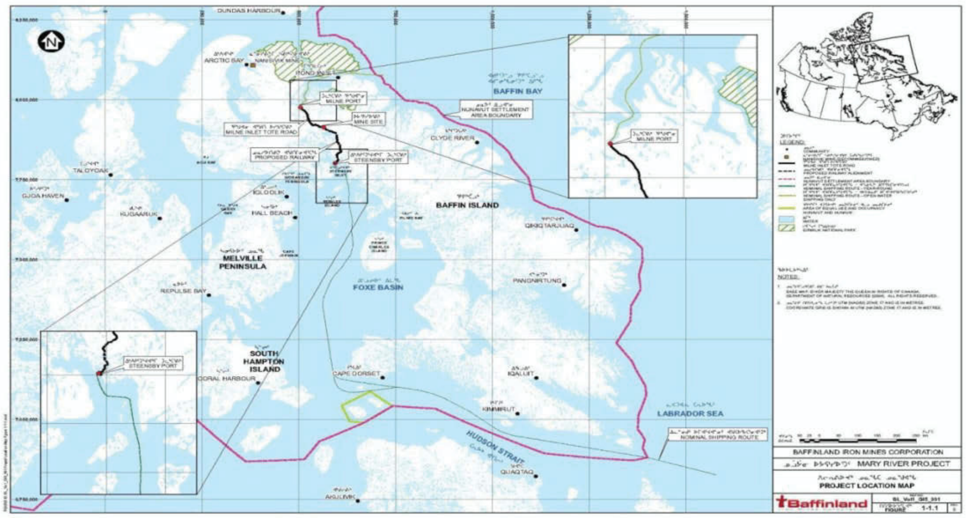


Figure C - 15: Mary River Project shipping routes (Baffinland Iron Mines Corp. 2012, Vol. 3)

Shipping of Freight and Fuel		Construction Phase				Operation Phase
		Year 1	Year 2	Year 3	Year 4	Year 5 - 26
Shipping Milne Port	Freight vessels	20	20	3	3	Only oversized equipment delivered when required
	Freight (tonnes)	165,000	95,000	43,000	46,000	See above
	Fuel tankers	2	3	3	3	0
	Diesel delivery	20 ML	30 ML	30 ML	30 ML	0
Shipping Steensby Port	Freight vessels	22	20	7	4	3
	Freight (tonnes)	206,000	150,000	107,000	80,000	60,000
	Fuel tankers	2	4	4	3	3-6
	Diesel delivery	40 ML	35 ML	35 ML	120 ML	160 ML
	Marine diesel				50 ML	50 ML

Fuel Storage		Construction Phase				Operation Phase
		Year 1	Year 2	Year 3	Year 4	Year 5 - 25
Milne Port	Arctic diesel	1 tank @ 5ML and 4 tanks @ 10ML				no requirements
	Jet A	2 tanks @ 1.5ML				no requirements
Mine Site	Arctic diesel	3 tanks @ 5.2ML				
	Jet A	2 tanks @ 1.5ML				
Railway	Arctic diesel	Multiple 20,000 L ISO containers positioned as required				no requirements
Quarries	Arctic diesel	Multiple 20,000 L ISO containers positioned as required				no requirements
Shipping Steensby Port	Arctic diesel	15 tanks @ 1ML 20ML fuel barge	15 tanks at 1 ML 4 tanks @ 40 ML		4 tanks @ 40 ML	
	Jet A	5 tanks @ 1ML				
	Marine diesel				1 tank @ 7.5 ML; 2 tanks @ 25 ML	

Production		Construction Phase				Operation Phase
		Year 1	Year 2	Year 3	Year 4	Year 5 - 25
Waste Rock & Overburden	Approximate Mt/a	0	0	0	22	30
Mine Ore Stockpiles	ROM, tonnes		0	0	400,000	400,000
	Rail Loadout, tonnes	--	--	--	--	1,400,000
Steensby Port	Steensby Port - 1.4 Mt fine ore stockpile capacity					900,000
	Steensby Port - 3.2 Mt coarse ore stockpile capacity					2,300,000
	Steensby Port Dedicated icebreaker ore carriers (160,000 to 190 ,000 DWT)					10

Figure C - 16: Key Project Facts (excerpt from Baffinland Iron Mines Corp. 2012, at p. 4).

The estimated number of annual voyages is based on use of conventional sea-lift ships with cargo capacities of 7,000 to 16,000 deadweight tonnage (DWT). Larger ships or barges may be used for delivery of supplies and equipment depending on cost and availability.

An estimated 18 Mt/a of ore will be transported from the Mine Site to Steensby Port via the railway year-round, with possible short breaks during significant weather events and scheduled maintenance shut-downs.

During the operation period, a dedicated fleet of 10 to 12 ice class cape-size vessels with a nominal capacity of 160,000 to 190,000 dead weight tonne (DWT) cargo capacity will operate year round to transport the annual ore production to market. It is anticipated that dedicated ore carriers will complete about 102 round trips from Steensby Port to customers across the Atlantic Ocean each year (i.e., 204 transits to and from Steensby Port). This equates to a ship moving through the shipping lane roughly every 1.8 days (43 hours). Shipping frequency will increase during the open-water season when sea-lifts will provide annual re-supply and supplemental vessels will be chartered to ship additional ore. These supplemental ore carriers are anticipated to be used, based on Baltic ice class designs, between approximately early August to about the third week of October. The number of supplemental ship voyages during the open-water season will vary from year to year. Some factors that influence the number of supplemental vessel voyages include the dry docking maintenance schedule for the dedicated fleet and the productivity of shipping through the winter. The chartered vessels will be similar to those used for the existing annual sea-lift operations and will comply with the requirements of the Arctic Shipping Pollution Prevention Regulation (ASPPR).

Icebreaker ore carrier designs have been and continue to be evaluated. The currently envisioned 160,000 to 190,000 DWT capacity icebreakers will be designed as Polar Class 4 vessels, which relate to Canadian classification between a CAC 3 and CAC 4 design (Consulting and Audit Canada, 1993) (the Polar Class 4 vessels identified for the Project are classed by IACS for “year-round operation in thick first-year ice with old ice inclusions.”). These ships will be approximately 329m long, 50 to 53 m beam and maximum draft 20 m when fully loaded. According to the project EI statement, it is anticipated that the ore carriers will have the following design features:

• Twin nozzle propellers (7.5 to 8.0 m diameter);
• Twin rudders (one behind each propeller) - approximately 11 m high by 6 m wide;
• Full power: 42,500 hp per shaft with engine running at constant 78 rpm; and
• Shaft centreline approximately 6.5 to 7.0 m above vessel baseline.

The service speed of the dedicated ice-capable ore carriers and other vessels in open water at full draught is about 14.5 knots; maximum speed is over 18.5 knots. Speed is governed by a number of factors including weather, ice conditions, observance of other vessels and marine mammals. In ice conditions and at full power, 1.2 m level ice can typically be broken at over 7 knots speed; 2 m ice at 3 knots. The duration of a round trip from Steensby Port to a European destination in open water is around 20 days; in the heaviest ice conditions during a severe winter, it may be over 45 days.

The ASPPR Zones that are transited to reach Steensby Port are Zones 15 and 8, with Zone 8 covering Foxe Basin being the limiting zone with the higher ice regime designation.

There will be two main shipping routes from Steensby Port:
• Steensby Port to the Project's European customer base, for the movement of ore; and
• Southern Canadian port to Steensby Port, for re-supply of materials and some fuel and equipment by conventional sea-lift during open water periods.

The nominal shipping route through Foxe Basin in and out of Steensby Port is along the east side of Koch and Rowley Islands to where it joins with the established shipping lanes in southern Foxe Basin accessing Hall Beach and Igloolik (Figure C - 15).

Sources:
Nunatsiaq Online, 2013, Baffinland slashes scope of Nunavut's Mary River project (10 January 2013).
Baffinland Iron Mines Corp. 2012. Mary River Project Final Environmental Impact Statement (22 February 2012) (see in particular Volume 3 Part 7).

- **Roche Bay** (Advance Explorations Inc.)

The iron ore mining project of Roche Bay is located on the shores of Nunavut's Melville Peninsula. Its location right next to tidal waters means that it does not require railway infrastructure, which makes it economically attractive. The iron ore concentrate would be shipped through a purpose-built port.

In August 2012 it was announced that the owner, Advanced Explorations Inc., together with the Chinese company XinXing Ductile Iron Pipes Co., was going to "put pedal" to the project. A positive feasibility study was announced on Aug. 10, 2012, confirming net present value of $642 million (pre-tax). In December 2012, Advanced Explorations received unanimous board approval to move ahead with engineering studies on powering Roche Bay, an iron mining project, with liquid natural gas. The target date to have permitting and impact benefits agreements in place to start construction at Roche Bay is 2015-16. Advanced Explorations is completing its environmental impact statement and has formed committees and held community meetings to keep people informed about the project.

On 19 February 2013, Advanced Explorations Inc. announced that it has signed a Memorandum of Understanding with Logistec Stevedoring Inc. for the further development of AEI's shipping concept, terminal, and marine services. Logistec and AEI will work jointly on the development and operation of the terminal facility with its related infrastructure servicing the Roche Bay Project. According to the company, the joint venture structure would allow it to focus on its core competencies, specifically exploration and mining, while the port operator will provide for an efficient and cost effective deployment of this key project asset. The parties contemplate a port facility to align with a start-up 5.5

Mtpy production rate as set out in the Roche Bay Feasibility Study while providing for significant future scalability.

Sources:
Nunatsiaq Online 2012c. Firms put pedal to the metal on Melville Peninsula iron projects in Nunavut (23 August 2012).
Northwest Territories News and Nunavut News 2012.
Advanced Explorations Inc. 2013. News Release: Advanced Explorations Signs MOU with Logistec Stevedoring Inc.
Advanced Explorations Inc. n.d. Roche Bay Project.

- **Chidliak, Quilak, Cumberland , Tuktu 2, Committee Bay Greenstone Belt**

All these properties are currently in different stages of exploration.

Chidliak, Quilak and Cumberland projects, all in Baffin Island, are being explored by Peregrine Diamonds Ltd.

Tuktu 2 project is being explored by Advance Explorations with Chinese capital.

Committee Bay Greenstone Belt, controlled by North Country Gold Corp., is one of the largest under-explored greenstone belts in Canada with numerous drill-ready high-grade gold targets. The gold-rich Committee Bay Greenstone Belt is located 180km northeast of the of Agnico Eagle's Meadowbank gold mine. The Three Bluffs deposit is geologically comparable, with similar grades, type of mineralization and age as Meadowbank and Meliadine Gold Deposits.

Sources:
Peregrine Diamonds Inc., n.d., Projects Overview, http://www.pdiam.com/s/Projects.asp
Advance Explorations Inc., n.d. Tuktu Project, http://www.advanced-exploration.com/projects/tuktu/index.html
North Country Gold Corp. n.d., www.northcountrygold.com.

f) Conclusions

General

For the remainder of the decade, mining output will more than double to reach $352 million in 2020—a compound annual growth rate of 8.8 per cent (Conference Board of Canada).

Kitikmeot Region

- This region has one mine with suspended operations (Jericho diamond mind) and three projects under consideration and at different levels of development: a) Izok Lake corridor; b) BIPR and Sabina’s Back River and Hackett River properties; and c) Hope Bay project. Two other properties are in exploratory stage.

- Jericho mine, a productive mine which production was suspended, is currently inactive. The owners appear to have financial difficulties and cannot be contacted.

- None of the mine projects has finished the environmental study. It is not clear if any authorization process would be ready by 2020 and therefore, if any of these mines will be in construction or operation phase. The Conference of Canada Board does not consider any of these projects in its 2020 forecast for Nunavut. Mining companies have more optimistic outlooks on initial dates of operation.

- MMG expects the Izok Lake complex to begin construction in 2015 and operation in 2018. However, it noted that these timeframes can be achieved “in a perfect world”. If in operation, Izok Lake considers shipping from Grays Bay port or dock. It has estimated a three-month shipping window (early to mid August to October) with the operation of 4 to 6 ships, with 3 trips each. Alternative container supply route with barges via Mackenzie River is also considered. Shipping routes include both east and west from Coronation Gulf (see map).

- BIPR project has received new impetus in January 2013, after being dormant for several years. Sabina and Xstrata are reviving the project to support operations in the Back River and Hackett River properties (in addition to general community re-supply). If in operation, the development of the BIPR project is predicted to cause a three-fold increase in shipping and truck traffic.

  Sabina’s Back River has recently finished the screening stage of the NIRB assessment. The project considers using 5-10 ships per year during construction and 3-5 ships per year during operations. Shipping routing would be to the north of Bathurst Inlet to the Coronation Gulf and into existing shipping corridors to the East or West.

  In the case of Xstrata Hackett River, draft environmental assessment has not been submitted. The company expects to submit it in 2013. Concentrate will be shipped out by two ice-class bulk carriers with a DWT of about 50,000 t. Each vessel will make call at the proposed BIPR port about five times each season. The first ship will make its first call on or about the first part of August; the last vessel will depart around mid-October. The ice-class bulk carriers will transfer their cargoes to other vessels at a transfer terminal in Greenland for the onward journey to the final destination, smelters in Europe or North America.

- Hope Bay project, as well, has received new impetus after being sold to TMAC (Chinese-based company) in January 2013. When the new firm raises the $50 million in share offerings, they’ll reactivate the necessary feasibility studies to put the Doris property in operation.

Kivallik Region

- This region has one mine in operation (Meadowbank mine), and three projects under review (Kiggavik, Meliadine and Garry Lake), in addition to other explorations.

- Meadowbank is expected to be extinct by 2017.

- Meliadine is expected to start production in 2017. Forecasts of the Conference Board of Canada support that estimate. The Draft EIS was submitted in January 2013. A 24-kilometre, all-weather access road connecting Meliadine site with Melvin Bay has already been approved. Shipping will be in the open-water season only (no ice-breaking, no winter shipping). The company believes that the majority of its shipping will be between Eastern Canada through the Hudson Strait. Annually, a total of 4 to 6 vessels will deliver dry goods, and 4 to 6 tankers will deliver diesel fuel.

- The Kiggavik uranium project proponents submitted a draft EIS and anticipate to submit responses to its Draft Environmental Impact Statement, to the impact review board by Jan. 31, 2013. Conference Board of Canada does not refer to this project in particular in its 2020 forecast.

  Marine Shipping Plan for the project has been based on a conservative operating season estimate of 60 days. No ice breaking activity is planned. Dry cargo and fuel will be off-loaded at a dock facility along the north shore of Baker Lake (64°19′05″N 096°01′03″W). Transportation then continues by winter road, and/or all-season road if necessary, to the site. Primary proposed marine routes for consideration are:
    - Marine shipment of fuel and dry cargo via ocean going vessels through Hudson Strait to Chesterfield Inlet. The cargo would then be lightered into barges or smaller self propelled vessels in Chesterfield Inlet and delivered to the final destination in Baker Lake.
    - Marine shipment via ocean going tug/barges from southern ports direct to Baker Lake.
    - Marine shipment via ocean-going vessels through Hudson Strait and Hudson Bay to Churchill. The cargo would be transhipped from Churchill to Baker Lake via tug and barge. A rail link connecting to major southern railways is also available for shipping fuel and dry cargo to Churchill.

- Garry Lake project does not include marine shipping.

Qikiqtaaluk (Baffin)

- Beside several sites in exploration stage, the region has one approved project (Mary River) and one project potentially in construction or operation by 2020.

- Mary River was approved by the NIRB on September 2012 (with 184 conditions). The final hearing report was sent to Northern and Aboriginal Affairs Canada for approval of the project. Production is expected to start in 2018 (Conference Board of Canada 2013).
  On January 10, 2013, the company announced that it was planning to slash scope of the project, postponing the construction of a railway, Steensby Inlet port and year-round shipping on Foxe Basin or Hudson Strait. Planned iron ore production would be slashed from 18 million tonnes a year to 3.5 million tonnes a year, and would be shipped only from Milne Inlet, in the summer (July 15 to Oct. 15), to European markets.
  The company needs to seek amendments to the project certificate. Construction is expected for 2013.

The original project (as described in the final Environmental Impact Statement) considered an estimated 18 Mt/a of ore will be transported from the Mine Site to Steensby Port via the Railway year-round, with possible short breaks during significant weather events and scheduled maintenance shut-downs. During operation of the mine, a dedicated fleet of 10 to 12 ice class cape-size vessels with a nominal capacity of 160,000 to 190,000 dead weight tonne (DWT) cargo capacity will operate year round to transport the annual ore production to market. It is anticipated that dedicated ore carriers will complete about 102 round trips from Steensby Port to customers across the Atlantic Ocean each year (i.e., 204 transits to and from Steensby Port). This equates to a ship moving through the shipping lane roughly every 1.8 days (43 hours). Shipping frequency will increase during the open-water season when sea-lifts will provide annual re-supply and supplemental vessels will be chartered to ship additional ore.

Note that this project description does not consider the recently announced reduction in production and change in shipping plan. Additionally, it does not consider the more than 180 recommendations included in the authorization of the project.

- Roche Bay has not been submitted to the NIRB to trigger an environmental assessment. However, news releases have reported that the owner Advanced Explorations Inc., together with the Chinese company XinXing Ductile Iron Pipes Co., has decided to “put pedal” to the project. The target date to have permitting and impact benefits agreements in place to start construction at Roche Bay is 2015-16.

  The project’s location is right next to tidal waters and thus doesn’t require railway infrastructure, making the project economically attractive. A memorandum of understanding with Logistec Stevedoring Inc. was signed in February 2013 for the further development of AEI's shipping concept, terminal, and marine services.

4. Northwest Territories

In addition to the general references already indicated, this particular section consulted the following source:

- Department of Industry, Tourism and Investment (NWT) 2013. Northwest Territories Mineral Development Strategy: Discussion Paper.

a) General information of Producing Mines and Expected Projects

According to Department of Industry, Tourism and Investment (NWT) 2013, four mines are operating in Northwest Territories: Ekati, Diavik, Snap Lake, and Cantung. Figure C - 17 provides information on the expected life time of each of the producing mines.

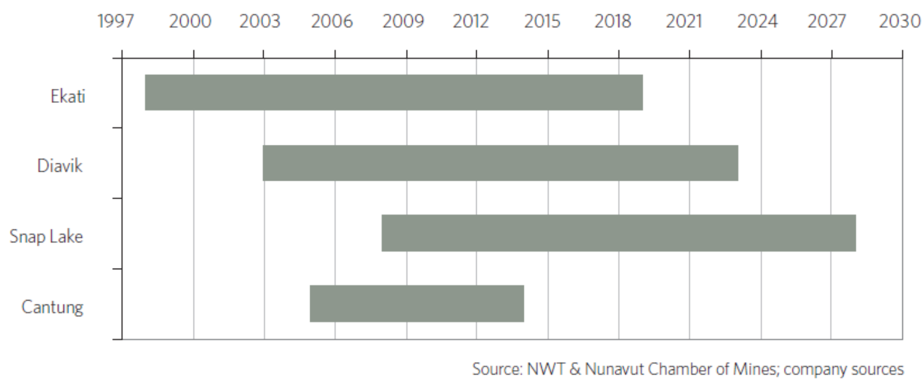


Figure C - 17: Projected Mine Life for Operating NWT Mines (Department of Industry, Tourism and Investment (NWT) 2013).

The same study provides a summary of potential mine developments, reproduced in Figure C - 18.

Project	Company	Commodity	Expected Production Start Date	Estimated Annual Direct Employment	Estimated Capital Costs for Mine Development ($ millions)
Yellowknife Gold Project	Tyhee Gold	Gold	2015	330	193
NICO	Fortune Minerals	Gold, Copper, Cobalt, Bismuth	2015	150	200
Nechalacho	Avalon Rare Earth	Rare Earth Metals	2015	216	541
Prairie Creek	Canadian Zinc	Silver, Zinc, Lead, Copper	2015	220	193
Gahcho Kue	De Beers/Mountain Province	Diamonds	2015-16	380	650
Pine Point	Tamerlane	Zinc, Lead	2014	131	154
Courageous Lake	Seabridge	Gold	2016-17	350	1,520[2]

Figure C - 18: Potential Mine Developments (Department of Industry, Tourism and Investment, 2013).

The Conference Board of Canada (2013), in turn, assumes that Nechalacho would start production in 2017. Employment in the mining sector in Northwest Territories was 2,200 in 2007, 1,200 in 2011, and the Board estimates it will be 700 in 2014 and 1,322 by 2020.

b) Information on Producing Mines and Expected Projects Transportation Plans

Table C - 2: Mines in Operation and Mining Projects in Northwest Territories

Mine	Project details relevant for this study
Ekati (BHP Billion)	Life estimate for the mine is early 2018. Source: Department of Industry, Tourism and Investment (NWT) 2013.
Diavik (Harry Winston, Rio Tinto)	Tibbitt to Contwoyto winter ice road is the lifeline to the Diavik Diamond Mine's operation. Source: Harry Winston n.d. Mining Diamons in the Arctic North.
Snap Lake (De Beeres)	The remote diamond mine is supplied by means of a winter road in February and March and by air all year round. Source: De Beeres. n.d. Snap Lake.
Cantung (North American Tungsten Corp.	A currently producing mine located in the border between Yukon and Northwest Territories. Life estimate for the mine is 4th quarter of 2014. Source: Department of Industry, Tourism and Investment (NWT) 2013.
Yellowknife Gold Project (Tyhee Gold Corp.)	It is expected to be in production by 2015. The site is accessible by seasonal winter road and year round by aircraft during daylight hours. Sources: Tyhee Gold Corp. 2012. Yellowknife Gold Project Feasibility Study, Northwest Territories, Canada.
NICO (Fortune Minerals Limited)	Mackenzie Valley Environmental Review Board recommended approval of the project on 26 January 2013. The proposed mine is 85 km north of the highway to Edmonton, Alberta and will be accessed by a proposed all-weather road also servicing nearby Tlicho aboriginal communities. CN operates a railway that terminates at Hay River on the south shore of Great Slave Lake, 450 road kilometres south of NICO and provides a rail link for haulage of concentrate to the proposed refinery near Saskatoon. Sources: CBC 2013b. Mackenzie Valley board approves NICO mine (26 January 2013). Fortune Minerals Limited n.d. NICO Gold-Cobalt-Bismuth-Copper Deposit.
Nechalacho (Avalon Rare Metals Inc.)	The feasibility study is expected to be completed in 2013. Production is expected for 2016. The property is directly accessible by barge in the summer (in Great Slave Lake), ice road in the winter, and year-round air transport. The rare earth deposit is to be mined through underground methods at rate of 2,000 tonnes per day. A flotation plant is to be erected onsite, while the hydrometallurgical facility would be constructed near Pine Point on the south shore of the Great Slave Lake. Concentrate is to be trucked to Hay River for on-shipment by rail to Geismar, Louisiana, USA at company's heavy rare earth separation plant and refinery. Sources: Department of Industry, Tourism and Investment (NWT) 2013. Avalon Rare Metals Inc. 2013. Project Fact Sheet: Nechalacho, Thor Lake.
Prairie Creek (Canadian Zinc Corp.)	The Mine is serviced by a 1,000 m gravel airstrip located approximately 1 kilometre to the north of the Mine Site. Access to the Project is via charter, either from Fort Simpson, NT, 150 kilometres to the east, or Fort Nelson, BC, 300 kilometres to the south. In 1980, a 180 kilometre Access Road was built from the Project to the confluence of the Blackstone and Liard Rivers connecting the Project with the Liard Highway. On April 11, 2007 the Company received a Land Use Permit from the

	Mackenzie Valley Land and Water Board which permits the re-establishment of the Access Road. Source: Canadian Zinc Corp. n.d. Prairie Creek.
Gahcho Kué (De Beers)	This development was initially referred to environmental assessment on 22 December 2005. On 13 June 2006, the Mackenzie Valley Environmental Impact Review Board ordered an environmental impact review to take place. The winter access road for this Project links with the existing Tibbitt-to-Contwoyto winter road. A 120-km winter access road will be constructed from MacKay Lake each winter to connect the Project site to the Tibbitt-to-Contwoyto winter road at km 271, just north of Lake of the Enemy. The main access to the site from the winter access road during operations will be via a service road connecting the site to Lake N11. The Project will generate two types of road traffic: 1) highway traffic on the winter roads and the road from Edmonton to Yellowknife and 2) mine production traffic. The permanent site airstrip will be designed to accommodate a wide range of aircraft, with the largest being the Hercules and Boeing 737. Sources: De Beers. 2010. Gahcho Kué Project Environmental Impact Statement, Section 3: Project Description.
Pine Point (Tamerlane Ventures Inc.)	The project would be connected by a paved road access with Edmonton. It will have a rail head at Hay River (42km). The final concentrate will then be stockpiled in a closed off building to wait for transport to the Hay River railhead. Source: Tamerlane Ventures Inc. n.d. Pine Point.
Courageous Lake (Seabridge Gold)	In July, 2012, Seabridge released the results of Courageous Lake's first Preliminary Feasibility Study which estimated 6.5 million ounces of proven and probable reserves, average annual production of 385,000 ounces of gold, cash operating costs of $780 per ounce and a mine life of 15 years. Year-round access is possible by air only, either by fixed wing aircraft to the airstrip at Salmita, located 6 km to the south, or by fixed wing aircraft equipped with skis or floats to nearby lakes. In addition, access in mid-winter is possible over a 32 kilometer winter road which branches off the main winter road from Yellowknife to the Lupin Mine. Access to the project under the current design is by winter road which is limited to less than three months per year. It is during this period that almost all of the project's supplies are transported to site. The Tibbitt to Contwoyto Winter Road Joint Venture proposes extending the winter road seasonal use by at least another month with a 150 km extension from the permanent road access at Tibbitt Lake to Lockhart camp. While this would result in some reduction in both operating and capital costs for Courageous Lake, an all-season access road from the Bathurst Inlet would provide considerably more benefit to Courageous Lake economics. Seabridge will continue to investigate these options as the project moves forward. Source: Seabridge Gold 2012. Preliminary Feasibility Study Completed For Seabridge Gold's Courageous Lake Project. Proven And Probable Gold Reserves Estimated At 6.5 Million Ounces. Seabridge Gold n.d. Courageous Lake.

c) Conclusions for Northwest Territories

1. There are several mines in operation and projects expected to be in operation by 2020. However, none of them uses Arctic shipping as transportation means.

2. One project may consider shipping is Courageous Lake. The project is considering several transportation alternatives, one of each considers an all-season road to Bathurst Inlet. It is considered to be a more economically convenient option for the project. However, it is not clear if the project will be in operation by 2020 or if it will ultimately consider this transportation option.

3. The Bathurst Inlet project description also indicated that the Gahcho Kué project may use the port facilities. No information on this respect was found in the Gahcho Kué project description.

5. Yukon

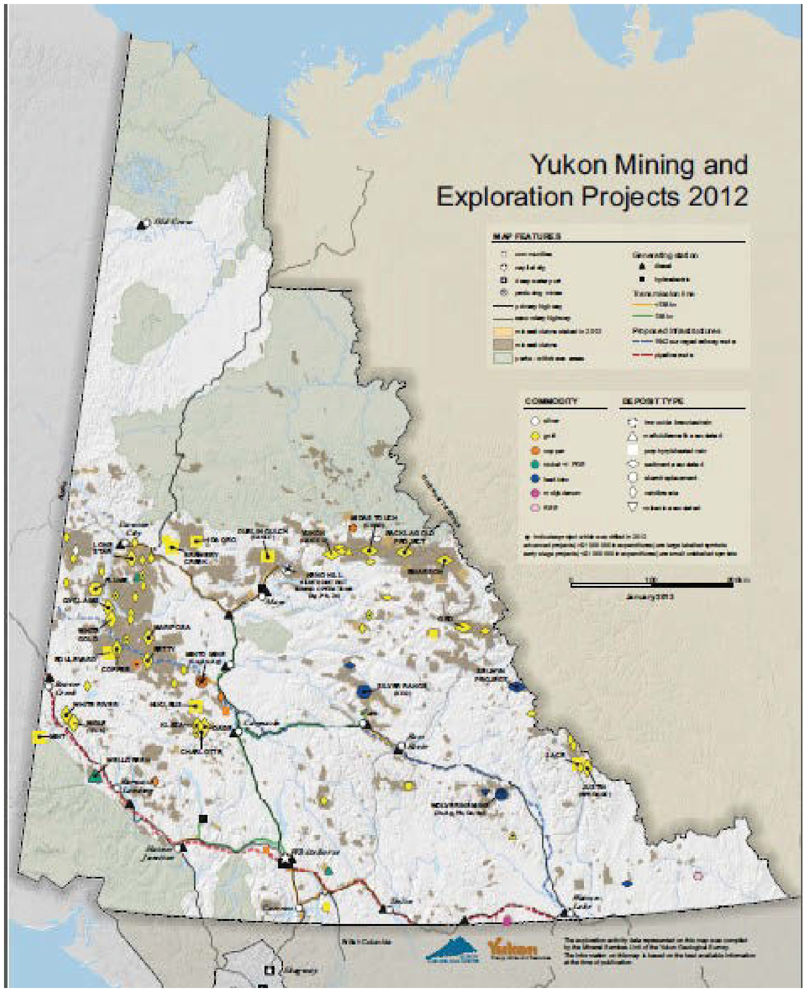


Figure C - 19: Yukon Mining and Exploration Projects 2012 (Energy, Mines and Reserves (YT) 2012).

In addition to general references, the following references were used for this particular section:

- Yukon Department of Economic Development, 2012, Yukon Economic Outlook 2012 (May 2012).
- Yukon Department of Economic Development, 2013, Yukon Economic Review 2012 (May 2012, updated as recently as 5 February 2013).

a) General Projections

According to the Yukon Economic Outlook 2012, with three producing mines and a number of other projects advancing towards development decisions, the future of Yukon's mining sector looks promising. Six projects have gone through permitting or are in the process of obtaining the appropriate permits. There are also 10 projects that are doing advanced exploration or are completing feasibility-related work. A number of the project proponents have proposed development timelines that could see development and production within five years.

In turn, the Conference Board of Canada 2013 expects significant increases in activity from 2014 onwards (See Figure C - 20). In 2011, there were 500 Yukon residents employed in the mining sector. The Boards expects that the mining boom will increase mining employment in the territory to 1,282 workers in the later years of the forecast (2020).

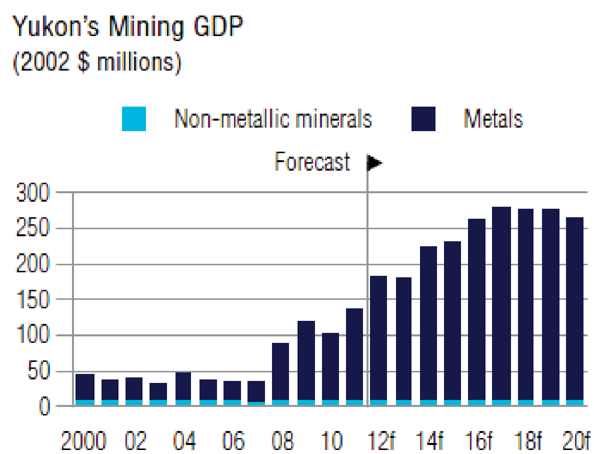


Figure C - 20: Yukon Mining GDP (Conference Board of Canada 2013)

However, it should be noted that a recent judicial decision ordered greater involvement of Ross River-area Aboriginal group in mineral claims process. The Court of Appeal concluded that where the granting of a mining claim or the working of that claim will have serious adverse effects on a credible claim to Aboriginal title or rights, the government must provide for consultation before the mining claim is granted or the work is commenced. It must also maintain the ability to prevent or regulate activities where it is appropriate to do so. This judgment may have broader impacts on the processes leading to mining developments in Yukon (Ross River Dena Council v. Government of Yukon, 2012 YKCA 14).

b) Mines in Production and Projects in Development

The following table provides a summary of the mines in production and the expected projects, indicating transportation plans. The information contained in the table was gathered using the general references listed above, as well as the mining companies' websites, and some mining-specific news websites. Specific sources are indicated in the table.

Table C - 3: Mines in Operation and Mining Projects in Yukon

In operation	**Minto mine** (copper-gold) Capstone Mining Corp	Opened in July 2007, with commercial production since October 2007.	Concentrates are currently being bagged in two-tonne supersacks in the concentrate storage shed at the Minto mine, which are then delivered by flat-deck trucks to the port of Skagway (Alaska). An amendment to the company's Quartz Mining License has been approved which allows to increase production to 3,600 tonnes of ore per day. The Minto mine will be in operation until 2022. Source: Capstone Mining Corp. n.d. Minto.
	Bellekeno mine (Kenno Hill) (silver) Alexco Resources Corp.	In production since January 2011.	Concentrate shipping began in early December 2011, through the port of Skagway in Alaska. Access to the property is via a paved, two-lane highway from Whitehorse to Mayo (407 km) and an all-weather gravel road northeast from Mayo to Elsa (45 km); a total distance of 452 km. The mine is currently operating a 250 tonnes per day operation and is planning to increase to a 400 tonnes per day operation for 3 to 5 years. Current life of mine is estimated at 5 years. Sources: Alexco n.d.a. Bellekeno mine. CBC 2011c. Bellekeno silver mine opens in Yukon.
	Wolverine mine (zinc-silver-copper) Yukon Zinc Corp	In production since March 2012	The property is connected by the Robert Campbell Highway leading southward through Watson Lake to the existing Stewart Bulk Terminal in Stewart, B.C. Source: Yukon Zinc Corp. n.d. Wolverine mine.
Projects	**Eagle Gold project** (nickel-copper) Victoria Gold Corp.	Production expected to start in 2013-2014.	The company wants to start production before the end of 2013. Conference Board of Canada 2013 considers it will start production in the next couple of years. The Dublin Gulch property is accessible by a government maintained road. There is also an airstrip located just north of the community of Mayo providing additional means of accessibility. Hydroelectric power is located within 25 km of the property. Source: Victoria Gold Corp. n.d. Dublin Gulch Property & Eagle Gold Project. Conference Board of Canada 2013.
	Carmacks project (copper) Copper North Mining Corp.	Production expected to start in 2013-2014.	High-purity copper cathodes will be produced in an electrowinning plant for shipment from the ice-free port of Skagway. Company wants to produce by the end of 2013. The project has been issued a Quartz Mining License. This license provides the authorization under the Quartz Mining Act for Carmacks Mining Corporation (subsidiary of Copper North Mining Corp.) to proceed with terrestrial operations (development, production, reclamation and decommissioning) of the proposed mine. Additional approvals for the major mine structures are subject to review by the Yukon government as detailed engineering designs are prepared and submitted by the company. Conference Board of Canada 2013 assumes it will start production in the next couple of years. Sources: Copper North Mining. n.d. Carmacks. Conference Board of Canada 2013.
	Onek Alexco Resources Corp.	Authorized on 28 Jan 2013, production	The mine is associated to Bellekeno (Keno Hill Silver District). No specific information on transportation was found, but it is likely that this property will use the same strategy as Bellekeno. Source:

		expected in 2013	Alexco. n.d.b. Onek. Yukon Government 2013.
	Lucky Queen Alexco Resources Corp.	Authorized on 28 Jan 2013, production expected in 2013	The mine is associated to Bellekeno (Keno Hill Silver District). No specific information on transportation was found, but it is likely that this property will use the same strategy as Bellenko. Source: Alexco n.d.c. Lucky Queen. Yukon Government 2013.
	Selwyn Chihong	Expected in 2015	The Selwyn Project is located in eastern Yukon and straddles the border with the Northwest Territories (NWT). On 12 December 2009, Selwyn signed a Framework Agrement with Yunnan Chihong Zinc and Germanium Co. Ltd. The formation of the Joint Venture with Chihong is seen as a major step towards advancing the Selwyn Project to production. In 2012, the Government granted the company a long-term tenure for the portion of the Howard's Pass Access Road that is under the jurisdiction of Aboriginal Affairs and Northern Development Canada (AANDC). The Howard's Pass Access Road is an existing 79 kilometres long road that links the Selwyn Project with the Yukon public highway system. On May 28, 2012 Selwyn Chihong announced that it is now focused on a smaller 3,500 tpd mine and mill operation with a feasibility study to be completed in the first quarter of 2013. The joint venture has deferred any further work on the 8,000 tpd underground mine development plan in favour of the new plan which indicates that it can provide favourable economic return; however it requires considerable additional study to confirm the preliminary findings. According to the Skagway News, the project plans to ship through Skagway, Alaska. Selwyn has even floated conceptual plans for a new ore dock southwest of the current TEMSCO heliport in this facility. Sources: Skagway News 2013. Top Stories, Volume XXXV Nr. 6 (13 April 2012). Selwyn Resources Ltd. n.d. Selwyn-Chihong Joint Venture. Selwyn Resources Ltd. 2012. News Release: Selwyn Chihong Receives Howard's Pass Mine Access Road Licence 2012 (April 30 2012).
	Mactung Tungsten North American Tungsten Corp.	Expected in 2015	In October 2012, the Executive Committee of the Yukon Environmental and Socio-Economic Assessment Board ("YESAB") completed a Draft Screening Report. YESAB's Report recommends to the Decision Bodies that the Mactung project be allowed to proceed without a review, subject to the terms and conditions specified in the report. The company's next objective in the permitting process is to obtain quartz mining and water licences. The mine has an expected lifetime of 11 years, and 15 more years with an open-pit mine. The project considers ground transportation of tungsten concentrate from the mine to market via Edmonton, AB, and Vancouver, BC, using the North Canol Road, Robert Campbell Highway, Alaska Highway. The Macmillan Pass Airstrip will be used to fly mine staff to and from the project area. Some supplies will also be flown in. It is considered in prospects of Skagway Port traffic. Information on transportation could not be found in the company's website. Sources: North American Tungsten Corp. 2008. Mactung Mine Project Proposal to YESAB–Executive Committee Submission: Executive Summary. Yukon Environmental and Socio-Economic Assessment Board (YESAB) Online

			Registry.
	Casino Western Cooper and Gold Corp.	Expected in 2017	The company expects to complete the permitting process between 2011 and 2013. It expects to start operation in the heap in 2015, and in the mill operating in 2016. Company expects to start shipments on the second or third quarter of 2019. The property has a projected life of 23 years (operation). The site is currently accessible year-round only by air. Various route options for a year-round access road were examined and the selected one was a new, 130 km, unpaved road extending from the current Freegold Road, which meets the Klondike highway at Carmacks. Amongst other functions, the road will be used to transport concentrate to the Skagway, Alaska port as well as to transport various commodities from the port to the mine. Copper concentrate will be thickened, filtered and transported by highway legal haul trucks to the Port of Skagway, Alaska. Western Copper and Gold. n.d. Casino Property. Skagway News 2012b. Top Stories, Volume XXXV Nr. 11 (22 June 2012).
	Korat Project (Gold) Northern Tiger Resources Inc.	Located in the White Gold district.	The property is in exploration stage. Source: Northern Tiger Resources Inc. n.d.
	Sonora Gulch (Gold-copper-molybdenum) Northern Tiger Resources Inc.	Located in the heart of Dawson Rage	The property is in exploration stage. Source: Northern Tiger Resources Inc. n.d.
	Sprogge Project (Gold) Northern Tiger Resources Inc	Located in Southeast Yukon	The property is in exploration stage. Source: Northern Tiger Resources Inc. n.d.
	3Ace Project (Gold) Northern Tiger Resources Inc.	Located in Southeast Yukon	The property is in exploration stage. Source: Northern Tiger Resources Inc. n.d.
	Whitehorse Copper		The project attempts to reclaim an abandoned site and mine the tailings. Authorizations are underway. Currently, an application for water licence was submitted. The intent is to remove the iron ore product, truck it to Skagway and then ship it overseas to smelters in Asia, most likely China. Sources: Whitehorse Daily Star. 2010. Plan would reinvigorate Whitehorse Copper site (20 October 2010). CBC 2013c. Concerns raised about re-starting old Whitehorse mine.
	Silver Hart Project (Silver) CMC Metals Ltd.	Located in Central Yukon	The property is in exploration stage. Source: CMC Metals n.d. Silver Hart Property.

	Ketza River Yukon-Nevada Gold Corp		Yukon-Nevada is undertaken an environmental review with the Yukon Socio-Economic Review Board (YESAB). In February 2012, YESAB found the proponent had not provided sufficient baseline information and found the company's filing inadequate. The company filed additional information in August to address the inadequacies. Franco-Nevada is trying to get regulatory approval to mine the Ketza property while selling the project to some party that would want to operate the mine. Source: YESAB Online Registry North of 56, 2012. Ketza River Gold Project (19 September 2012).
	Yukon Base Metals Overland Resources Ltd.		The project consists of several properties located close to each other, at a maximum distance of 20 kilometres (Andrew Zinc Project; Scott Zinc-Lead Project; Myschka Copper-Gold Project; Atlas Lead-Zinc Area; Darcy Zinc Deposit). A winter access road exists to enable the cost effective mobilisation of heavy equipment and supplies to site. The project considers the use of the Port of Skagway, Alaska, which provides a year round ice free deepwater port to service the Yukon and has existing concentrate loading facilities available for use. Source: Overland Resources Ltd. n.d. Project Overview.

*Blue cell: Mines and projects included in the AMT-Ph2-Part1 Report, with updated information.

c) Conclusions for Yukon

1. There are currently three productive mines in Yukon: Minto, Bellenko and Wolverine. More than 10 projects are in different stages of the review process, and some are expected to be in operation in 2020.

2. However, all the projects use either the port of Sagkway in Alaska, Stewart terminal in British Columbia, or ground transportation. The location of the mines in southern Yukon makes those ports more accessible.

3. For this reason, it is not expected that the active mining sector in Yukon will have an impact on Arctic shipping by 2020.

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Analysis of Marine Traffic along Canada's Coasts Phase 2 – Part 2: A spatio-temporal simulation model for forecasting marine traffic in the Canadian Arctic in 2020

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Etienne, L.; Pelot, R.; Engler, C.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
December 2013	175	134

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

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10bl03	W7714-093795
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	**10b. OTHER DOCUMENT NO(s).** (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
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This document describes the results of the study conducted as Phase 2 – Part 2 of the Analysis of Marine Traffic (AMT) Project, conducted under contract W7714-093795. The purpose of this Part is to develop a spatio-temporal model that can be used to represent current maritime traffic in the Canadian Arctic and sub-arctic, and also simulate future traffic projections. The simulation model comprises a network of feasible routes connecting possible areas where vessels may go, such as communities, mines, offshore developments, and fishing grounds. A route is deemed feasible based on water depth and ice conditions, depending on the vessel type. Specifically, a simulation was run for the year 2020, based on key drivers that may lead to changes in traffic in terms of activity type, vessel mix, volume by vessel type, location, and timing. The search for, and extraction of, resources are major drivers of arctic traffic, encompassing oil and gas, mining and fishing. Increased cruise ship tourism is likely in the North, and the sealift operation to supply communities is contingent on population changes and spending patterns. Pleasure boating levels are largely tied to community population as well. However, there is great uncertainty around most of these factors as well as the ice predictions for the year 2020, therefore the simulation model relies on Monte Carlo simulation to account for the range of possible values. Maps are generated for the forecast traffic, and the simulation model was designed to be easily rerun using different parameters.

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